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Fruit quality of ‘Stanley’ plums based on soil composition across diverse agro-ecological zones of Morocco

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Abstract

The national production of plums, especially prunes, is strongly increasing, attracting attention in the local market. This study aims to assess the impact of soil chemical composition on the nutritional and physicochemical quality of plums of the variety ''STANLEY'' (*Prunus Domestica L.*) across diverse agro-ecological zones of Morocco. Through a preliminary survey of 21 growers in three distinct regions: Sais, Atlas and Oriental. Supplemented by sampling at eight locations in eastern and western Morocco, three categories of parameters were considered in this study: (1) parameters related to cultivation conditions, including climate, geographical structuring, plot size and planting age; (2) those providing information on physico-chemical properties, nutritional value and sugar content; (3) parameters related to soil quality. The surveyed farmers are proprietors of cultivated plots ranging from 6 to 70 hectares, with an average yield of 12T/ h. Notably, 28% of producers with recently established plantations (less than 10 years) have achieved yields exceeding 15T/h, indicating the fertility of trees at this stage of maturity. The findings affirm that soil fertility and soil amendment are the major factors contributing to high-quality fruit (large caliber, high Brix rate, intact product). Additionally, this study highlights the significance of climate and irrigation in achieving the desired quality of plums.

Keywords: cultivation conditions, Potash, Prunus domestica, sugar content

Introduction

In Morocco, plum trees hold significant economic value due to their wide usage in the food industry. According to statistics from the Ministry of Agriculture, Maritime Fisheries, Rural Development, and Water and Forests, the plum tree cultivation area covers approximately 15,000 hectares, with 14,000 hectares being productive. The annual average production, as per the Food and Agriculture Organization of the United Nations (FAO), has seen remarkable growth, increasing from 5,000 tonnes in 1969 to 205,222 tonnes in 2018, representing a noteworthy annual average growth rate of 10.29%. This growth has positioned Morocco among the top 10 leading countries in plum and prune production (FAO, 2018). Morocco's plum serves various purposes, being used as jam, fresh fruit, or dried. Moroccan plum cultivars encompass international Japanese varieties such as "Golden Japan," "Santa Rosa," and "Angeleno," as well as European cultivars like "Stanley," which dominate the national market. Additionally, local plum cultivars of unknown origin (Aitbella et al., 2023). The «Stanely» (Prunus domestica L.) variety holds exceptional economic importance due to its self-fertilizing properties and its specificity in biotechnological processes. It exhibits high tolerance to cold, blooms from March to April and ripens its fruits from late August to mid-September (**Figure1**).

Given the increasing significance of plum production in Morocco, it is critical to comprehend the variables affecting plum quality. Plums' nutritional and physicochemical characteristics are largely determined by the composition of the soil, in particular. Fruit output, size, sweetness, and marketability can all be strongly impacted by changes in soil fertility, pH, nutrient availability, and organic matter content. For this reason, determining how soil chemical composition and plum quality are related is crucial to improving production

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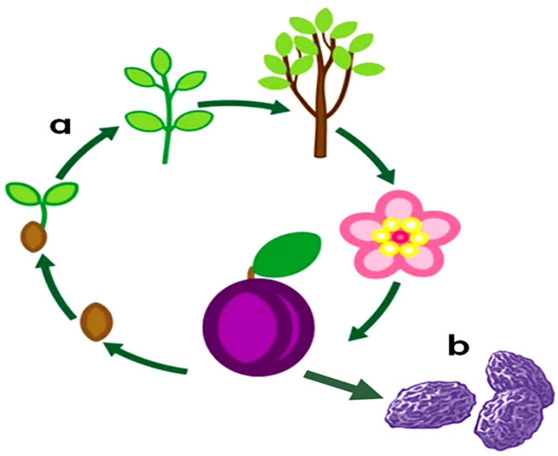

Figure 1 - Vegetative cycle of plum tree flowering (a), plums after industrial drying (b)

techniques and guaranteeing uniform fruit quality throughout various agro-ecological zones.

The development of production and yield in the plum sector represents a major challenge for the agricultural industry, especially given the recent increase in demand outpacing supply. This necessitates farmers' detailed understanding of parameters and conditions conducive to improving fruit quality and yield, including selecting varieties suited to specific climatic and soil conditions (Evangelos et al., 2023). Achieving high yield and optimal fruit quality depends on numerous factors, including climate, soil type, and effective management practices, notably water management (Reig et al., 2018). Despite its importance, there is limited literature available regarding the role of soil in plum quality and yield (Mestre et al., 2017). This study aims to investigate the effect of soil on the yield and the quality of the dominant plum variety "Stanley" across various agro-ecological zones of Morocco.

Material and methods

1 - Survey procedure and sampling

Preliminary Survey of Growers

For research on the state of Stanley plum production in the wetlands of Morocco. Three fruit production sites were selected based on climate conditions, geographical diversity, planting age, plot size, etc.: The Fes-Meknes (Saïs) zone, the Atlas zone, and the Oriental zone. Three Moroccan regions characterized by different bioclimatic stages were included in our study (**Table 1**). The study involved 21 growers in Meknes, ElHajeb, Azrou, Agourai, Khenifra, Atlas, Oujda and Berkane respectively, and was conducted according to the set criteria. The questionnaire included the respondent's age, sex, level of education, area and plum variety. Factors such as selling price, plot size, planting age, and favorable conditions for high production were considered.

2. Sampling at Various Locations

Following the preliminary survey, sampling was carried out at eight locations in eastern and western Morocco, representing diverse agro-ecological zones. Sampling sites were selected to capture variations in soil composition, climate, and other environmental factors that could influence plum quality.

At each location, both soil samples and plum fruit samples were collected for analysis.

3 - Geographical delimitation of the three regions surveyed

Diverse agro-ecological sites (8 sites) of Morocco were included in this study, covering three distinct regions: Sais, Atlas and Oriental (**Figure 2**):

Site 1 : Meknes	Site 5 : Berkane
Site 2 : ElHajeb	Site 6 : Oujda
Site 3 : Azrou	Site 7 : Khenifra
Site 4 : Agourai	Site 8 : Atlas

Meknes

GPS coordinates are 36°48'49" latitude and 03°14'56" longitude north. It is characterized by a mild Mediterranean climate, with hot, dry summers and mild, rainy winters; snow is rare, rainfall is high and can be heavy, and temperatures are generally between 0°C and 45°C.

ElHajeb

GPS coordinates are 36°48'49" latitude and 03°14'56" longitude north. It is characterized by a mild Mediterranean climate, with hot, dry summers and mild, rainy winters; snow is rare, rainfall is high and can be heavy, and temperatures are generally between 0°C and 45°C.

Azrou

GPS coordinates are 33.442844 degrees' north latitude and 5.227082 degrees' west longitude, with a continental climate and hot, dry summers. Winters are very cold, with an average temperature of -2°C in January and 30°C in July.

Oujda

GPS coordinates are latitude 34.677874° north longitude 1.929306° west longitude. It has a Mediterranean climate, with mild to cold, rainy winters and average summer temperatures of 0°C, the coldest month being January at 40°C.

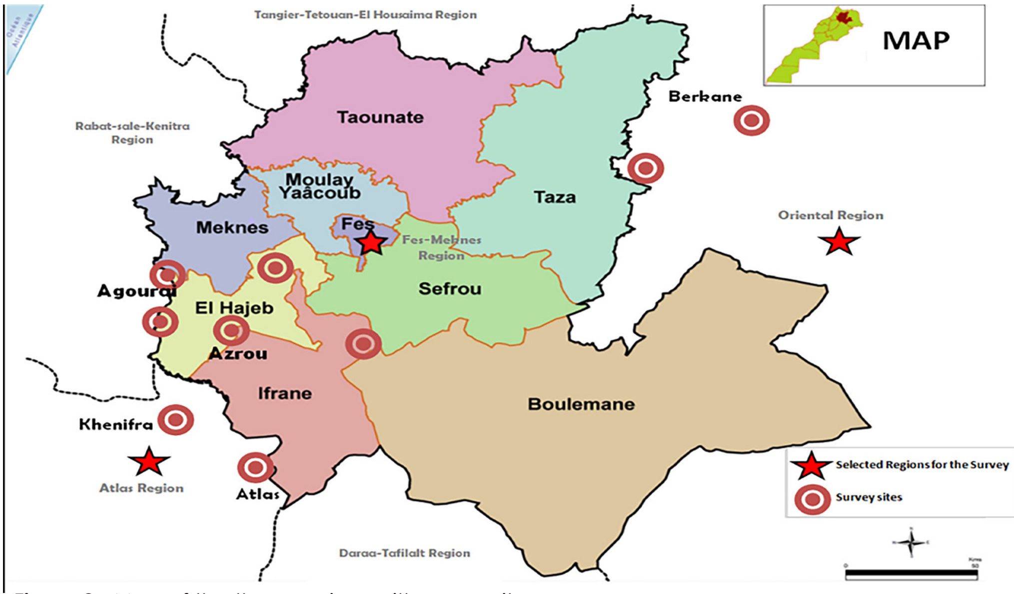

Figure 2 - Map of the three regions with survey sites

Berkane

GPS coordinates are 34.9266755° N, 2.3294087° W. Summers are short, hot, humid, dry and generally clear; winters are long, cool and partly cloudy. Throughout the year, temperatures generally range from 7°C to 33°C, rarely falling below 4°C or rising above 36°C.

Atlas

GPS coordinates are 31.059683 N, 7.900009 W. Summers are brief, influenced by the mountainous climate. The weather is pleasant on one side and dry on the other. In winter, it snows up to 900 meters.

Agourai

GPS coordinates are latitude 33.643846 and longitude 5.589918 W. Western Agourai has a short summer and a Mediterranean climate. Summers are hot and dry, and winters are cold. The average annual temperature in Agourai is 25°C.

Khenifra

GPS coordinates are 32.9357718 N, 5.6696504 W. The region's climate is continental. A harsh winter is followed by a very hot summer. Rainfall averages between 400 and 700 mm annually, depending on the region. The average annual temperature is 16°C, but can dip as low as 5°C.

Survey sites

Soil analysis

Sampling

Twenty soil cores were collected randomly from each study site to ensure the representativeness of soil samples. (Random) samples were taken in a zigzag pattern throughout the study area. Samples were collected to a depth of approximately 6 cm, corresponding to the depth of nutrient mixing during tillage. Deeper sampling may not be representative of the field, as the underlying soil layers generally contain far fewer nutrients. In the end, 400 grams were recovered from each site. However, this must be representative of the quantity contained in 20,000 tons of soil, or 10 hectares (Patrick et al., 2020).

Physico-chemical analysis

The main reference techniques employed for analyzing the studied soils are outlined in **Table 1**.

Plum Fruit Analysis

Plum fruit samples were collected from multiple trees within each orchard to ensure representativeness. The Plum fruit samples were transported to the laboratory for analysis.

Nutritional and physicochemical analysis of plum fruits

The main reference techniques for assessing the nutritional and physico-chemical quality of plums are represented in **Table 2**.

Data analysis

Principal Component Analysis (PCA) was conducted to assess whether specific soil characteristics could account for variations in the intrinsic quality of plums across different plots. The graphs were drawn by the STATISTICA ® software 10.0 (Stat Soft, Inc., www.statsoft.com) and the Origin Lab 2024 software ® (Origin Lab, https://www.originlab.com). Multiple comparisons for the

Table 1 - Physico-chemical soil analysis at study sites

Analysis	Method	Reference
Hydrogen potential (pH)	pH measurements were conducted using a pH meter (HANNA 209), with the soil extract diluted at a ratio of 1 part soil to 5 parts water.	(Biyashev et al., 2023)
Organic matter (OM)	Determined by using the dry combustion method, according to Walkley and Black.	Verdugo-Vásquez et al. (2021)
Total limestone content (%)	The Bernard calcimetric method was employed for the analysis.	NF P 94-048.
Active limestone content (%)	Colorimetric dosage	ISO 10693 (1995)

Table 2 - Plum quality control techniques

Analysis	Method	Reference
pH	Juice pH is determined by direct measurement using a pH meter.	Aitbella et al. (2023)
Titratable acidity	the acidity was determined titrimetrically with 0.1 M NaOH until pH 8.1	Ordóñez-Díaz et al. (2020)
Sugar content	The Brix degree is determined directly by the refractometer.	Ordóñez-Díaz et al. (2020)
Dry matter	Oven-drying and freeze-drying methods	Hadidi et al. (2023)
Water content	Moisture content is determined by oven-drying for 24 h at 105°C..	NM ISO 662 (2016)
Ash	The determination of ash after subjecting the samples to 6 hours of heating at 550°C, aligned with AOAC method 942.05	Rashidinejad&Mirja Kaizer (2024)
Sodium chloride	Spect ICP-OES	Reckenholz&Agroscope (2020)
Dietary Fiber	Enzymatic gravimetric	Rashidinejad&Mirja Kaizer (2024)
Carbohydrates	Total carbohydrate content was determined by calculation.	MOACP04 Rashidinejad&Mirja Kaizer (2024)
Moisture	Oven method	(Asbai et al., 2024)
Total fat	NMR, to quantitatively determine the solid and liquid fractions of a sample according to the AOAC method.	Rashidinejad&Mirja Kaizer (2024)
Proteins	Elemental analyzer	NM ISO 1971: 2011
Total Sugar	NMR, quantitatively determine the solid and liquid fractions of a sample.	Dogbe&Revoredo-Giha (2021)
Energy value (kcal)	Calculated based on the macro-nutrient data	Rashidinejad&Mirja Kaizer (2024)
Energy value (KJ)	Calculated based on the macro-nutrient data	Rashidinejad&Mirja Kaizer (2024)
Vitamin A, B12, E, C, D	Vitamins A and E were determined according to the modified AOAC method. Vitamins C by HPLC	Rashidinejad&Mirja Kaizer (2024)
Na, Ca, Fe, K, Mg, P, Cl^-	by using atomic absorption Spectrophotometer ICP- -AES (Inductively Coupled Plasma-Atomic Emission Spectrometry; Optima 8000 ICP-AES Spectrometer)	Aitbella et al. (2023)
Glucose	glucose is determined by an enzymatic method.	Nadeem et al. (2019)
Lipids	Solvent gravimetric methods	NF V 03-030

1-way ANOVA with repeated measures (3 repetitions), followed by Tukey's HSD test were performed. The significance level was set at 0.05.

Results and Discussion

Cultivated ecotype

This study identified two plum ecotypes grown by growers in the three regions studied. The "Stanley" ecotype is grown by all the farmers surveyed. According to these farmers, the 'Stanley' variety is considered best suited to the conditions of Sais, Atlas, and Oriental, consumed in July. Farmers are also accustomed to growing this ecotype and have mastered cultivation practices and the management of phytosanitary issues. The second ecotype is the President (or Santa Clara), a recent variety that is not very popular. The fruit of this variety is ovoid, with good flavor and very firm flesh, consumed around September. It is cultivated by a producer in Agourai (Sais). Among the plum cultivars grown, the 'Stanley' variety remains the most productive, yielding an average of up to 26 tons per hectare. the average weight of its fruit is around 40 g, making it one of the large plum fruits most recommended by processors.

Nutritional quality of 'Stanley' plum fruit on the Moroccan market

Table 3 presents the nutritional quality analysis carried out on a sample of 10 pieces (number of replicates 3), taken from dried prunes of super giant size. It also shows the richness of this fruit in vitamins and minerals that are highly beneficial to health.

Nutritional analysis of dried plums has shown their potential health benefits (Table 3). Water and ash contents are crucial for nutritional analysis, as they directly influence the fruit's nutritional composition. The water content of dried plums was 38.7% respectively, and 0.19g of fat was found in the sample, showing that it is low, but

Table 3 - Nutritional values for 100 g of Stanley dried prunes, harvest 2023, dosing in 2024. (3 repetitions and 1 to 15% uncertainty)

Parameters	Units	Our study*	According to Mehta et al. (2014)
Carbohydrate	g/100g	57.80 ± 10.00	62.70
Saturated fatty acid	g/100g	0.0274 ± 2.00	0.051
Ash	%	3.38 ± 3.80	-
Sodium chloride	g/100g	0.028 ± 2.00	0.043
Dietary fiber	g/100g	6.70 ±13.00	6.60
Carbohydrates	g/100g	51.10 ± 11.00	53.80
Moisture	%	38.70 ± 3.00	36.20
Total fat	g/100g	0.19 ± 2.00	0.50
Protein	g/100g	2.13 ± 2.20	1.96
Total sugar	g/100g	26.10 ± 10.00	43.10
Energy Value	kcal/100g	219 ± 15.00	225.90
Energy Value	KJ/100g	917.00 ± 15.00	958.90
Sodium	mg/100g	10.90 ±10.00	0.84
Vitamin A	(µg)/100g	1.21 ±14.00	0.00
Vitamin B12	(mg)/100g	0.00 ±14.00	0.00
Vitamin C	(mg)/100g	0.38 ±14.00	0.50
Vitamin E	(mg)/100g	12.63 ±14.00	0.42
Vitamin D	(µg)/100g	0.21 ±14.00	0.25
Calcium	(mg)/100g	64.00 ± 10.00	48.90
Iron	(mg)/100g	0.30 ± 10.00	2.13
Potassium	(mg)/100g	780 ± 10.00	620.70
Magnesium	(mg)/100g	38.00 ± 10.00	29.90
Phosphorus	(mg)/100g	84.40 ± 10.00	70.30
Chloride	(mg)/100g	25.00 ± 10.00	20.00
Glucose	g/100g	35.00 ± 6.00	42.70
Lipids	g/100g	0.25 ± 1.80	0.260

*Mean ± standard deviation

has many health benefits. These results also show a total ash content of around 3.38%, which can be broken down into potassium (780 mg/100 g); magnesium (38 mg/100 g); iron (0.3 mg/100 g); phosphorus (84.4 mg/100 g); sodium (10.9 mg/100 g). The 'Stanley' prune is also rich in Calcium with a content of 64 mg/100 g. It also contains 0.38 mg/100g vitamin C and 4% protein. The chemical components of plums have biological effects on human health. Plums are renowned for their sweet taste and mild laxative effects, positioning them as quintessential functional food. However, the mechanisms underlying these effects remain poorly understood. Dried plums, containing approximatively 6.7g of dietary fiber per 100g (24% of the DRV), exhibit notable anti-constipation properties owing to their high fiber content. In addition, dried prunes provide a substantial amount of energy (219 kcal/100g prunes) in the form of simple sugars, but do not lead toa rapid rise in blood sugar levels, while also resulting in reduced levels of insulin secretion, probably due to their high fiber, fructose and sorbitol content. Prunes are rich in potassium (780 mg/100 g), which can be beneficial for cardiovascular health.

Dried prunes contain around 64 mg calcium, the same amount of magnesium and 84.4 mg phosphorus per 100 g. While prunes may not have a high mineral content, they are rich in organic acids, which can enhance the absorption of bone minerals, especially when consumed alongside other calcium-containing foods. The elevated Ca content of 64mg/100g could significantly contribute to skeletal strength, besides playing essential roles in neuromuscular function, blood coagulation and various metabolic processes (Chargo et al., 2024). A notable quantity of magnesium (38mg/100g) can facilitate bone development and release energy for muscle function. Additionally, the moderate iron content observed in the mineral composition can contribute to protein metabolism and support the production of hemoglobin and red blood cells.

Caloric distribution

Consuming too many calories leads to weight gain and obesity. The low-fat content of dried plums, at 0.47%, (**Figure 3**) can help prevent weight gain due to their lower calorie content. The protein content of dried plums was 4% Bones, muscles, cartilage, skin and blood, as well as enzymes, hormones and vitamins, are made up of building blocks called proteins (Alasalvar et al., 2023).

Plot size and land tenure status of farmers surveyed

53% of farms surveyed are smaller than 10 hectares, while 47% are larger than 10 hectares.

The technical cultivation on these plots is advanced, leading to higher production. Moreover, all these growers own their land, with some cultivating crops

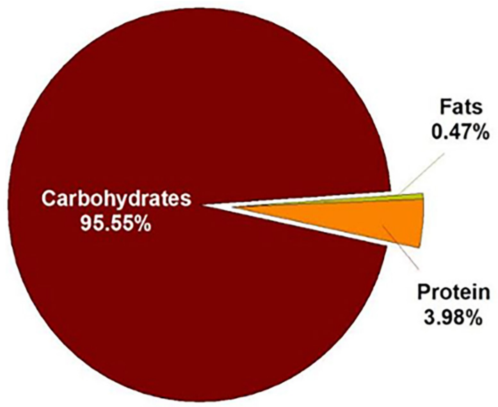

Figure 3 - Caloric repair of 'Stanley' prunes

other than plums. Large plots exceeding10 hectares are mainly found in (**Figure 4**a): Agourai, Atlas and Berkane (47%). Several factors likely contribute to the existence of these expansive plots, including specialization in drying plum production, engagement in export activities, established distribution and marketing networks, and a customer base primarily within the agro-industrial sector. Furthermore, the abundance of water and fertile soil in these areas serves as additional incentives for growers to establish their operations in these regions.

Age of plantations

The survey revealed that most plum plantations are between 5 and 10 years old (48%) (Figure 4b). These young plantations are generally very productive, with a good-quality crop, compared with those over 10 years old (38%). These older plots have lower yields, as they are affected by several pests and diseases that can cause numerous phytosanitary problems.

Yield of the areas studied

For yield per hectare, an average of 10 tones/ha is assumed. However, our studies have shown average yields more or less differentiated between the three regions. In the Sais region, yields are around 16 tons per hectare, in the Oriental region 15 tons per hectare and in the Atlas region 12.5 tons per hectare (Figure 4c).

The selling price on the domestic market

The selling price depends largely on the quality of the plums, in particular their size, but also their sugar content. Three types of farms correspond to production costs, with an average yield of 15t/ha (this yield appears to be fairly stable across the different types of farms). As already mentioned, quality (size and sugar content) is very important in determining the selling price in the field. However, within each type, there may be farms producing plums of varying qualities. According to the respondents, the average selling price is determined in 2023, i.e., 10DH/kg (**Figure 5**). However, plums of good quality, based on our research, were sold at 12DH/kg. In exceptional cases, this price can reach 13DH/kg (Sellika et al., 2015).

Based on a survey of farmers and merchants, we determined the evolution of field selling prices by size between 2014 and 2023. Significant increases were observed, all depending on plum quality. This sharp increase can be explained, on the one hand, by strong demand for supply, particularly from processing operations and, on the other hand, by Moroccans' consumption habits when it comes to plums and prunes. Plum consumption in Morocco has been increasing in recent years, with plums rivalling many other fruits. As a consequence, Moroccan consumer demand for plums and prunes varies significantly based on price, often resulting in shifts in both supply and demand prices.

Plum selling prices are significantly influenced by various factors, including size (**Figure 6**) and sugar content, reflecting consumer preferences and market dynamics. Based on a survey of farmers and traders, we calculated outdoor selling prices according to size, noting a price exceeding 10DH. This indicates a significant increase in price in recent years, contrary to expectations from other studies that suggested a different valuation scenario (Sellika et al., 2015).

Drivers of change

Three main factors favoring driving the sector's

Figure 4 - (a) Size of plum plots in the survey area; (b) Average plantation age; (c) Average yields in tons per hectare (T/h) in the main producing regions

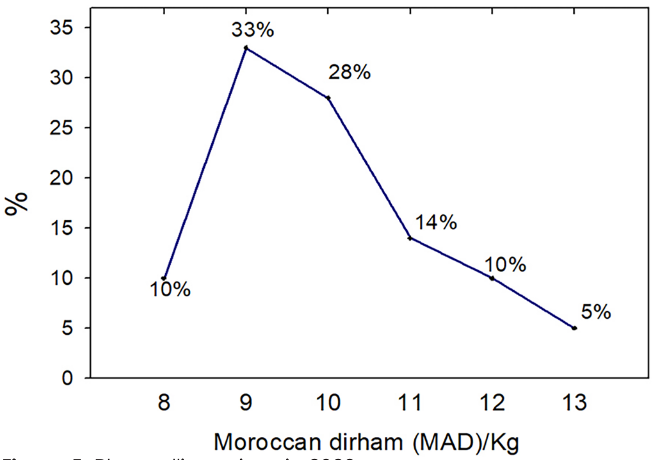

Figure 5. Plum selling prices in 2023

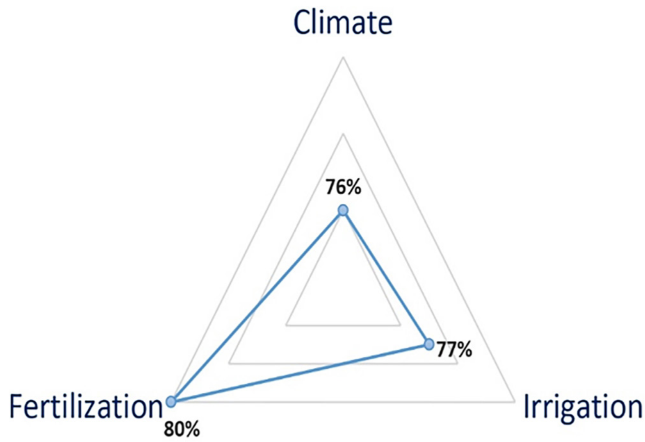

Figure 6 - Factors influencing plum quality

development have been identified (Figure 6): 1) soil fertilization and the use of fertilizers, 2) climate, 3) irrigation.

Our respondents highlight the necessity for plums to meet specific conditions to achieve ideal market quality, including considerations of size, shape, and Brix levels. These factors significantly influence pricing decisions for each batch.

Respondents express their opinions about the factors that have an impact on the productivity and quality of this year's plums, 80% of which are related to soil fertility and fertilizers. In this regard, some farmers mention the critical demand for potash, a key element in fruit quality (Large-caliber fruit). Stanley plum trees extract nutrients from their environment to provide nutrition for this year's crop. As a perennial crop, mineral nutrition also ensures the development of structures and the accumulation of reserves. These reserves play an important role, especially for a fresh start in spring.

76% of growers emphasize the crucial role of climatic conditions in ensuring good fruit. In fruit growing, particularly plum production, the composition of the ripe fruit significantly adds value to the crop, with this composition being closely tied to climatic conditions. The respondents mentioned that plum trees require cold weather, which explains why this sector is located in humid areas.

Additionally,77% of respondents emphasized the importance of irrigation. They noted that the water requirements of plum trees vary depending on the region's climatic conditions and the age of the trees. In mature orchards with sufficient production, an adequate water supply increases fruit size and reduces renewal and senescence.

Physicochemical parameters of plums in the studied cultivars

As is common with most fleshy fruits (Xuemin et al., 2021), water content is most abundant component. The average water content for the Atlas 'Stanley' plum is 80.80% ± 0.5%, followed by the Sais plum at 79.73% ± 0.01%, and the Oriental plum at 67.58% ± 0.02% (**Figure 7**). The weight of dried plums is an essential factor for both the consumer and the industry. In this regard, the "SAIS" and "ATLAS" cultivars exhibit the highest weight at 28.64 and 28.31g, respectively, while the "Oriental" cultivar measures just 26.12g. The disparity between the cultivars is significant. One of the most important elements in fresh plums, particularly dried plums, is Brix. The "Atlas" cultivar stands out with the highest available glucose content.

Chemical properties of the studied soils

Regarding the chemical properties of the studied soils (**Table 5),** the majority of plots exhibit values below 1 ds/m. Additionally, the pH values are predominantly basic, except for the two Atlas soils, which display a neutral pH. The assimilable P205 content ranges from 19 to 39 mg/kg in 75% of the plots, with 25% of plots showing values ranging from50 to 114mg/kg. Plot FSA03 notably has the lowest assimilable P205 content, with an average

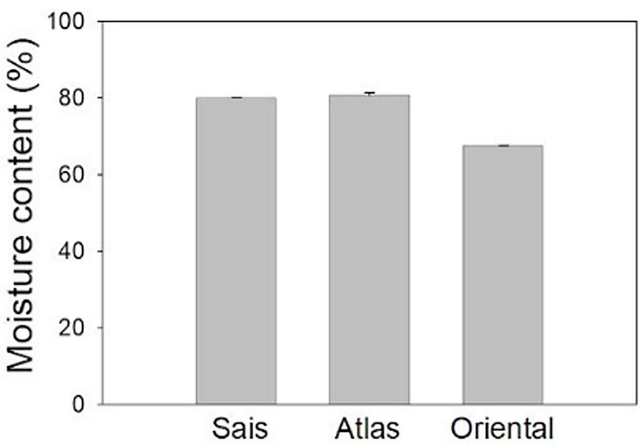

Figure 7 - The moisture content of "Stanley" plums in 3 study regions

of 19mg/kg. Regarding the total limestone content, 62.5% of plots exhibit values between 2.4 and 5.2%, while the remaining 37.5% have values below 6%.

In this study, the pH value of plum juice from the Stanley variety ranged from 3.42 to 3.9, consistent with findings from previous studies on the same variety, which set the pH of the fruit at average of 3.33 (Aibella et al., 2023). The titratable acidity (0.36-0.47) corded in this study were lower to that reported by (Aibella et al., 2023). (0.78-1.78%).

Soil type significantly influences acidity levels of grape production, but not in the accumulation of sugar (Evangelos et al., 2023). The respective pH, acidity and Brix values for the different cultivars are presented in **Table 4**. The sugar content varies significantly among cultivars, with 'Sais' and 'Atlas' exhibiting the highest values of 19.41°Brix and 19.18°Brix, respectively, while 'Oriental' demonstrates the lowest value at 17.12° Brix. These values exceed the 10-12° Brix described in the literature for the variety Prunus Domestica L. (Maglakelidze et al., 2017). The results obtained show that the soluble solids content is lower in the fruits of the cultivar Stanley grown in the 'Atlas' region Regarding the soluble solids content of plums at harvest, these parameters were found to be influenced by soil. Thus, it is valuable to compare and differentiate the fruit quality originating from different soils during harvest. Contrary results were obtained by (Mikhailichenko et al., 2022) concluded that cultivars haven't a significant effect on soluble solids. The overall chemical requirements of plums are relatively low. Additionally, Studies have shown that blueberry cultivars differ significantly in their growth characteristics, quality and mineral content due to soil type and its pH (Hao et al., 2022). Furthermore, our findings suggest that plums with high physicochemical quality can still be cultivated under moderately limiting conditions in organic matter and potash resources. Plums with high sugar content are produced under conditions with moderate limitations in organic matter and total limestone. Such soil characteristics contribute to enhancing the overall quality of plums. These results make it possible to develop hypotheses highlighting the role of soil parameters, namely the level of active limestone, the main active limestone whose many studies have shown that it acts directly on 3 elements: manganese, calcium, and nitrogen. This element negatively impacts the productivity of Prunus Domestica L. due to its antagonistic effect with the nitrogen, which is necessary for the plant's nutrition. The physical and chemical composition of plum trees depends on growing conditions, soil quality, climate, irrigation, etc.) and the harvest period (early or late).

We conducted a principal component analysis (PCA) to assess whether specific soil characteristics could account for variations in the intrinsic quality of plums across different plots. According to the Biplot (Fig 8a), three groups of individuals can be distinguished from each other. The first group consists of the two parcels FO1 and FO2 of the eastern region, the second constituted by the parcels FSA1, FSA2, FSA3 and FSA4 of the Sais

Table 4. Some physico-chemical parameters of plums in the studied cultivars

Region	Farm	°Brix	Titratable acidity (%)	pH	Moisture (%)	Dry matter (%)	weight (g)
Sais	FSA1	20.19±0.49ab	0.36±0.07a	3.87±0.12a	81.32±1.37bc	15.68±0.39a	28.69±0.43acd
	FSA2	19.06±0.29bc	0.37±0.14a	3.84±0.22a	79.65±1.86bc	20.35±0.56bc	27.85±0.92a
	FSA3	19.41±0.79b	0.34±0.00a	3.82±0.13a	80.26±1.22bc	19.74±0.29c	30.11±0.60c
	FSA4	19.00±0.44bc	0.37±0.54a	3.74±0.13a	78.48±1.18c	21.52±0.43b	27.92±0.42af
Atlas	FAT1	21.37±0.57a	0.28±0.11a	3.93±0.12a	83.12±2.05b	16.88±0.25a	29.31±1.24ac
	FAT2	18.00±0.57cd	0.40±0.17a	3.86±0.17a	77.33±1.3c	32.67±0.59d	27.32±0.56ab
Oriental	FOR1	17.33±0.26d	0.42±0.28a	3.56±1.21a	69.18±1.04a	30.82±0.48e	26.92±0.49bdf
	FOR2	16.92±0.25d	0.47±0.00a	3.42±0.10a	65.97±1.09a	34.03±0.52f	25.33±0.58b

Note: Mean (± standard deviation). Values with the same letters differ non-significantly (P > 0.05)

Table 5. Soil properties in the studied cultivars

Cultivar	Electrical Conductivity (EC) (ds/m)	MO%	pH water (soil)	Potash mg/kg	P205 Assimilable mg/kg	Total limestone (%)	Active limestone (%)
FSA 1	0.23±0.00a	2.32±0.28a	8.70±0.27a	346.50±2.33a	50.00±0.79c	5.20±0.39a	0.50±0.01bc
FSA 2	0.17±0.03a	2.15±0.09a	8.80±0.22a	326.00±5.21b	24.00±0.41a	10.50±0.24bc	3.50±1.60ad
FSA 3	0.16±0.02a	2.19±0.09a	8.80±0.17a	278.50±4.43c	19.00±0.31d	13.40±0.24e	4.20±0.27a
FSA 4	0.18±0.03a	2.27±0.41a	8.75±0.35a	238.50±3.91d	39.00±0.65b	2.80±0.11f	0.02±0.00b
FAT 1	0.20±0.02a	1.60±0.14a	7.05±0.17b	417.00±6.45e	39.00±0.63b	5.40±0.14a	0.70±0.01be
FAT 2	0.17±0.00a	1.95±0.27a	7.00±0.24b	438.00±6.71f	28.00±0.45e	10.00±0.21b	2.60±0.19ad
FOR 1	0.70±0.05b	3.30±0.19b	8.55±0.27a	239.00±3.79d	117.00±1.79f	27.00±0.45g	1.90±0.02cde
FOR 2	0.38±0.00c	3.69±0.45b	8.85±0.36a	237.00±1.87d	24.00±0.39a	11.00±0.22c	2.00±0.50cde

Note: Mean (± standard deviation). Values with the same letters differ non-significantly (P > 0.05) region and FAT2 of the atlas region, and the third group constituted by the parcel of the Atlas region FAT1. The overlay of the distribution on the biplot (**Figure 8**b) onto the correlation circle reveals a clear correlation between parcels FA1 and FA2 in the Atlas region. FAT1 presents exhibit particularly optimal properties in terms of acidity, humidity, Brix and Caliber of the fruit produced. FO1eand FO2 of the eastern region seem to be negatively correlated with potash indicating the absence of this element Figure 8b. In group 3, the parcels for correlations with all the parameters present in the circle, suggesting a low contribution of their nutrients. Pearson (Factor2) analysis indicates that plums from Sais plots exhibit higher levels of reducing sugars, water accumulation, and titratable acidity compared to other plots, suggesting distinct fruit composition characteristics. Plums are highly concentrated, especially in FAT1 plots. Closely related to soils poor in total limestone, assimilable P205 and organic matter as reported for plots FSA1, FSA2, FSA3, FSA4and FAT2. The abundance of nutrients such as potash in the soil appears to be independently correlated with other type of ripening.

Plum plantations are strategically established considering the mild climate and winter cold requirements, positively impacting productivity. This has a positive effect on the productivity of the plots. This was demonstrated by recording high yields in plots where ventilation fans were used to ensure favorable cooling conditions for the respective crops (**Figure 9**). The figure reflects the variation in the production rate of different plots in three distinct regions.

Fruit size varies according to specific cultivars, cropping practices and environmental conditions (climate, irrigation). Final plum size is strongly influenced by water availability during development (Hajlaoui et al., 2022) and this cordially depicts to irrigation quality. Of the three sites planted with STANLEY plums, plots FAT1, FSA1, FSA2, FSA3 and FSA4, which received artificial irrigation (drip irrigation), recorded high yields of 20T/H at Sais and 28T/H at Atlas, the sites with the highest yields at 28.64 and 28. 31g as shown in table (4). In addition, Plots subject to natural treatment, and thus receiving lower irrigation levels, yielded approximately 10T/H annually, while plum sizes at the "Oriental" site measured only 26.12g, confirming the influence of irrigation practices on fruit size. Then the data suggests that artificial irrigation, specifically

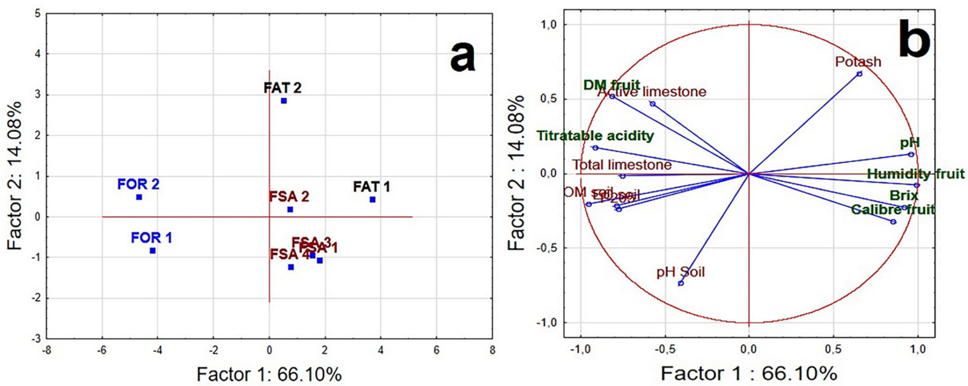

Figure 8. Principal Component Analysis for the contribution of soil parameters on nutritional and physicochemical quality of fruit (a) biplot and (b) correlation circle between factors and parameters

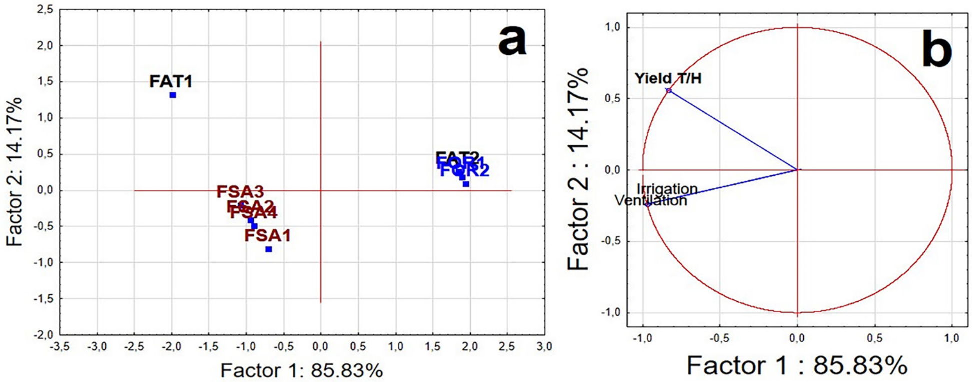

Figure 9. Principal Component Analysis for the contribution of the technical conditions on Yield (a) biplot and (b) correlation circle between factors and parameters

drip irrigation, leads to higher yields and larger fruit sizes compared to natural or lower levels of irrigation. This highlights the effectiveness of controlled water delivery systems in ensuring adequate moisture for optimal fruit development. Moreover, the significance of these findings extends beyond plum production to other fruit crops and agricultural systems. The relationship between water availability and fruit size is a fundamental aspect of plant physiology and can be applied to various fruit crops grown under different environmental conditions. Therefore, the insights gained from studying irrigation effects on plum size can inform broader strategies for sustainable water management in agriculture, contributing to improved crop productivity and resource efficiency (Hajlaoui et al., 2022).

Conclusion

This study of the 'Stanley' chain shows the chemical and nutritional composition of the variety, taking into account the impact of soil chemistry and certain factors that independently influence its quality. The results showed that soil potash content with low limestone inputs had a positive effect on plum weight and sugar content, alongside adequate environmental conditions. However, based on the findings of this study, it can be concluded that optimal terroir conditions for producing high-quality plums are achieved under two key conditions. On the one hand, when plum ripeness is in harmony with local climatic conditions, and on the other, when pedoclimatic factors promote the expression of the plums' nutritional and physicochemical properties. This last desirable condition is advantageous when plum trees grow in environments lacking in water and minerals.

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Disclosure of potential conflicts of interest

No potential conflict of interest was reported by the author(s).

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