Leaf Mineral Composition in Plum Cultivars (*Prunus salicina* Lindl. and *Prunus domestica* L.) Related to Yield Levels

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Summary

The plum tree is a major crop in Morocco, and one that has developed rapidly and plays a very important environmental role in the protection, restoration and fixation of soils. It also plays an economic role, which lies in its fruit, which has a high nutritional value comparable to that of fruits such as almonds, peaches, apples and others. However, there is no national study to assess the variability among cultivated plum cultivars to supply descriptors that are important, especially in the case of the evaluation of plum genotypes. In this study, 27 plum cultivars grown in the Ain Taoujdate experimental field of Morocco's National Institute for Agronomic Research were examined to assess the variability among them. Measurements were made on yield, macronutrient content of leaves: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) and micronutrients: sodium (Na), iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu). All analyses revealed significant variation in terms of yield and leaf mineral composition between the cultivars studied. PCA using the mean of the traits revealed that fruit yield and foliar content of potassium (K), zinc (Zn), nitrogen (N), iron (Fe), sodium (Na), copper (Cu), magnesium (Mg) and calcium (Ca) had the greatest impact on the discrimination of cultivars to reveal their variability. Analysis of the clusters identified three separate groups among the cultivars examined in order to assess their variability. These findings are of considerable value for the breeding of cultivars for plum trees based on their agronomic and mineral attributes for cultivation.

Key words

Prunus domestica L., *Prunus salicina* Lindl., productive potential, leaf macro and micro micronutrient

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Introduction

In the agricultural sector, the fruit trees constitute an essential economic engine for farmers by providing a source of foodstuffs, income and jobs, etc (Milosevic et al., 2020). Among the most common cultivars used in arboriculture is the plum (*Prunus domestica* L. and *Prunus salicina* Lindl.), which is ranked third because of its worldwide production of nearly 11 million tons (Milosevic et al., 2012; Hamdani et al., 2024a). In Morocco, plum cultivation occupies an area of about 16.198 ha for a production of about 143.457 tones/year, making it the ninth-largest producer of plums in the world (Hamdani et al., 2021). Cultivated national varieties belong to two plum species, the Japanese plum group (*Prunus salicina* Lindl.) which includes introduced varieties: Santa Rosa, Methley, Golden Japan and local clones from seedlings: Timehdite, Zerhouni, Fassi, Meless and Zouitni, and the group of domestic plums (*Prunus domestica* L.): Stanley and Prune d'Ente (Hamdani et al., 2023). The choice of plum cultivar is considered a relevant and very important trait in fruit production to determine fruit quality and productivity as well as its economic interest. The main processed products of plums are compôtes, mousses, pulps, candied fruits, and frozen fruits (Milosevic et al., 2010). Plum consumption has considerably expanded in the last few years. This is due to two things: (i) the extension of the crop and (ii) the expansion of the season thanks to the selection of a variety of Japanese cultivars. In fact, these cultivars are best suited to many regions with hot climates for both early and late crops (Okie et al., 2008).

Plums are used both for fresh and dry consumption. They represent a major contributor to minerals and vitamins that constitute a considerable nutritional part in our daily life by providing our dietary needs (Gregory 1993; Milosevic et al., 2011). This mineral source is due to macronutrient and micronutrient including nitrogen (N), potassium (K), phosphorus (P), calcium (Ca) and iron (Fe) that are essential for increasing the quality and yield of rosaceous fruit (Bai et al., 2021). Mineral deficiencies can strongly affect growth, metabolism, plant development, and eventually affect yield, nutritional value and fruit quality (Nunes et al., 2022). The fruit has high water quantity with a share of carbohydrates (glucose, sucrose and fructose), fibre, pectin, organic acids including tartaric, malic and citric acids as well as minerals, tannins, and enzymes, etc. (Forni et al., 1992). The mineral attributes and productivity of plums depend on the cultivar, the conditions in the environment and crop cultivation-based techniques, etc. (Nergiz and Yildiz 1997; Usenik et al., 2008).

To the best of our information, no research has yet been conducted to compare agronomic attributes and leaf mineral content among plum cultivars under Moroccan climate. The objective of this research was to assess the variability among these plum cultivars under the same climatic conditions and the nutrient uptake and utilization efficiency. In parallel, this research will determine the interrelation of all the characteristics in a bid to identify the potentially significant descriptors for the evaluation of plum genotypes.

Material and Methods

Plant Material and Experimental Conditions

The zone of study is situated in the National Institute for Agronomic Research station at Ain Taoujdate, far from Meknes city by 30 km and situated in the Sais plain at an altitude of about 550 m (33° 56'E. 5° 13'N. 499 m). Soil in the area under study is clay, limestone and alluvial sediment (Table 1). Mean temperatures are as follows: the minimum is in January (2.8 °C) and the maximum in July (37 °C). Annual precipitation is around 440 mm and the amount of cold is 540 hours of temperature below 7 °C. The study was conducted in 2021 using a collection of plum trees made up of 16 local and 11 foreign cultivar of fourteen years old (Table 2), which were grafted on 'Myrobolan' stock and transplanted in two lines at a distance of 5 x 5 m and with 10 trees in every line. The collection was irrigated using drip irrigation system from the end of February corresponding to the flowering stage until the beginning of October, the ripening stage receiving a total water volume of about 1800 m^3/h, plant trees were fertilized using 150 g N, 90 g P_2O_5 and 180 g K_2O per tree. All trees were conducted under the same geographical conditions and underwent the same horticultural management practices including pest control, which was carried out in accordance with local trade practices as well as weed removal and tree thinning in order to homogenize the size of the whole collection.

Sampling and Measurements

Young leaf samples were taken 70 days after full flowering. As advised by Freire and Magnani (2005), the samples of 100 leaves (blade and petiole) were taken in a randomized way for each cultivar. The leaf samples were then lyophilized in a WPA Biowave S2100 lyophilizer and then ground, and were used for the preparation of ethanolic extracts obtained by using 1 g of the freeze-dried and ground sample with 30 ml of ethanol (80%) and were processed by maceration and filtration to determine macro and micronutrient content in different samples (Nunes et al., 2022). The macronutrient contents of nitrogen (N), phosphorus (P), potassium (K) were expressed by percentage unit, however calcium (Ca) and magnesium (Mg) by ppm (parts per million), as well as for the micronutrients: sodium (Na), iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu), expressed in (ppm) (Tedesco 1995; CQFS-RS/SC 2016).

At the harvest stage, two yield traits were determined, namely the fruit counted on each tree and the fruit weight, as measured by randomly collecting 30 ripe fruits of every tree. The yield characteristics were then utilized to compute the fruit yield by multiplying the average fruit weight and fruit count for each tree.

Statistical Analysis

The data were analyzed using SPSS v22 software. A two-way analysis of variance (ANOVA) test was performed here to determine the differences among the different samples. The Student-Newman and Keuls (SNK) test was used to identify sample averages at $P < 0.05$. A PCA (Principal Component Analysis) was applied to identify levels of discrimination between the various variables. The correlation indices and significance

Table 1. Physical and chemical soil composition at the experimental site

Soil depth	Clay (%)	Silt (%)	Sand (%)	Organic matter (%)	$CaCO_3$ (%)	P_2O_5 (ppm)	K_2O (ppm)	pH	EC (mS cm^{-1})
0-35 cm	42.23	11.4	46.3	4.21	4.1	76.24	423.67	8.30	0.12
35-70 cm	35.7	14.1	42.9	1.58	3.9	15.09	221.28	7.81	0.07

levels were computed by Pearson Correlation. Finally, the cultivars were grouped hierarchically using the UPGMA (Unweighted Pair Group with Arithmetic Mean) approach, on the basis of the most discriminating variables.

Results and Discussion

Yield and Leaf Macronutrient Content

Table 3 represents the yield results and the leaf micronutrient content of the different studied cultivars. Cultivar yields ranged from 5.42 to 59.27 kg $tree^{-1}$. The highest yield was recorded by the genotypes 'Friar' and 'INRA-PR34' with mean values of 47.62 and 59.27 kg $tree^{-1}$, respectively. The weakest values were registered for the cultivars 'Timhdit', 'INRA-PR38' and 'INRA-PR42' with mean values of 5.42, 8.95 and 9.18, respectively. These findings agree closely with several studies of plum trees in the past, including those by Grzyb et al., (1998), Milosevic et al., (2011) and Hamdani et al., (2024b) who explain that yield differences between cultivars can be due to several external and internal factors such as adapting the cultivar to different climatic and soil factors, cultivation practices, the 'Myrobolan' rootstock and the period of maturity of the cultivar (early and late cultivars) (Nunes et al., 2009; Singh et al., 2009; Ionica et al., 2013).

The nitrogen (N) content of leaves showed significant differences between cultivars. The content varied from 0.77 to 3.29%. The richest content was registered by the genotype 'Stanley' and the smallest value by the genotype 'INRA-PR43'. Our results regarding nitrogen (N) content of leaves are consistent with the results obtained in seven plum cultivars by Mayer et al., (2018), who found the percentage ranging from 2.22 to 2.25% and Toplu et al., (2009) in an olive collection with values ranging from 1.5 to 2.00%. According to Nava et al., (2010), nitrogen (N) is a major constituent as it is considered as ubiquitous in secondary metabolites, amino acids, proteins and chlorophyll, making it an essential nutrient required by fruit plants for their growth and vigor This leads to a balance between vegetative and reproductive parts and consequently to a regular production over the years (Neilsen et al., 1999).

The phosphorus (P) content of leaves displayed a range of significant variations from a range of 0.23 to 0.59% depending on the variety. The highest content was observed by the genotype 'Angelino' with an average of 0.59%, while the lowest value was observed in the cultivars 'INRA-PR37' and 'INRA-PR39' with an average of 0.23%. This phosphorus (P) content is higher than that found by Mayer et al., (2018), whose phosphorus (P) content varies from 0.25 to 0.33%. Phosphorus availability is critical as it is involved in the synthesis of several compounds that are linked to fruit yield and quality, including soluble solids and fruit flavonoids (Afroz et al., 2016).

The potassium (K) content of leaves of the cultivars ranged from 1.02 to 2.52%. The highest content was recorded in genotypes 'INRA-PR46', 'INRA-PR47' and 'INRA-PR44' with means of 2.48 and 2.52%, respectively, while the lowest content was recorded in cultivars 'Black Amber' and 'Singlobe' with means of 1.02 and 1.33%, respectively. Our results regarding the potassium (K) content of the leaves are in accord with those found by Mayer et al., (2018) who mentioned that the percentage of this element varied from 1.91 to 2.74%. However, Toplu et al., (2009) revealed low values ranging from 0.72 to 0.10%. Potassium (K) is an indispensable element as it is implicated in total soluble sugar synthesis in fruit especially in *Rosaceae* including apple and almond (Kumar and Ahmed 2014). This macronutrient has an important effect on the growth and production of plants, as well as the quality of fruit, and may help to promote the transfer of sugars generated by photosynthesis in the leaf to the fruit (Taiz and Zeiger 2013).

The calcium (Ca) content of leaves demonstrated statistically significant results across a range of 2.46 to 4.92 ppm depending on the variety. The greatest increase was observed in the cultivar 'Angelino' with an average of 4.92 ppm, whereas the weakest values were obtained by the cultivars 'Prune d'Ente', 'INRA-PR39' and 'Stanley' with averages of 2.46, 2.50 and 2.51 ppm, respectively. However, Mayer et al., (2018) showed a difference between cultivars with a lower range of 0.81 to 2.01 ppm. Earlier research has demonstrated the role of calcium (Ca) in cell wall structure, as it can affect the integrity of the cell membranes. It also plays a key part in membrane functioning, signaling in plants and water balance (Fallahi et al., 2001; Hocking et al., 2016).

Regarding the magnesium (Mg) content of leaves, the cultivars ranged from 939.25 to 1798.25 ppm. The highest levels were recorded in the cultivars of 'INRA-PR41', 'Singlobe' and 'INRA-PR47' with means of 1541.12, 1781.87 and 1798.25 ppm, respectively, while the lowest values were recorded in cultivars 'Prune d'Ente', 'Fortune' and 'INRA-PR34' with means of 939.25, 978.75 and 981.25 ppm, respectively. Our results are higher than the magnesium (Mg) quantity found by Mayer et al., (2018) who found that the percentage of magnesium at the leaf level varied from 230 to 430 ppm.

There were significant variations in leaf yield and macronutrient content between cultivars investigated in this study. However, Couvillon (1982) showed there was no significant variation in the macronutrient content of the leaves (N, P, K, Ca, and Mg) in peach, which can be explained by the low soil moisture, the higher leaf water potential due to the high number of stomata (Couvillon et al., 1989). Also, nutrient concentrations in leaves differ according to the sampling period and fertilization practice (Nava et al., 2010).

Table 2. Cultivars of local and international plum trees studied in this work

Local cultivars	Species	Foreign cultivars	Species
INRA-PR35	*Prunus salicina* Lindl.	Friar	*Prunus salicina* Lindl.
INRA-PR35	*Prunus salicina* Lindl.	Singlobe	*Prunus salicina* Lindl.
INRA-PR37	*Prunus salicina* Lindl.	Monglobe	*Prunus salicina* Lindl.
INRA-PR38	*Prunus salicina* Lindl.	Golden Japan	*Prunus salicina* Lindl.
INRA-PR39	*Prunus salicina* Lindl.	Santa Rosa	*Prunus salicina* Lindl.
INRA-PR40	*Prunus salicina* Lindl.	Methley	*Prunus salicina* Lindl.
INRA-PR41	*Prunus salicina* Lindl.	Fortune	*Prunus salicina* Lindl.
INRA-PR42	*Prunus salicina* Lindl.	Angelino	*Prunus salicina* Lindl.
INRA-PR43	*Prunus salicina* Lindl.	Black Amber	*Prunus salicina* Lindl.
INRA-PR44	*Prunus salicina* Lindl.	Stanley	*Prunus domestica* L.
INRA-PR45	*Prunus salicina* Lindl.	Prune d'Ente	*Prunus domestica* L.
INRA-PR46	*Prunus salicina* Lindl.		
INRA-PR47	*Prunus salicina* Lindl.		
INRA-PR48	*Prunus salicina* Lindl.		
INRA-PR49	*Prunus salicina* Lindl.		
INRA-PR37	*Prunus salicina* Lindl.		
INRA-PR38	*Prunus salicina* Lindl.		
INRA-PR39	*Prunus salicina* Lindl.		
INRA-PR40	*Prunus salicina* Lindl.		
INRA-PR41	*Prunus salicina* Lindl.		
INRA-PR42	*Prunus salicina* Lindl.		
INRA-PR43	*Prunus salicina* Lindl.		
INRA-PR44	*Prunus salicina* Lindl.		
INRA-PR45	*Prunus salicina* Lindl.		
INRA-PR46	*Prunus salicina* Lindl.		
INRA-PR47	*Prunus salicina* Lindl.		
INRA-PR48	*Prunus salicina* Lindl.		
INRA-PR49	*Prunus salicina* Lindl.		
Timhdit	*Prunus salicina* Lindl.		

Table 3. Yield and N, P, K, Ca and Mg content of leaves of different plum cultivars

Local cultivars	Yield (kg.tree^{-1})	%N	%P	%K	Ca (ppm)	Mg (ppm)
INRA-PR34	59.27 ± 4.5^{d}	2.28 ± 0.12^{efg}	0.30 ± 0.02^{ab}	1.98 ± 0.005^{defghi}	3.61 ± 0.02^{bcde}	981.25 ± 2^{a}
INRA-PR35	13.82 ± 2.5^{a}	2.18 ± 0.26^{defg}	0.35^{abc}	2.29 ± 0.04^{fghi}	4.29 ± 0.31^{ef}	1037.5 ± 0.25^{a}
INRA-PR37	41.00 ± 3^{c}	2.56^{fgh}	0.23^{a}	2.18^{efghi}	3.53^{bcde}	1055.75 ± 5.25^{a}
INRA-PR38	8.95 ± 2.4^{a}	2.19 ± 0.02^{defg}	0.33 ± 0.03^{abc}	2.06 ± 0.08^{efghi}	3.97 ± 0.28^{bcde}	1773.5 ± 3^{b}
INRA-PR39	24.51 ± 3^{ab}	2.12 ± 0.11^{defg}	0.23 ± 0.02^{a}	2.10 ± 0.01^{efghi}	2.50 ± 0.66^{a}	1048.12 ± 0.12^{a}
INRA-PR40	21.52 ± 8^{a}	1.17 ± 0.04^{abc}	0.29 ± 0.01^{ab}	2.15 ± 0.02^{efghi}	3.17^{abcd}	1037.62 ± 3.87^{a}
INRA-PR41	30.08 ± 3.5^{b}	1.35 ± 0.05^{abcd}	0.48^{bcd}	1.96 ± 0.18^{defgh}	3.38 ± 0.21^{bcde}	1541.12 ± 470.62^{b}
INRA-PR42	9.18 ± 3^{a}	0.95 ± 0.03^{ab}	0.36 ± 0.01^{abc}	1.90 ± 0.02^{cdefg}	3.62 ± 0.002^{bcde}	1083.12 ± 1.62^{a}
INRA-PR43	26.04 ± 3.5^{ab}	0.77 ± 0.11^{a}	0.28^{ab}	2.10 ± 0.01^{efghi}	3.37 ± 0.008^{abcde}	1060.12 ± 0.62^{a}
INRA-PR44	10.45 ± 1.5^{a}	1.67 ± 0.56^{bcdef}	0.48 ± 0.02^{bcd}	2.52 ± 0.25^{i}	2.99 ± 0.07^{abc}	1006.25 ± 0.5^{a}
INRA-PR45	42.38 ± 5.5^{c}	1.51 ± 0.01^{ab}	0.37^{abc}	2.27 ± 0.01^{efghi}	3.15 ± 0.002^{abcd}	1037 ± 0.25^{a}
INRA-PR46	17.41 ± 13.5^{a}	1.33 ± 0.33^{abcd}	0.43 ± 0.05^{abcd}	2.48 ± 0.04^{hi}	3.06 ± 0.07^{abc}	1019.43 ± 13.18^{a}
INRA-PR47	17.74 ± 1.6^{ab}	1.86 ± 0.23^{cdefg}	0.52 ± 0.01^{cd}	2.48 ± 0.15^{hi}	3.70 ± 0.14^{bcde}	1798.25 ± 0.75^{b}
INRA-PR48	11.76 ± 1.5^{a}	1.30 ± 0.04^{abcd}	0.49 ± 0.01^{bcd}	2.43 ± 0.14^{ghi}	3.67 ± 0.04^{bcde}	1064.25 ± 0.75^{a}
INRA-PR49	34.71 ± 5.5^{ab}	0.96 ± 0.01^{ab}	0.26^{a}	2.30 ± 0.19^{fghi}	3.57 ± 0.02^{bcde}	1075.75 ± 0.5^{a}
Stanley	14.00 ± 1.5^{a}	2.33 ± 0.03^{efg}	0.26 ± 0.02^{a}	2.17 ± 0.02^{efghi}	2.51 ±0.001^{a}	1015.5 ± 0.5^{a}
Prune d'Ente	16.76 ± 1.7^{a}	3.29 ± 0.06^{h}	0.42 ± 0.01^{abcd}	1.75 ± 0.07^{bcdef}	2.46 ± 0.13^{a}	939.25 ± 10.5^{a}
Friar	47.62 ± 11.5^{c}	2.79 ± 0.007^{gh}	0.33 ± 0.05^{abc}	1.40 ± 0.005^{bc}	4.05 ± 0.01^{cde}	1054.62 ± 1.12^{a}
Fortune	47 ± 4.3^{c}	2.68 ± 0.07^{gh}	0.44 ± 0.04^{abcd}	1.89 ± 0.04^{cdef}	4.01 ± 0.01^{bcde}	978.75 ± 2.25^{a}
Methley	31 ± 8^{ab}	2.64 ± 0.01^{fgh}	0.33 ± 0.01^{abc}	1.47 ± 0.26^{bcd}	2.92 ± 0.03^{ab}	1019 ± 1^{a}
Santa Rosa	21.76 ± 5.5^{ab}	2.24 ± 0.21^{efg}	0.54 ± 0.05^{cd}	1.70 ± 0.01^{bcde}	4.35 ± 0.005^{ef}	1036.75 ± 0.5^{a}
Angelino	19.24 ± 1^{ab}	2.60 ± 0.05^{fgh}	0.59 ± 0.03^{d}	1.80 ± 0.004^{bcdef}	4.92 ± 0.03^{f}	1070.87 ± 0.12^{a}
Black Amber	41.47 ± 4.5^{c}	2.54 ± 0.49^{fgh}	0.41 ± 0.13^{abcd}	1.02 ± 0.01^{a}	3.20 ± 0.002^{abcd}	1085.62 ± 1.87^{a}
Golden Japan	40.47 ± 1^{c}	2.42 ± 0.07^{efgh}	0.54 ± 0.08^{cd}	1.48 ± 0.002^{bcd}	3.83 ± 0.07^{bcde}	1075.62 ± 3.1^{a}
Monglobe	13.65 ± 0.9^{a}	2.47 ± 0.16^{fgh}	0.43 ± 0.03^{abcd}	1.82 ± 0.01^{bcdef}	3.91 ± 0.13^{bcde}	1025.75 ± 0.25^{a}
Singlobe	11.76 ± 0.5^{a}	2.51 ± 0.08^{fgh}	0.36 ± 0.01^{abc}	1.33 ± 0.17^{b}	3.51 ± 0.55^{bcde}	1781.87 ± 4.87^{b}
Timhdit	5.42 ± 1.5^{a}	2.69 ± 0.017^{gh}	0.26 ± 0.02^{a}	2.14 ± 0.08^{efghi}	4.24 ± 0.24^{def}	1008.25 ± 5.5^{a}

Note: Averages marked with a letter are statistically significantly different ($P \leq 0.05$), using the SNK test

Leaf Micronutrient Content

Significant differences in leaf micronutrient content were observed between the cultivars studied (Table 4). The sodium (Na) content of cultivar leaves varied from 0.03 to 0.10 ppm. The highest content was recorded in cultivar 'INRA-PR41' with an average of 0.10 ppm, while the lowest value was recorded in cultivar 'INRA-PR44' with an average of 0.03 ppm, which is in agreement with the leaf sodium (Na) content found in olive by Toplu et al., (2009) which varied between 0.03 and 0.04 ppm. The high potassium concentration might explain the lower sodium (Na) concentration as the amount of these two elements is often reciprocal and the difference in their concentration could be related to the genetic variation of cultivars and soil and geographical conditions (Tahir et al., 2011).

Table 4. Na, Fe, Mn, Zn and Cu content of leaves of different plum cultivars

Local cultivars	Na (ppm)	Fe (ppm)	Zn (ppm)	Mn (ppm)	Cu (ppm)
INRA-PR34	0.04 ± 0.008^{a}	239.87 ± 25.37^{abc}	8.23 ± 0.68^{abcde}	51.93 ± 0.31^{fghij}	15.88 ± 0.13^{a}
INRA-PR35	0.05 ± 0.002^{a}	300 ± 17.75^{abcd}	14.25 ± 0.17^{bcdefg}	52.75 ± 0.52^{ghij}	18.32 ± 0.62^{a}
INRA-PR37	0.04^{a}	519.5 ± 48.5^{defg}	12.6 ± 0.4^{abcdefg}	76.9 ± 2.2^{L}	19.22 ± 0.37^{a}
INRA-PR38	0.08 ± 0.003^{a}	173.5 ± 27.5^{a}	21.65 ± 0.05^{gh}	46.12 ± 0.07^{def}	30.47 ± 0.32^{b}
INRA-PR39	0.05 ± 0.006^{a}	1002.25 ± 0.25^{j}	14.05 ± 2.12^{bcdefg}	37.72 ± 0.17^{bc}	18.2 ± 0.025^{a}
INRA-PR40	0.05 ± 0.005^{a}	263.37 ± 14.62^{abc}	9.28 ± 0.56^{abcde}	45.35 ± 1.9^{de}	17.01 ± 0.01^{a}
INRA-PR41	0.10 ± 0.05^{a}	353.25^{abcde}	8.78 ± 1.48^{abcde}	59.08 ± 2.41^{k}	26.53 ± 7.96^{b}
INRA-PR42	0.06 ± 0.005^{a}	$383.37 \pm 13.87^{abcdef}$	11.66 ± 1.73^{abcdef}	47.67 ± 0.95^{efgh}	15.58 ± 0.01^{a}
INRA-PR43	0.05 ± 0.005^{a}	250.62 ± 0.12^{abc}	18.55 ± 0.5^{efgh}	54.06 ± 0.06^{hij}	17.02 ± 0.1^{a}
INRA-PR44	0.03 ± 0.001^{a}	325 ± 16.75^{abcd}	15.03 ± 3.76^{cdefg}	47.2 ± 0.07^{efg}	17.5 ± 0.2^{a}
INRA-PR45	0.05 ± 0.001^{a}	344.37 ± 12.12^{abcde}	9.42 ± 0.17^{abcde}	52.93 ± 0.63^{ghij}	15.83 ± 0.33^{a}
INRA-PR46	0.04 ± 0.005^{a}	302.18 ± 22.81^{abcd}	16.73 ± 1.69^{defg}	48.95 ± 1.75^{efghi}	17.40 ± 0.09^{a}
INRA-PR47	0.07 ± 0.004^{a}	415 ± 65^{ancdefg}	14.65 ± 5.95^{cdefg}	36.15 ± 0.8^{bc}	57.4 ± 0.5^{c}
INRA-PR48	0.05 ± 0.004^{a}	778.12 ± 131.62^{hi}	8.01 ± 0.36^{abcde}	40.42 ± 0.52^{bcd}	19.1 ± 0.05^{a}
INRA-PR49	0.06 ± 0.001^{a}	$457.12 \pm 28.37^{bcdefg}$	11.08 ± 2.91^{abcdef}	59.65 ± 0.72^{k}	27.13 ± 0.03^{b}
Stanley	0.05 ± 0.002^{a}	467.62 ± 15.12^{cdefg}	25.18 ± 0.16^{h}	75.17 ± 0.3^{L}	19.75^{a}
Prune d'Ente	0.04 ± 0.007^{a}	304.75 ± 51.75^{abcd}	12.91 ± 4.71^{abcdefg}	26.92 ± 5.15^{a}	19.71 ± 1.18^{a}
Friar	0.06 ± 0.002^{a}	808.75 ± 14.75^{hi}	2.55 ± 0.55^{a}	54.37 ± 0.72^{ijk}	15.63 ± 0.61^{a}
Fortune	0.06 ± 0.001^{a}	566.87 ± 103.37^{efg}	5.2 ± 0.4^{abc}	36.65 ± 0.65^{bc}	18.81 ± 0.26^{a}
Methley	0.06 ± 0.009^{a}	1643.50 ± 71^{k}	11.12 ± 0.17^{abcdef}	34.42 ± 0.67^{b}	17.41 ± 0.23^{a}
Santa Rosa	0.05 ± 0.008^{a}	583 ± 11.5^{fg}	8.63 ± 0.61^{abcde}	56.17 ± 0.8^{jk}	15.38 ± 0.31^{a}
Angelino	0.05 ± 0.001^{a}	625.25 ± 52.25^{gh}	20.48 ± 2.03^{fgh}	37.07 ± 0.025^{bc}	14.93 ± 0.31^{a}
Black Amber	0.06 ± 0.002^{a}	845.62 ± 3.87^{ij}	6 ± 0.5^{abcd}	36.83 ± 0.96^{bc}	14.55 ± 0.02^{a}
Golden Japan	0.05 ± 0.003^{a}	767 ± 28.5^{hi}	7.45 ± 1.15^{abcd}	41.58 ± 0.73^{cd}	16.5 ± 0.22^{a}
Monglobe	0.07 ± 0.003^{a}	$441.62 \pm 18.12^{bcdefg}$	4.58 ± 0.48^{abc}	40.96 ± 0.18^{bcd}	17.56 ± 1.56^{a}
Singlobe	0.05 ± 0.003^{a}	883.25 ± 96.75^{ij}	3.58 ± 1.51^{ab}	40.38 ± 1.88^{bcd}	15.27^{a}
Timhdit	0.06 ± 0.001^{a}	215.87 ± 27.87^{ab}	12.48 ± 0.43^{abcdefg}	52.01 ± 1.36^{fghij}	16.02 ± 0.2^{a}

Note: Averages marked with a letter are statistically significantly different ($P \leq 0.05$), using the SNK test

The iron (Fe) content of leaves demonstrated significant changes over a range of 173.5 to 1643.50 ppm depending on the variety. The highest content was registered in the 'Methley' cultivar with a mean of 1643.50 ppm, while the smallest value was registered in the cultivar 'INRA-PR38' with an average of 173.5 ppm. Our results regarding leaf iron (Fe) content are compatible with those found by Mayer et al., (2018) who found that the content varied from 325 to 752 ppm. Iron (Fe) element is an important essential nutrient which is a major factor in enhancing the taste quality of fruit since it is involved in the decrease of total sugar/ total organic acid ratios and an improvement of phenolics and vitamin C in different *Rosaceae* species (Alvarez-Fernandez et al., 2003). It is also implicated in oxygen transportation and protein and metabolic enzyme integration (catalase) (Nunes et al. 2022).

The zinc (Zn) content of leaves of the cultivars ranged from 2.55 to 25.18 ppm. The highest levels were recorded in cultivars 'INRA-PR38' and 'Stanley' with an average of 21.65 and 25.18 ppm, respectively, while the lowest value was observed in the 'Friar' and 'Singlobe' cultivars with a mean of 2.55 and 3.58 ppm, respectively. Our results are higher than those found by Mayer et al., (2018) whose range of variation in zinc (Zn) content varies between 5.9 to 15.6 ppm, and lower than those found by Toplu et al. (2009) who showed that the values varied from 17.1 to 27.1 ppm.

The manganese (Mn) content of leaves revealed significant differences with a range of 26.92 to 76.9 ppm by variety. The highest levels were registered in cultivars 'Stanley' and 'INRA-PR37' with averages of 75.17 and 76.9 ppm, respectively, while the lowest value was recorded in cultivar 'Prune d'Ente' with an overall mean of 26.92 ppm. In the same way Mayer et al., (2018) discovered a variation from 35.8 to 79.7 ppm in plum leaves. In general, manganese (Mn) is an important mineral in leaves for breathing, trapping reactive oxygen species (ROS), pathogen defense and hormonal signaling, as well as playing an important role in phoysynthesis (Nunes et al., 2022). In addition, *in vitro* studies have demonstrated that manganese (Mn) is an essential co-factor in the signaling of abscisic acid (ABA) and auxin by respectively promoting the phosphatases PP2C and IPA and the conjugated amino acid hydrolases IAA (LeClere et al., 2002).

The copper (Cu) content of cultivar leaves ranged from 15.38 to 30.47 ppm. The highest levels were registered in the cultivars 'INRA-PR41', 'INRA-PR49' and 'INRA-PR38' with averages of 26.53, 27.13, and 30.47 ppm, respectively, while the weakest values were reported in the cultivars 'Santa Rosa', 'INRA-PR42', 'INRA-PR42' and 'INRA-PR34' with means of 15.38, 15.58, 15.63 and 15.88 ppm, respectively. Similarly, Toplu et al., (2009) shows foliar copper (Cu) content ranging from 11 to 24.3 ppm. However, Mayer et al., (2018) found a lower content ranging from 2.9 to 11.2 ppm.

Principal Component Analysis

PSA was applied to better reveal the most discriminating traits among those used in this study, taking into consideration that only the loading of each variable above 0.5 is significant (Table 5). The variance of over 58.92% was accounted for by three components. The first component explains 24.31% of the total variance. It is correlated in a positive way with potassium (K) content of leaves (r = 0.838), zinc (Zn) content of leaves (r = 0.620) and is negatively associated with nitrogen (N) content of leaves (r = -0.635) and iron (Fe) content of leaves (r = -0.702). The second component represents 21.12% of the total value of inertia and is primarily correlated positively with sodium (Na) content of leaves (r = 0.741), copper (Cu) content of leaves (r = 0.683) and magnesium (Mg) content of leaves (r = 0.794). The third component accounts for 13.48% of the total value of inertia and is positively associated with calcium (Ca) content of leaves (r = 0.710) and yield (r = 0.724). If we consider only principal component loadings higher than 0.7, we note that the most discriminating traits according to PCA for the characterization of plum cultivars were: potassium (K), iron (Fe), sodium (Na), magnesium (Mg), calcium (Ca) contents of leaves and yield.

Table 5. Principal component eigenvectors of the PCA analysis using the mean ratios of the traits studied among the plum cultivars

	Composante			
	1	2	3	4
%N	**-0.635**	0.057	0.067	0.139
%P	-0.245	0.504	0.307	-0.642
%K	**0.838**	-0.137	-0.098	-0.350
Ca (ppm)	-0.093	0.368	**0.710**	-0.156
Na (ppm)	0.172	**0.741**	0.092	0.382
Fe (ppm)	**-0.702**	0.037	-0.308	0.202
Zn (ppm)	**0.620**	-0.080	-0.267	-0.120
Mn (ppm)	0.536	-0.427	0.379	0.483
Cu (ppm)	0.488	**0.683**	-0.162	0.027
Mg (ppm)	0.232	**0.794**	-0.048	0.313
Yield	0.119	-0.277	**0.724**	0.132
% of Variance	24.31	21.12	13.48	10.26
Cumulative %	24.31	45.43	58.92	69.19

Note: Eigenvectors above 0.5 are indicated in bold

Correlation

Bivariate correlation based on Pearson's coefficient has been applied to determine the relations among all the traits recorded for all the plum cultivars. Potential correlations that were significant at the 0.05 or 0.01 level are summarized in Table 6. The potassium (K) content of the leaves was correlated in a negative way with nitrogen (N) and iron (Fe) content of leaves with coefficients of -0.543 and -0.552, respectively. The results are in agreement with Rosolem (2005) who explained this correlation by an antagonistic effect since potassium (K) is considered as a strong conqueror and plants find it very difficult to absorb other mineral elements in the presence of potassium (K) and their leaf concentration is said to be reciprocal (Suzuki et al., 2002).

Table 6. Correlation coefficient matrix showing the average ratios of the plum cultivar's traits included in the research

	%N	%P	%K	Ca (ppm)	Na (ppm)	Fe (ppm)	Zn (ppm)	Mn (ppm)	Cu (ppm)	Mg (ppm)	Yield
%N	1										
%P	0.084	1									
%K	**-.543****	-0.119	1								
Ca (ppm)	0.134	0.368	-0.106	1							
Na (ppm)	-0.093	0.124	-0.117	0.282	1						
Fe (ppm)	0.329	0.057	**-.552****	-0.145	-0.095	1					
Zn (ppm)	-0.166	-0.142	**.495****	-0.159	-0.011	-0.312	1				
Mn (ppm)	-0.249	-.443*	0.311	0.011	-0.006	-0.327	0.250	1			
Cu (ppm)	-0.150	0.162	0.377	0.009	.446*	-0.179	0.234	-0.079	1		
Mg (ppm)	-0.070	0.151	-0.031	0.126	**.566****	-0.050	0.055	-0.103	**.652****	1	
Yield	-0.013	0.054	0.020	0.140	-0.180	-0.168	-0.087	.425*	-0.083	-0.090	1

Note: ** Significant at $P < 0.01$ level (two-tailed)
* Significant at $P < 0.05$ level (two-tailed)

However, potassium (K) content of leaves was positively correlated with leaf zinc (Zn) content of leaves with a coefficient of 0.495, also the magnesium (Mg) content of leaves was positively correlated with leaf copper (Cu) and sodium (Na) content of leaves with coefficients of 0.652 and 0.566, respectively. The obtained results showed that the yield of different cultivars was not correlated with the leaf macro and micronutrient contents. Similarly, Toplu et al., (2009) found no relationship between mineral elements and yield. This is because the leaf mineral contents of different cultivars varied from medium to high, with the total absence of cultivars showing low mineral efficiency, which makes the macro and micronutrient as a non-limiting factor for yield. However, Bai et al., (2021) reported that yield was strongly correlated with leaf nitrogen (N) and phosphorus (P) contents since the latter was involved in the synthesis of the organic content in the fruit by raising the level of anthocyanins and flavonoids, which improved yield, weight, quality and firmness of the fruit (Afroz et al., 2016).

Cluster

Group analysis was carried out using the UPGMA and the coefficient of Euclidean distance to identify the similarities and variability among the cultivars which have been classified into three major groups (Fig. 1). Group C1 was composed of 21 genotypes, divided into two separate and similar sub-groups (C1-1 and C1-2). The first subgroup (C1-1) contained 17 genotypes, characterized by medium yield (5.5 to 47 kg tree^{-1}), high macronutrient content and medium micronutrient content. The second subgroup (C1-2) included 4 genotypes, namely 'INRA-PR38', 'INRA-PR47', 'INRA-PR41' and 'Singlobe', characterized by an average yield (8 to 30 kg tree^{-1}), an average content of macro and micronutrient except for manganese (Mn), which was high. The second group (C2) contained a single genotype 'Methley', which was characterized by a low yield (31 kg tree^{-1}), an average content of macro and micronutrient except for iron and copper (Cu), which were high. The third group (C3) contained five genotypes 'INRA-PR37', 'INRA-PR45', 'INRA-PR34', 'Santa Rosa', 'Golden Japan', which were characterized by a high yield (22-59 kg tree^{-1}), an average content of macro and micronutrient except for iron and manganese (Mn), which were high. The variability revealed between the plum cultivars studied can be explained by differences in adaptability and physiological process involved within the ex-situ collection under similar soil and climatic conditions. The final grouping obtained in this study based on all the traits analyzed is of major significance to the farmer as it shows the differences and similarities among the cultivars tested for the market in the dry zone.

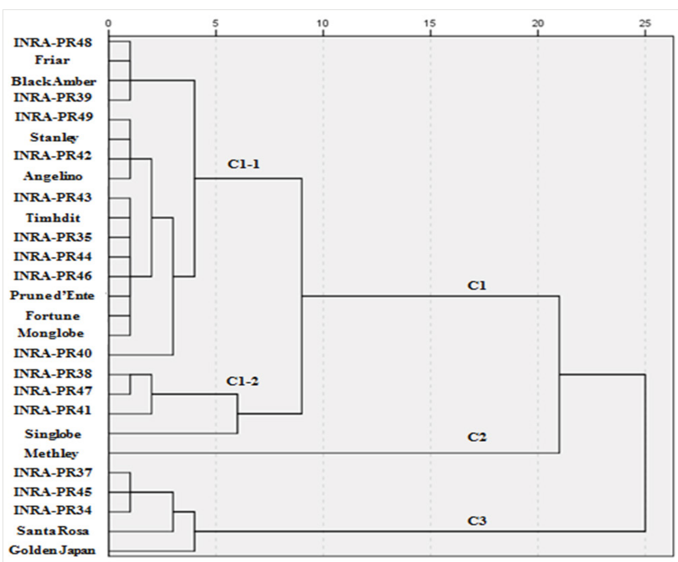

Figure 1. Classification of different plum cultivars on the basis of average values of traits recorded between cultivar

Conclusion

The plum cultivars studied showed a great difference in agronomic traits and in their measured macro and micronutrient content. This was the first study to compare various plum cultivars cultivated in Morocco. Using principal component analysis, the leaf contents of potash, zinc, nitrogen, iron, sodium, copper, magnesium, calcium and yield were found to be the most discriminating factors in the classification of the cultivars studied. Using the UPGMA method, the cultivars have been classified into three major groups for all measured traits. The selection of plum cultivars grown in Morocco is very important for scientific and farming use. As such, the findings revealed from this study have significant consequences for better managing the plum collection to ensure the maintenance of longevity, variability and species diversity and to include it easily in breeding programmes. Therefore, further analyses should be carried out at the molecular, physiological and biochemical studies to support the idea of a shared gene pool.

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CRediT Authorship Contribution Statement

Rachid Razouk: Study design. **Anas Hamdani, Abdellatif Boutagayout and Atman Adiba:** material preparation, data collection and analysis. **Anas Hamdani:** The first draft of the manuscript. **Anas Hamdani, Said Bouda, Atman Adiba, Lahcen Hssaini and Rachid Razouk:** The final version of manuscript and all authors commented on previous drafts of the manuscript.

Declaration of Competing Interest

The authors disclose that they do not have any known conflicting business or personal interests that could be perceived as having influenced the present work.

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Data Availability

Data sets produced and/or reviewed in this study are made available by the corresponding author on reasonable demand.

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