Agro-Morphological Characterization of Adaptive Ability of Four Plum Varieties under Two Climate Environments

Anas HAMDANI[1,2]
Said BOUDA[2]
Atman ADIBA[3]
Hakim OUTGHOULIAST[1]
Jamal CHARAFI[1] (✉)

Summary

The agro-morphological and vegetative traits of fruit trees such as plums vary according to the type of genotype and the sampling site. This work focuses on the characterization of four varieties planted in two contrasting experimental zones of the INRA of Meknes (Ain Taoujdate (T) in the Saïs plain and Annoceur (A) in the foothills of the Middle Atlas). The adaptability of plum trees under two contrasting climates was assessed by fruit yield and vegetative traits. All the varieties showed significant differences in their results at the two sites for all the measured traits mentioned, as well as variety and site factors, influencing the adaptation of the four varieties studied by acting significantly on production and phenology. The variety 'Methley' installed at 'Ain Taoujdate' proved to be the least tolerant to high winter temperatures by showing the highest yield decrease with a rate of 90%, fruit size decrease with a rate of 27% and the lowest growth among the varieties installed at both sites. In general, the traits of the four plum varieties were significantly affected by climatic conditions, plum genotypes and their interaction.

Key words

Prunus salicina L., *Prunus domestica* L., climate, production, phenology

[1] Research Unit of Plant Breeding and Plant Genetic Resources Conservation, National Institute of Agricultural Research, Regional Agricultural Research Center of Meknes, BP 578, Meknes, Morocco

[2] Laboratory of Agro-Industrial and Medical Biotechnologies, Faculty of Sciences and Techniques, University of Sultan Moulay Slimane, BP 523, Beni Mellal, Morocco

[3] Research Unit of Irrigated Production Systems, National Institute of Agricultural Research Regional Center of Agricultural Research of Tadla, B.P. 567, Provincial Beni-Mellal, Morocco

✉ Corresponding author: jamal.charafi@inra.ma

Received: May 21, 2024 | Accepted: July 1, 2024 | Online first version published: September 20, 2024

Introduction

The biodiversity of the biosphere and its natural balance is maintained by the existence of fruit trees which can adapt to different climates, with the expected response of species varying according to the type of tree, and impacts leading to irregularities in profitability (Gleizer et al., 2007). Under the impact of climate change, plum cultivation has been experiencing adaptation problems (López-Ortega et al., 2016). The Japanese plum (*Prunus salicina* L.) is a diploid species containing 16 chromosomes (2n = 16) which originated in China and was first domesticated in Japan. The European plum (*Prunus domestica* L.) is a hexaploid species with 48 chromosomes (2n = 6x = 48) and was possibly originated in Eastern Europe or Western Asia (Hamdani et al., 2022a). World plum production is estimated at more than 12.8 million tonnes in 2022, more specifically at more than 126160 tonnes/year, equivalent to the surface area of 14178 ha (Hamdani et al., 2024).

The development of plum species depends not only on climatic and edaphic factors, but also on their strategies for adapting to a constantly changing environment (Dinu et al., 2022). According to several studies, one of the main factors limiting productivity and development in plum varieties is their agroclimatic requirements, particularly 'Angelino' and 'Methley', which are characterized by their low chill and heat requirements, while 'Fortune' and 'Stanley' have the highest agroclimatic requirements, although these requirements are intermediate in 'Black Amber' (Li et al., 2016; Ruiz et al., 2018; Hamdani et al., 2024). The edapho-climatic conditions that generally limit plum vigor and affect plant phenology, fertilization, pollination and fruit set are wind, soil moisture, precipitation and, in particular, temperature, i.e. low temperatures in winter and wide temperature variations in winter and spring (Eremin et al., 2017).

Phenology, which is the set of recurrent and annual biological processes, provides a critical signal regarding climate variability and its effect on crops. It is as important a factor as any in illustrating the impact of climate change on living beings (Poggi et al., 2022). Understanding climate variation can be used for several reasons, namely planting and choosing varieties that can adjust and adapt to conditions resulting from climate change, which can cause yield losses (Stefanova 2019; Adiba et al., 2024). This is to avoid the risk of climatic anomalies that jeopardize crops in particular regions. As a consequence of climate change, the environment has been modified, resulting in a disruption of phenological stages in many species, early vegetative development in spring, and a longer growing season (Lee et al., 2020).

Determining the mechanisms explaining the agro-morphological processes of crops exposed to different climatic conditions is crucial to being able to forecast the feedback of the carbon cycle from the biosphere and the capacity of the geosphere to attenuate climate change, the effects of the latter on fruit trees, in specific, in answering questions regarding the ability of fruit trees to adapt to the climate change (Cox PM et al., 2000). From the first year onwards, trees grown under conditions of abiotic stress can have effects on production, vegetative and growth traits to give an idea about their adaptability (Razouk et al., 2021). Many traits, including photosynthetic activity and foliar accumulation of proline and raffinose have been analyzed to evaluate the versatility and adaptation of different plum cultivars under two contrasting climates (Gitea et al., 2019). Consequently, the overall aim of this work was to study the adaptability of four plum varieties grown in two contrasting climates (the Atlas foothills and the Saïs plain) by investigating the influence of location and variety on pomological and morphological traits in order to assess the effect of climate and its interaction on variety characterization.

Materials and Methods

Plant Material and Experimental Conditions

This study was rolled out in 2021 on four plum varieties 'Methley', 'Black Amber', 'Fortune' (*Prunus salicina* L.) and 'Stanley' (*Prunus domestica* L.), fourteen years old, planted on 'Myrobolan' grafting stock; these four varieties are installed in two experimental fields of INRA at 'Ain Taoujdate' (Meknes) and 'Annoceur' (Sefrou). The Ain Taoujdate field is located at 33°55N/5°13'W in the Saïs plain, Morocco at an altitude of 550 m. The clay soil is calcareous and alluvial. (Table 1). Temperatures are hottest in July (37 °C) and coldest in January (2.8 °C). The fruit orchard also gets 460 mm per year of rainfall, a water quantity of approximately 1700 m^3 per ha provided by drop-by-drop irrigation from May to September corresponding to the annual evapotranspiration of the crop (ETc). The Annoceur domain is located in the province of Sefrou, Morocco at 33°42'E/4°49'N and an altitude of 1350 m. The soil is Hamri and moderately stony (Table 1). Temperatures vary between a maximum of (40 °C) in July and (-7 °C) in January. The average annual rainfall is about 500 mm, using a quantity of water of approximately 1800 m^3/ha provided by drop-by-drop irrigation from May to September corresponding to the annual evapotranspiration of the crop (ETc). The varieties were planted at a distance of 5x5 m with 15 trees per variety. Preventing parasites process was applied in compliance with local commercial methods, weeds were eliminated and all trees were pruned in a similar way to better homogenize their size.

Climatic and Phenological Data

Maximum and minimum temperature data were collected from the official weather station situated near the orchard. The average temperatures were calculated from the maximum and minimum temperatures. In Fig. 1, it can be seen that the average minimum and maximum temperatures at the 'Annoceur' site are 7 and 25.5 °C respectively and those at the 'Ain Taoujdate' site are 12.5 and 27.5 °C respectively, and that the average temperatures at the 'Ain Taoujdate' site are higher than those at the 'Annoceur' site with an average of 3.6 degrees.

Production Measurements

According to Razouk et al. (2021), fruit yield at maturity was established by the overall number of fruits counted for each tree and the average weight of fruits counted. In the fields, fruit was scored on every tree and ripe fruit samples were collected from 10 randomly chosen fruiting branches per repetition (tree) for fruit weight determination. Fruit size was determined by measuring length, width and height. Measurements were made with a digital

Table 1. Physical and chemical soil characteristics at field stations

Station	Soil depth	Clay (%)	Silt (%)	Sand (%)	Organic matter (%)	P_2O_5 (ppm)	K_2O (ppm)	pH	EC (mS cm^{-1})
Ain Taoujdate	0-35 cm	42.09	10.0	46.6	2.51	73.36	458.87	7.30	0.10
	35-70 cm	37.6	15.9	46.3	1.58	15.12	222.48	8.04	0.07
Annoceur	0-35 cm	29.5	31.9	38.6	1.03	28.7	361.4	8.36	0.27
	35-70 cm	22.9	34.7	42.4	1.24	15.8	146.3	8.38	0.13

Note: Measurements carried out in 2021 by the laboratory team at INRA Meknes

caliper on five randomly selected fruits for every tree. The weight of the fruit cores was determined by weighing 5 samples of 5 pits each taken at random from 5 different trees using a precision balance.

Morphological Measurements

To determine some outside performance variables, including shoot length (cm), number of shoots and number of leaves per fruit, two two-year-old shoots were selected at random from one tree side (Hamdani et al., 2023) as well as a growth monitoring where five shoots per tree were selected for weekly measurements to measure growth and the final length of shoots of the year (cm).

The pigment concentration was determined using the method cited by Adiba et al. (2021). Following freeze-drying and grinding of the leaf material, 5 mg of the milled material was shaken in 1 ml of 80% acetone in Eppendorf tubing for 1 hr and 30 min to remove all traces of the chlorophyll content.

The extracts obtained were then subjected to centrifugation at 4000 rpm for 15 min at 4 °C. The optical density (OD) of the supernatant was determined at 645 nm and 663 nm. The chlorophyll-a (Ch*a*) and chlorophyll-b (Ch*b*) concentrations were calculated using the formulae below:

$$Cha = [12.7 (OD663) – 2.69 (OD645)]$$

$$Chb = [22.9 (OD645) – 4.86 (OD663)].$$

Proline Content

Leaf proline content was analyzed by the method mentioned by Wang et al. (2022) using 100 mg of freeze-dried and ground leaf samples. A quantity of 2 mL of 40% methanol was mixed with the powder example. The mix was next warmed to 85 °C in a bain-marie for 1 h. Once the extract had cooled to room temperature, 1 ml of acetic acid, 25 mg of ninhydrin and 1 mL of a mix of dist. water, acetic acid and orthophosphoric acid (120, 300, 80 : v/v/v) were added to 1 mL of extract. The mixture was brought to the boil in a bain-marie for 30 min, then allowed to cool. Next, 5 mL of toluene was stirred in. A dash of sodium sulphate was stirred with a vortex. The tubes were then stirred for 15 s and allowed to rest for 10 min to allow the phases to be separated. The top phase was removed and the absorbance was read at 528 nm using a spectrophotometer (Unico S-2150E UV/Visible spectrophotometer) and the level of free proline was determined using Proline standards.

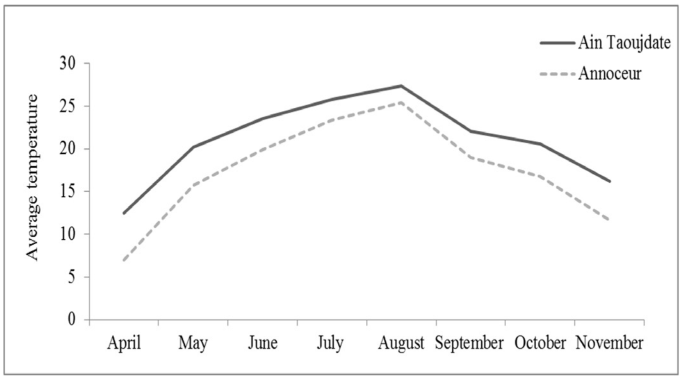

Figure 1. The temperature (°C) difference between the two sites 'Annoceur' and 'Ain Taoujdate'

Statistical Analysis

The database was processed using software of SPSS v22. The analysis of variance (ANOVA) was carried out to compare the differences between the means of the traits analyzed. A Student–Newman–Keuls test (SNK) was used for the comparison of sample means at $P \leq 0.05$. Principal Component Analysis (PCA) was applied to identify the degree of discrimination of different variables. A correlation test was performed, using a Pearson model between the traits analyzed.

Results

Production Traits

The measured production traits are presented in Table 2. Significant differences between varieties at the two studied sites were observed for yield, average weight and fruit size. The climate factor influenced the yield in all varieties, with the exception of the variety 'Stanley', which was reduced by 28% on average between the two contrasting climates studied, since at the 'Annoceur' site, which is characterized by a cold winter and fairly hot summer climate, the average yield was 23.92 kg per tree, while at the 'Ain Taoujdate' site, which is characterized by a mild winter and dry summer climate, the average yield per tree was 6.71 kg. Similarly, in all varieties, the influence of the climate reduced the weight of the fruit except the variety 'Methley' with an overall average of 13%. Indeed, the average fruit weight in the 'Annoceur' site was 51.50 g and that of the 'Ain Taoujdate' site was 44.75 g. Fruit size (length, width, and height) was significantly affected by climate with decreases of 15%, 13% and 8%, respectively, except for fruit height in the variety 'Stanley'.

Table 2. Effect of the site on plum fruit production traits.

Varieties	Sites	Yield (Kg per tree)	Fruit weight (g)	Fruit length (mm)	Fruit width (mm)	Fruit height (mm)	Core weight (g)
Methley	Annoceur	46.42 ± 14.66[a]	24.16 ± 1.68[a]	37.94 ± 1.13[a]	38.16 ± 0.19[a]	32.68 ± 0.37[a]	1.19 ± 0.04[a]
	Ain Taoujdate	4.52 ± 1.33[b]	34.53 ± 1.93[b]	26.14 ± 1.20[b]	28.05 ± 1.06[b]	26.04 ± 2.13[b]	1.37 ± 0.26[a]
Black Amber	Annoceur	18.27 ± 2.66[a]	51.47 ± 0.75[a]	42.59 ± 0.39[a]	43.49 ± 0.34[a]	39.46 ± 1.64[a]	0.59 ± 0.06[a]
	Ain Taoujdate	4.67 ± 0.66[b]	42.15 ± 2.09[b]	40.83 ± 0.26[b]	42.09 ± 0.42[b]	39.05 ± 0.19[a]	0.93 ± 0.02[b]
Fortune	Annoceur	19.47 ± 2[a]	70.05 ± 0.31[a]	51.73 ± 1.15[a]	48.41 ± 0.94[a]	42.69 ± 0.46[a]	1.33 ± 0.03[a]
	Ain Taoujdate	3.85 ± 1.66[b]	44.26 ± 0.63[b]	44.55 ± 0.52[b]	43.02 ± 0.91[b]	41.04 ± 0.03[b]	0.90[b]
Stanley	Annoceur	11.52 ± 3.33[a]	60.34 ± 1.03[a]	49.75 ± 1.03[a]	44.06 ± 0.62[a]	41.44 ± 0.95[a]	1.09 ± 0.01[a]
	Ain Taoujdate	13.78 ± 4.33[a]	58.06 ± 0.1[b]	42.77 ± 0.36[b]	37.63 ± 1.09[b]	52.69 ± 2.96[b]	0.73 ± 4.5[b]
Avenage	Annoceur	23.92 ± 11.25[a]	51.50 ±13.68[a]	45.50 ± 5.23[a]	43.53 ± 2.70[a]	39.07 ± 3.19[a]	1.05 ± 0.23[a]
	Ain Taoujdate	6.71 ± 3.53[b]	44.75 ± 6.66[b]	38.57 ± 6.21[b]	37.70 ± 4.86[b]	39.70 ± 7.16[b]	9.31 ± 12.36[b]

Note: Means indicated by different letters are significantly different ($P \leq 0.05$) according to the SNK test

Core weight was affected by climate while showing an average decrease of 33% between the two contrasting climates. However, the effect was not significant in both varieties 'Methley' and 'Stanley'. In fact, the average core weight in the 'Annoceur' site was 0.96 g and that in the 'Ain Taoujdate' site was 0.91 g.

Vegetative Traits

The vegetative traits measured revealed significant differences within varieties at the two sites studied (Table 3, Fig. 2). The comparison of vegetative shoot elongation between the two sites varied between varieties. For the 'Methley' variety, no significant variation was found between the two climates. The length is significant at the 'Ain Taoujdate' site for the varieties 'Black Amber' and 'Stanley' with differences of 17.37 cm and 2.92 cm, respectively. For the variety 'Fortune', growth is more significant at the 'Annoceur' site with a difference of 5.4 cm. These results show that the responses of the varieties in terms of vegetative growth are variable depending on the genotype. Genotypes with low chill requirements begin early dormancy breaking and are likely to have high vegetative growth, as in the case of the Methley variety.

However, the effect of climate was non-significant on the number of shoots/mL in all four varieties in the two contrasting climates. The number of leaves per fruit decreased in the site of 'Annoceur' compared to 'Ain Taoujdate' in all varieties with an overall average of 27%. Indeed, the two varieties, 'Black Amber' and 'Fortune,' showed the greatest decreases with 33% and 31%,

Table 3. Effect of the site on vegetative traits of plum tree studied

Varieties	Sites	Shoot length (cm)	Number of shoots	Number of leaves per fruit
Methley	Annoceur	55.13 ± 1.57[a]	1.00[a]	7.00 ± 0.44[a]
	Ain Taoujdate	57.03 ± 1.57[a]	1.00[a]	9.00 ± 0.66[b]
Black Amber	Annoceur	55.90 ± 0.93[a]	1.00 ± 0.44[a]	10.00 ± 0.66[a]
	Ain Taoujdate	73.27 ± 1.17[b]	2.00 ± 1.11[a]	15.00 ± 1.77[b]
Fortune	Annoceur	64.50 ± 1.8[a]	1.00 ± 0.44[a]	9.00 ± 1.11[a]
	Ain Taoujdate	59.10 ± 1.26[b]	1.00[a]	13.00 ± 1.55[b]
Stanley	Annoceur	61.48 ± 0.86[a]	1.00[a]	11.00 ± 0.66[a]
	Ain Taoujdate	64.40 ± 1.73[b]	1.00[a]	14.00 ± 1.33[b]

Note: Means indicated by different letters are significantly different ($P \leq 0.05$) according to the SNK test respectively. The monitoring of shoot growth of the four varieties at the two sites is presented in Fig. 2. The results showed that the monitoring of vegetative growth in the four varieties is marked by two phases of active growth. For the 'Methley' variety, the first phase is accelerated and shows an elongation of 34 cm and in the second phase, which starts in October, the growth is strongly slowed down with an elongation of 3 cm. For 'Black Amber' variety, the first phase shows an elongation of 42 cm, while the second phase is slowed down by showing a growth of 7 cm. The 'Fortune' variety shows a growth of 38 cm in the first phase and 3 cm in the second phase. Similarly, the 'Stanley' variety shows a growth of 41 and 2 cm in the two growth phases, respectively. In general, the growth in the 'Annoceur' site is less developed (41 cm on average) compared to that in the 'Ain Taoujdate' site (45 cm on average).

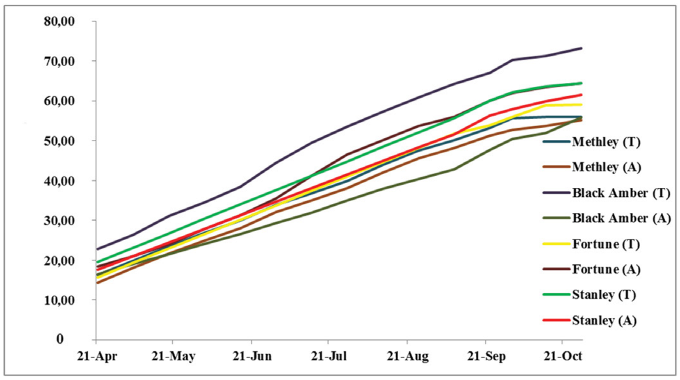

Figure 2. Growth of shoots (cm) as a function of time at the 'Ain Taoujdate' (T) and 'Annoceur'(A) sit

Foliar Proline and Chlorophyll Content

Varieties at both sites showed significant differences in leaf proline and chlorophyll content (Table 4).

The climate factor influenced the foliar proline content of all varieties and it increased in the varieties 'Methley', 'Black Amber', 'Fortune' and 'Stanley' at the 'Annoceur' site with 42, 51, 30 and 35%, respectively. For all varieties, it was noticed that the levels at the 'Ain Taoujdate' site were higher than at those in the 'Annoceur' site. Thus, these differences show that the temperature increase at 'Ain Taoujdate' constitutes stress in plum. The varieties 'Methley' and 'Black Amber' showed the greatest differences with values of 0.14 g L^{-1} and 0.17 g L^{-1}, respectively. However, leaf content of chlorophyll pigments a and b declined under the influence of climate in the 'Ain Taoujdate' site for varieties 'Methley', 'Black Amber', and 'Stanley', with averages of 13, 62%, respectively except for the chlorophyll content of the variety 'Fortune'.

Interactions between Experimental Design Factors

In order to evaluate the impact of the interaction between variety and site on the measured production and vegetative traits, a two-factor analysis of variance was performed (Table 5). We note that λ (varieties) = 0.000 < λ (site) = 0.001, which means that the effects of variety, site and varieties * sites are very highly significant. It can be seen that all the traits analyzed were influenced by climatic conditions, genotypes, and their interaction. These findings are particularly useful as they show the magnitude of the impact of individual factors on the traits being measured and how this is influenced by levels of interaction. As a result, the variety factor and their interactions with the site showed a statistically significant impact ($P < 0.05$).

Multivariate Analysis

Principal component analysis (PCA) was determined to better reveal the most discriminating traits among those used in this study, taking into account that only the loading of each variable above 0.5 is significant (Table 6). For the 'Ain Taoujdate' site, the first component explains 53.18% of the total variance.

Table 4. Effect of site on leaf proline and chlorophyll *a* and *b* content of plum tree studied

Varieties	Sites	Proline (g L^{-1})	Chlor a (mg L^{-1})	Chlor b (mg L^{-1})
Methley	Annoceur	0.33^a	9.03 ± 0.11^b	9.01 ± 0.41^b
	Ain Taoujdate	0.47^b	7.63 ± 0.01^a	8.12 ± 0.07^a
Black Amber	Annoceur	0.33^a	8.25 ± 0.18^b	8.18 ± 0.2^b
	Ain Taoujdate	0.50 ± 0.03^b	7.34 ± 0.08^a	7.91 ± 0.83^a
Fortune	Annoceur	0.42^a	6.83 ± 0.04^a	18.18 ± 0.02^b
	Ain Taoujdate	0.55^b	6.17 ± 0.43^a	7.38 ± 0.93^a
Stanley	Annoceur	0.40 ± 0.01^a	9.22 ± 0.02^b	11.22 ± 0.11^b
	Ain Taoujdate	0.45^b	3.32 ± 0.28^a	4.50 ± 0.24^a
Average	Annoceur	0.40 ± 0.04^a	8.82 ± 1.20^b	14.54 ± 2.62^b
	Ain Taoujdate	0.49 ± 0.03^b	5.15 ± 1.05^a	10.06 ± 4.12^a

Note: Means indicated by different letters are significantly different ($P \leq 0.05$) according to the SNK test

Table 5. Multivariate ANOVA showing the within-subject effect and their interaction

Statistics	Varieties		Sites (climate)		Varieties * Sites	
	F	Sig.	F	Sig.	F	Sig.
Pillai's Trace	35.38	0.00	289.864[b]	0.00	53.722	0.01
Wilks' Lambda	69.853 (V = 0.000)	0.00	289.864[b] (V = 0.001)	0.00	83.867	0.00
Hotelling's Trace	85.384	0.00	289.864[b]	0.00	80.117	0.02
RoyRacine's biggest	418.171[c]	0.00	289.864[b]	0.00	293.171[c]	0.00

Note: b. Exact statistic, c. The statistic is an upper limit of F which gives a lower limit to the significance level

Table 6. The rate of variance explained by the first three components of PCA using the average measured values of plum variety traits

	Component matrix					
	Component					
	Ain Taoujdate			Annoceur		
	1	2	3	1	2	3
Yield	**0,712**	-0,554	-0,432	**-0,920**	0,391	-0,024
Fruit weight (g)	**0,994**	-0,111	0,013	**0,983**	-0,065	0,170
Fruit length (mm)	**0,759**	0,514	0,399	**0,979**	0,202	0,005
Thickness of fruits (mm)	0,499	0,775	0,387	**0,925**	0,018	0,381
Fruit height (mm)	**0,992**	0,095	0,089	**0,983**	-0,150	0,107
Core weight (g)	**0,857**	-0,460	-0,234	0,156	**0,988**	-0,008
Shoot length (cm)	0,350	0,758	-0,550	**0,775**	0,632	-0,016
Number of shoots	-0,076	0,856	-0,512	0,167	**-0,719**	0,675
Number of leaves per fruit	**0,751**	0,642	-0,153	0,660	-0,604	-0,446
Proline	-0,251	0,649	0,718	-0,405	**0,900**	-0,164
Chlor *a*	-0,540	0,768	0,345	**-0,802**	0,083	-0,591
Chlor *b*	**-0,856**	0,264	-0,445	-0,110	0,684	0,721
of variance	**53,18**	**28,21**	**18,18**	**48,96**	**32,85**	**18,18**
Cumulative %	**53,18**	**81,40**	**100,00**	**48,96**	**81,81**	**100,00**

Note: The most significant coefficients (> 0.70) are highlighted in bold

It is correlated positively with yield (r = 0.712), fruit weight (r = 0.994), fruit height (r = 0.759), fruit height (r = 0.992), core weight (r = 0.857), number of leaves per fruit (r = 0, 751) and correlated negatively with chlorophyll *b* content (r = 0.856). For the 'Annoceur' site, the first component explains 48.96% of the total variance. It is correlated positively with fruit weight (r = 0.983), fruit height (r = 0.979), fruit width (r = 0.925), fruit height (r = 0.983), shoot length (r = 0.775) and correlated negatively with yield (r = 0.920) and chlorophyll *a* content (r = 0.802). The second component represents 32.85% of the total inertia and is mainly positively correlated with core weight (r = 0.988) and proline content (r = 0.900). It is negatively correlated with the number of shoots/mL (r = 0.719). It is important to consider that with the main component load of more than 0.7, these traits were revealed as the most discriminating for the adaptability of the four varieties in different climates. For the 'Ain Taoujdate' site, the most discriminating traits are yield and fruit size. Similarly, for the 'Annoceur' site, yield, fruit size and vegetative traits are the most discriminating.

Correlation between the Effects of the Two Contrasting Climates

The correlation was determined to understand the relationship between all the measured traits of the plum varieties studied in the two contrasting sites. The correlations are summarized in Table 7. The correlation shows that the yield is negatively correlated with fruit height and chlorophyll content with coefficients of 0.925 and 0.959 and correlated positively with core weight with a coefficient of 0.966. Similarly, fruit weight was correlated positively with fruit size (length, thickness and height) with correlation coefficients of 0.937, 0.973, and 0.912, respectively. Chlorophyll content was correlated negatively with fruit thickness with a coefficient of 0.965.

Discussion

The effect of the contrasting climates on the production traits obtained in this study corroborates with other studies carried out by Gitea et al. (2019) and Fischer et al. (2016), respectively on plum, apple and peaches, which showed that the climate factor influenced production within the varieties studied in two different climates and consequently the fruit yield was decreased by 8%, 24% and 46%, respectively. These differences can be explained by the soils that differ from one site to another because the quantity of organic matter and micro-organisms varies from one soil to another (Moisa et al., 2018), as well as the soil quality index directly reflects the changes in the soil influenced by environmental conditions that affect fruit production and the efficiency with which these crops use nutrients (Samuel et al., 2017). Other factors that can influence the production of the studied varieties include the varietal effect since the varieties involved in this study are characterized by high genetic variation (Hamdani et al., 2022b), as well as the climatic conditions since the climate is cold winter and a rather hot summer in 'Annoceur' and hot and dry summer and a mild winter in 'Ain Taoujdate' which explains the variation in chill requirement accumulation between the four varieties 'Methley', 'Black Amber', 'Fortune', 'Stanley' ranging from 118-239, 389-432, 436-447 and 561-630 CH, respectively (Li et al., 2016). This means that good chill satisfaction equates to good flowering implying good yield. However, the regression of yield and fruit size in the 'Ain Taoujdate' site compared to the 'Annoceur' site is due to the

Table 7. Correlation matrix between the different measured parameters of four plum varieties studied

	Y	FW	FL	FT	FH	CW	SL	NS	NF	Proline	Chlor *a*	Chlor *b*
Y	1											
FW	0,308	1										
FL	0,160	.937*	1									
FT	-0.853	.973*	0,308	1								
FH	-.925*	.912**	0,160	0,512	1							
CW	.966*	-0,842	0.352	0,113	0,376	1						
SL	-0.465	-0,400	0.886	0,572	-0,043	0,903	1					
NS	-0.451	0,010	0.022	0,512	0,581	0,028	-0,136	1				
NF	-0,095	-0,053	-0,095	0.429	0,458	0,030	-0,069	0.244	1			
Proline	0,062	0,093	-0,062	-0.420	0,576	-0,480	-0,808	0,236	0,098	1		
Chlor *a*	-.959*	-0,588	-0,656	-.965*	-0.864	0,084	-0,329	0,654	0,526	0.496	1	
Chlor *b*	-0,139	-0,751	-0,139	0,899	-0.133	-0,323	-0,676	0,045	-0,107	0.541	0,720	1

Note: **. Correlation is significant at the $P < 0.01$ level; *. Correlation is significant at the $P < 0.010.05$ level; significant and potential correlations are indicated in bold.

Y: Yield, FW: Fruit weight, FL: Fruit length, FT: Fruit thickness, FH: Fruit height, CW: Core weight, SL: Shoot length, NS: Number of shoots, NF: Number of leaves per fruit, Chlor *a* : Chlorophylle *a*, Chlor *b* : Chlorophylle *b*.

increase of temperature during winter; flowering and fruit set by a few degrees that could reduce fruit formation time, size, and yield (Stockle et al., 2011). According to the yield and pomology traits, it appears that 'Stanley' variety is best suited to areas with mild winters and that the 'Methley', 'Black Amber' and 'Fortune' varieties require heavy chill to achieve better production.

The influence of site on growth and vegetative development is close to that reported by Minin et al. (2016) on peach who mentioned a climate influence on the growth and vegetation of varieties which might be due to an environmental factor limiting the success of vegetative growth in plum trees. It could be the low temperatures in winter and the changes in winter and spring temperatures that allow the trees to emerge from the pause in vegetative growth and enter the annual development phase while showing a faster and/or shorter flowering period because the average monthly temperature is rising (Butac and Chitu, 2007; Gitea et al., 2019). This may explain the early growth of these varieties in the 'Ain Taoujdate' site compared to the 'Annoceur' site. According to Butac and Chitu (2007), relatively high temperatures in the dormancy and emergence phases are positively correlated with a longer dormancy breaking period, vegetative growth and a shorter period of flowering onset, which explains the non-significant effect of climate on growth and vegetative development in the 'Methley' variety characterized by its low chill requirement and thus less extensive dormancy than the other three varieties with relatively high requirements whose growth is affected by temperature variation between the two contrasting climates.

Similarly, Cosmulescu et al. (2010) and Minin et al. (2020) in theit study on plum reported that environment-related factors, including climate temperature and bran mineral content, as well as certain factors relating to varietal effects (chill requirements, cold stress response plasticity, leaf age, leaf structure, degree of carbohydrate accumulation in the leaf) influenced the proline and chlorophyll content. It was revealed that chlorophyll content decreased with increasing average temperatures, which is explained by the inactivation of the photosynthetic apparatus including photosystem II (PSII) and its complex responsible for oxygen production, which is immediately deactivated by heat, thereby disrupting electron transfer. PSII repair is inhibited by damaging the D1 protein (which is one of the proteins forming the heart of PSII) through the generation of active oxygen species which generally act differently on enzymes and physiology, disrupting both primary and secondary metabolism and affecting photosynthesis, organic matter, fruit quality and yields (Orduz-Rodriguez and Fischer 2012; Jarma et al., 2012). From the traits analyzed above, it is revealed that the four varieties show significant differences in the two contrasting climates, and thus both, variety and site factors influence the adaptation of varieties studied by affecting production and phenology. The 'Methley' variety installed at the 'Ain Taoujdate' site was found to be the least tolerant by showing the highest yield decline and the lowest growth among the varieties installed at both sites. The variety 'Stanley', installed at the same site, was found to be the most tolerant while showing the lowest yield decrease and its growth was weakly affected.

With regard to the interactions between the experimental design factors, our results concerning the interaction between variety and site on the parameters measured are in line with those found by Gitea et al. (2019) on plums which showed that production was unaffected by weather conditions and growth of plum genotypes ($p = 0.549$ and $p = 0.252$) grown in two contrasting climates, however no varietal effect was observed between plum varieties ($p = 0.549$). This may be due to several external factors including different climatic conditions, soils and their mineral nutrients and microflora and microfauna (Samuel et al., 2017). From these results, it can be seen that the production traits are generally positively correlated with each other, which was confirmed by Beyer et al. (2002) and Khadivi et al. (2018) who argued that fruit size was considered to be as important a factor as fruit cracking in sweet cherries fruits and negatively correlated with chlorophyll content, which is contradictory to Mars and Marrakchi, (1998) who also reported that there was no correlation between production traits and chlorophyll content. The correlation obtained can also provide us with the information on discriminating descriptors in the evaluation of the varieties studied.

Conclusion

The four plum varieties showed different levels of agronomic and vegetative response under two contrasting climatic environment sites. The 'Annoceur' site was found to be more suitable for the plum species as it allowed the varieties to easily accumulate chill requirements. Although heat stress (environmental factor) affects all agronomic and morphological traits, its effect differs between varieties. The traits yield, fruit size and vegetative traits are the agro-morphological markers that largely determine the tolerance of varieties to heat stress. The 'Stanley' variety is the most tolerant to high winter temperatures and the' Methley' variety is the most sensitive. The results will help to better understand the mechanisms of varietal tolerance of plum trees to heat stress. In this way, they can guide the spatial allocation of crops of the species according to the evolution of climate change and according to the tolerance plasticity revealed by varieties, particularly the 'Stanley' variety. The study will be a pioneering step towards the implementation of a genetic selection program that takes heat stress tolerance into account.

CRediT Authorship Contribution Statement

Jamal Charafi: Study design and production. **Anas Hamdani:** Material preparation, collection of data and subsequent analysis, the first draft of the paper writing. **Anas Hamdani, Jamal Charafi, Said Bouda, Atman Adiba and Hakim Outghouliast:** revision and preparation offinal manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

The data sets produced and/or processed as a result of this research are accessible from the respective authors upon request.

Funding

This work was financed by the Ministry of Agriculture Fisheries, Rural Development, Water and Forests of Morocco (MCRDV program).

Acknowledgements

The authors thank Younes Ogad and Houssam Ouhoussa for their help in the field work.

References

Adiba A., Razouk R., Charafi J., Haddioui A., Hamdani A. (2021). Assessment of Water Stress Tolerance in Eleven Pomegranate Cultivars Based on Agronomic Traits. Agric Water Manag 243: 106419. doi: 10.1016/j.agwat.2020.106419

Adiba A., Haddioui A., Hamdani A., Kettabi Z. E., Outghouliast H., Charafi J. (2024). Impact of Contrasting Climate Conditions on Pomegranate Development and Productivity: Implications for Breeding and Cultivar Selection in Colder Rnvironments. Vegetos (in press). doi:10.1007/s42535-023-00771-6

Al-Yahyai R., Al-Said F., Opara L. (2009). Fruit Growth Characteristics of Four Pomegranate Cultivars from Northern Oman. Fruits 64 (6): 335-341 doi: 10.1051/ fruits/2009029

Beyer M., Hahn R., Peschel S., Harz M., Knoche M (2002). Analysing Fruit Shape in Sweet Cherry (*Prunus avium* L.). Sci. Hortic 96: 139–150.

Butac M., Chitu E. (2007) Impactul schimbarilor climatice asupra dinamicii fenologice a unor soiuri de prun cultivate în bazinul pomicol Arges,. Fruit Grow Res XXIII: 139-147. Available at: https://publications.icdp.ro/publicatii/LS%20ICDP%20vol%20XXIII%20-%202007.pdf [Accessed 15 February 2022].

Cosmulescu S, Baciu A, Cichi M, Gruia M (2010) The Effect of Climate Changes on Phenological Phases in Plum Tree (*Prunus domestica*) in South-Western Romania. Southwest J Hort Biol Environ 1: 9-20.

Cox P. M., Betts R. A., Jones C. D., Spall S. A., Totterdell I. J. (2000). Acceleration of Global Warming Due to Carbon-Cycle Feedbacks in a Coupled Climate Model. Nature 408: 184-187. Doi: 10.1038/35041539

Dinu M. D., Mazilu I. E., Cosmulescu S. (2022). Influence of Climatic Factors on the Phenology of Chokeberry Cultivars Planted in the Pedoclimatic Conditions of Southern Romania. Sustainability 14: 4991. doi: 10.3390/su14094991

Eremin G. V. (2017). Improving the Assortment of Russian plums. Fruit Growing and Berry Growing in Russia 48 (1): 98-102.

FAO (2022) FAOSTAT. Available at: http://www.fao.org/faostat/en/#data/QC. [Accessed 15 February 2022].

Fischer G., Ramírez F., Casierra-Posada F. (2016). Ecophysiological Aspects of Fruit Crops in the Era of Climate Change. A Review. Agronomía Colombiana 34 (2): 190-199.

Gitea M. A., Gitea D., Tit D. M., Purza L., Samuel A. D., Bungău S., Aleya L. (2019). Orchard Management under the Effects of Climate Change: Implications for Apple, Plum and Almond Growing. Environ Sci Pollut Res Int 26 (10): 9908-9915. doi: 10.1007/s11356-019-04214-1

Gleizer B., Legave J. M., Berthoumieu J. F., Mathieu V. (2007). Arboriculturists Facing Climate Change. Evolution of floral phenology and the risk of spring frost. Infos-Ctifl 235: 37-40.

Hamdani A., Bouda S., Houmanat K., Outghouliast H., Razouk R., Adiba A., Charafi J. (2022a). Genetic Diversity Revealed via Molecular Analysis of Moroccan and Foreign Plum (*Prunus domestica*; *Prunus salicina*) Genotypes from an *ex-situ* Collection. Vegetos (2022). doi: 10.1007/s42535-022-00463-7.

Hamdani A., Hssaini L., Bouda S., Adiba A., Razouk R. (2022b). Japanese Plums Behavior under Water Stress: Impact on Yield and Biochemical Traits. Heliyon 8 (4): e09278. doi: 10.1016/j.heliyon.2022.e09278

Hamdani A., Hssaini L., Bouda S. J., Adiba M., Kouighat A., Razouk R. (2023). The Effect of Heat Stress on Yield, Growth, Physiology and Fruit Quality in Japanese Plum 'Angelino'. Vegetos 2023. doi: 10.1007/s42535-023-00644-y

Hamdani A., Yaacoubi A. E., Bouda S., Erami M., Adiba A., Outghouliast H., Charafi J. (2024). Chilling and Heat Requirement for Dormancy Breaking and Flowering of the Plum Accessions Belonging to the Living Collection of Morocco. Theoretical and Applied Climatology: 1-14. Doi: 10.1007/s00704-024-05067

Jarma A., Ayala C. C., Aramendis H. (2012). Efecto del cambio climatico sobre la fisiologia de las plantas cultivadas: Una revision. Rev. UDCA Act. & Div. Cient. 15: 63-76.

Khadivi A., Ayenehkar D., Kazemi M., Khaleghi A. (2018). Phenotypic and Pomological Characterization of a Germplasm Collection of Pomegranate (*Punica granatum* L.) and Identification of Promising Selections Sci Hortic 238: 234 - 245. doi: 10.1016/j.scienta.2018.04.062

Lee H. K., Lee S. J., Kim M. K., Lee S. D. (2020). Prediction of Plant Phenological Shift under Climate Change in South Korea. Sustainability 12 (21): 9276. doi: 10.3390/su12219276

Li Y., Fang W. C., Zhu G. R., Cao K., Chen C. W., Wang X. W., Wanf L. R. (2016). Accumulated Chilling Hours during Endodormancy Impact Blooming and Fruit Shape Development in Peach (*Prunus persica* L.). J Int Agric 15 (6): 1267-1274. doi: 10.1016/S2095-3119(16)61374-6

López-Ortega G., García-Montiel F., Bayo-Canha A., Frutos-Ruiz C., Frutos-Tomás D. (2016). Rootstock Effects on the Growth, Yield and Fruit Quality of Sweet Cherry cv.'Newstar' in the Growing Conditions of the Region of Murcia. Sci Hortic 198: 326-335. doi: 10.1016/j.scienta.2015.11.041

Mars M., Marrakchi M. (1999). Diversity of Pomegranate (*Punica granatum* L.) Germplasm in Tunisia. Genet Resour Crop Evol. 46: 461–467. doi:10.1023/A:1008774221687

Martinez-Luscher J., Torres N., Hilbert G., Richard T., Sanchez-Diaz M., Delrot S., Aguirreolea J., Pascual I., Gomes E. (2014). Ultraviolet-B Radiation Modifies the Quantitative and Qualitative Profile of Flavonoids and Amino Acids in Grape Berries. Phytochem 102: 106-114. doi: 10.1016/j.phytochem.2014.03.014

Minin A. N., Nechaeva E. K., Markovskaya G. K., Stepanova J. V. (2020). Creation and Study of Russian Plum Varieties in the Middle Volga. BIO Web of Conferences 27: 00043). EDP Sciences. doi: 10.1051/bioconf/20202700043

Monneveux P., Nemmar M. (1986). Contribution à l'étude de la résistance à la sécheresse chez le blé tendre (*Triticum aestivum* L.) et chez le blé dur (*Triticum durum* Desf.): étude de l'accumulation de la proline au cours du cycle de développement. Agronomie 6 (6): 583–590. doi: 10.1051/agro:19860611 (in French)

Orduz-Rodriguez J., Fischer G. (2007). Water Balance and Influence of Water Stress on Floral Induction and Flower Development of 'Arrayana' Mandarin in the Piedemont Plains of Colombia. Agronomia Colombiana 25: 255-263. (in Spanish)

Poggi G. M., Aloisi I., Corneti S., Esposito E., Naldi M., Fiori J., Piana S., Ventura F. (2022). Climate Change Effects on Bread Wheat Phenology and Grain Quality: A Case Study in the North of Italy. Front Plant Sci 13: 936991. doi: 10.3389/fpls.2022.936991

Razouk R., Kajji A., Hamdani A., Charafi J., Hssaini L., Bouda S. (2021). Yield and Fruit Quality of Almond, Peach and Plum under Regulated Deficit Irrigation. Front Agric Sci Eng 8 (4): 583-593. doi:10.15302/j-fase-2020325

Samuel A. D., Brejea R., Domuta C., Bungau S., Cenusa N., Tit D. M. (2017). Enzymatic Indicators of Soil Quality. J Environ Prot Ecol 18 (3): 871–878.

Ruiz D., Egea J., Salazar J. A., Campoy J. A. (2018). Chilling and Heat Requirements of Japanese Plum Cultivars for Flowering. Sci Hortic 242: 164-169. doi: 10.1016/j.scienta.2018.07.014

Samuel A. D., Brejea R., Domuta C., Bungau S., Cenusa N., Tit D. M. (2017). Enzymatic Indicators of Soil Quality. J Environ Prot Ecol 18 (3):871–878.

Singh V. P., Mall S. L., Biillor S. K. (1975). Effect of pH on Germination of Four Common Grass Species of Ujjain (India). J Range Manag 28: 497–498.

Sparks T. H., Menzel A. (2002). Observed Changes in Seasons: An Overview. Int. J. Climatol., 22: 1715-1725. doi: 10.1002/joc.821

Stefanova B. (2019). Plum Phenology in Troyan Region and the Influence of Climatic Factors on Phenophases. Rastenievadni nauki 56 (4) 32-36.

Stockle C. O., Marsal J., Villar J. M. (2011). Impact of Climate Change on Irrigated Tree Fruit Production. Acta Hortic 889: 41- 52. doi: 10.17660/ActaHortic.2011.889.2

Wang Z., Yang Y., Yadav V., Zhao W., He Y., Zhang X., Wei C. (2022). Drought-Induced Proline Is mainly Synthesized in Leaves and Transported to Roots in Watermelon under Water Deficit. Horticultural Plant Journal 8 (5): 615-626.

aCS89_25