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Research Article

Effect of Sugar Beet Harvest Date on Its Technological Quality Parameters by Exploratory Analysis

Lamiae Alami[1] **Wafa Terouzi,**[2,3] **Manar Otmani,**[1] **Oussama Abdelkhalek,**[2] **Souad Salmaoui,**[4] **and Mohamed Mbarki**[1]

[1]*Laboratory of Organic and Analytical Chemistry, Faculty of Sciences and Technics, Sultan Moulay Slimane University, Beni Mellal, Morocco*
[2]*Laboratory of Applied Spectro-Chemometry and Environment, Faculty of Sciences and Technics, Sultan Moulay Slimane University, Beni Mellal, Morocco*
[3]*Laboratory of Engineering and Applied Technology, Superior School of Technology, Sultan Moulay Slimane University, Beni Mellal, Morocco*
[4]*Laboratory of Environment and Agro-Resources Valorization, Faculty of Science and Technics, Sultan Moulay Slimane University, Beni Mellal, Morocco*

Correspondence should be addressed to Lamiae Alami; lamia.alami@usms.ma

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Choice of the harvest date is one of the foundations of vintage quality and good-yield sugar in sugar beet. However, it is difficult to define the harvest date and more precisely the date of maturity of beet roots, in an exact and absolute way. Indeed, maturity is divided into several stages and degrees depending on environmental and climatic conditions such as temperature, precipitation, geographic area, and others. The present study evoked the effect of three harvest dates (at esteemed maturity, 7 days after maturity, and 15 days after maturity) on the technological quality parameters, namely, sucrose, nitrogen, potassium, and sodium, using the most popular chemometric method, principal component analysis (PCA). To do this, samples from the Tadla irrigated perimeter were used. The results of exploratory analyses by the application of PCA clearly showed the influence of harvest date, in an important way, on the three quality parameters, composition of sucrose, potassium, and sodium. But, for nitrogen composition, there were negligible variations between samples.

1. Introduction

Sugar beet (*Beta vulgaris* L.) is a dicotyledon belonging to the Chenopodiaceae family known today by Amaranthaceae and from the Caryophylla order which has a photosynthetic system C3 [1]. It is a conical root, traversed by two sacchariferous furrows and having a flat neck; it is almost completely buried in the ground. Sugar beet root is characterized by a very high content of soluble sugars which depends on several variables, namely, region, season, plant biology, agronomy, harvest time, and postharvest practices [1]. Beetroot is a biennial plant, and its vegetative cycle spans two years. The process of manufacturing sugar takes place during the first year; during this period, the sugar reserves are maximum and the sugar produced in the leaves by photosynthesis is stored in the form of sucrose in the root. It is a constant translocation of sucrose from the leaves which is stored in concentric rings of vascular tissue derived from the secondary cambium originating in early root development and in parenchyma cells which increase in number and grow larger during growth [2]. The harvest is, therefore, performed at that time. During the second year, the plant reproduces; it then draws on its sugar reserves to produce a floral stalk which evolves into fruits and seeds in order to continue its vegetative cycle [3]. Sugar beet is a crop that can be planted as one of the many rotation crops for the purpose of fully exploiting land and resources in an agricultural system [4]. Also, this very consistent plant can be resistant to water stress [5], resistant to frost [6], or even tolerant to salt stress [7, 8] and may have higher water and nitrogen use efficiency than other industrial crops such as maize, wheat, and alfalfa [9]. Sugar beets are grown in 41 countries around the world covering an area of 8.1 million hectares [8, 10] and have been bred for over a century to increase the yield and purity of sucrose and now represent nearly 30% of world sugar production [11]; this contribution to world production was also revealed by Salim et al. [12]. According to FAO 2019 [13], the classification of top ten sugar beet producers is as follows: Russia, France, Germany, the United States of America, Turkey, Poland, China, Egypt, Ukraine and the United Kingdom.

At the national level (Morocco), the area sown to sugar beet increased by around 4% to reach around 61,000 ha during 2015/2016 campaign against 58.00 ha the previous campaign, and total production increased to around 61,000 ha during 2015/2016 campaign and reached 4.2 million tons, an increase of 17% compared to the production of the past year [14], and the average yield of sugar beet rose from 61 to 71 T/ha, an increase of 16% compared to the previous campaign [14]. At the regional level, the average production obtained in the Tadla perimeter under the 2015/2016 campaign is around 813,000 T or 26% of the achievements. The sown area is around 13,040 Ha in 2015/2016 against 11,200 Ha in 2009/2010 [15].

In Morocco, sugar beet is an autumn crop sown in October and November and harvested in June, July, and August. The harvest date of beet is not defined by a stage of physiological maturity, but rather this crop is harvested when its sugar production is optimal. Maturity of beet, which results in the yellowing of the leaves, is difficult to assess with precision. Research work carried out in various Moroccan beet areas shows that the beet ripening phase must be as sunny as possible and sufficiently long, without, however, being exaggerated [16]. In general, the sugar content in the root follows a bell curve: it is too low in April-early May, acceptable in late May, good in June, high in July, and decreases in August [16, 17].

As soon as they are harvested, the beets go through different stages before going to the sugar factory (leaf stripping, turning, and loading into trucks), and therefore, the time elapsing between harvests and processing in the factory must be short in order to preserve their high sugar content because once extracted from the ground, their sugar content decreases rapidly. The effect of harvest date study on crops is a scourge concerning not only sugar beet but also other fruits and vegetables and has been addressed by many researchers. Nadori et al. [18] studied the influence of rootstock and harvest date on fruit quality of mandarin during cold storage, Esmaeilpour and Shakerardekani [19] studied the effects of early harvest times on nut quality and physiological characteristics of pistachio (*Pistacia vera*) trees, Doua and Shid [20], for their part, studied the influence of harvest season on volatile aroma constituents of two banana cultivars, Feyem et al. [21] studied the influence of harvest date on seed germination of some varieties of rainfed rice, and finally, Dibi et al. [22] determined the harvest period of sweet potato varieties.

It is in this context that this work was carried out with the objective of studying the effect of harvest date of sugar beets, precisely after a delay of 5, 10, and 15 days, on its technological quality, sucrose, and the melassogenic elements. Also, the exploration of the analytical results of the samples was studied by the application of the principal component analysis (PCA) in order to visualize the numerical data in the form of spacial representation for grouping samples which have high or low contents depending on the harvest date and the parameters studied.

2. Materials and Methods

The present study was conducted in the irrigated perimeter of *Tadla* during 2011-2012 agricultural seasons.

2.1. Plant Materials. A total of 70 sugar beet roots were used (each 5 roots represents a study sample), all from a single plot. They were harvested under controlled conditions. The samples were all of the same *ARDAN-N* monogermic variety which presents an average saccharin richness, average yield, and an average cycle, and all respected the same cultivation conditions; the sowing date was 3 October 2011, soil quality was clay loam with a pH close to neutral, mode of sowing was mechanical, the fertilization as for it was divided into two types of inputs, the first is the basic fertilizer which was Phosphate Diammoniaque 18.46 or DAP and the second input was the cover fertilizer Ammonitrate 33.5% which was applied twice, the precedent culture was cereals, and finally, the same irrigation mode was used which was by gravity with a flow of 20 L/s. However, there were no phytosanitary treatments.

To study the influence of the harvest date on the quality of sugar beet, the following process was followed:

(i) 25 sugar beet roots are harvested on the estimated maturity day: 30 May 2012

(ii) 20 sugar beet roots are harvested after 7 days: 06 June 2012

(iii) 25 sugar beet roots are harvested after 15 days: 14 June 2012

Analyses were carried out on the same day of harvest, after preparation of the representative samples. Each representative sample studied was the mixture of 5 beet roots so as to have 5 representative samples (A1, A2, A3, A4, and A5) for the first harvest date, 4 representative samples (E1, E2, E3, and E4) for the 2nd harvest date, and finally, 5 representative samples (J1, J2, J3, J4, and J5) for the 3rd harvest date.

The maximum time between harvest and analysis of samples was no more than 3 hours.

2.2. Preparation of Samples. Beets are uprooted by hand, sound, unbroken, and manually stripped in field after uprooting. All beet roots were washed, making sure that there is no soil left in the saccharifying furrow, and then, the beet root collar was cut. Subsequently, a subsampling (sample in the form of grating whose weight was equal to 10% of the starting weight to be able to easily extract the soluble materials) was carried out, and finally, a homogenization was performed.

2.3. Preparation of a Clear Solution. A sample of 40 g of homogenized rasp was placed on a glossy paper; then, the rasp was transferred into a beaker of the automatic digestion chain and 165 mL of a dilute solution of lead acetate Pb $(CH_3COO)_2$ was added ($3H_2O$). Conventionally, total volume was 200 mL, and the lid was placed on the beaker with rigorous agitation. After 15 min, samples were filtered.

2.4. Chemical Analyses. All analyzes were carried out according to the procedures described by the technical committee for standardization of sugars (SNIMA, 2005) [23].

2.4.1. Sucrose Determination. It was carried out using a saccharimeter which was a saccharimeter polarimeter (brand Schmidt + Haensch, type SACCHAROMAT) bearing graduations defining the percentage (%) of sugar contained in the grating and which was specially designed for the sugar industry.

2.4.2. Determination of Melassogenic Elements. These were elements that reduce the extraction of sugar, namely, Na, K, and N α-amino. The concentrations of these elements in sugar juice give an idea about molasses sugar; that is, how much sugar cannot be extracted by the classic sugar industry process. The concentrations are expressed in mmol per 100 g of sugar juice. The determination of sodium and potassium was carried out by flame photometry (type PHF 104) which consists in vaporizing the sample to be analyzed in flame which causes excitation of atoms. When the electrons pass to a more stable energy level, photons were emitted [24]. Photometry consists of relating the intensity of emission with the concentration of the element to be assayed. The sodium and potassium emissions were measured at 589.6 nm and 766.5 nm, respectively.

For nitrogen determination, the method was that of Crruthers and Oldfield [25] derived from the colorimetric method of Moore and Stein [26]. It allows the measurement of alpha-amino nitrogen in beet juice after lead defecation. This method was officially adopted as a reference method by the *ICUMSA* (International Commission for Uniform Methods of Sugar Analysis).

The sample was subjected to the action of hydrazine (N_2H_4) to denature the proteins. The free amino acids react with ninhydrin to give a blue-colored complex in the presence of propanol. The absorbance of this solution was then measured at 570 nm.

2.5. Principal Component Analysis. PCA is considered to be the basic method of analyzing multidimensional data, when all variables observed are of a numerical type, and of seeing if there are any links between these variables and between samples. Its purpose is to describe the data contained in a table with *n* rows (individuals/samples) and *p* columns (variables/parameters) [27].

The principal components were obtained by diagonalization of the matrix of bivariate correlations. This diagonalization defines a set of eigenvalues whose observation for each component makes it possible to determine the number of graphs to be examined [28]. The final phase of the PCA consists of a graphical representation that provides an overview of the results that numerical expressions do not provide [29].

Statistical analyses of the various analytical data were performed using Unscrambler version 10.2 software.

3. Results and Discussion

3.1. Univariate Descriptive Study of the Quality Parameters of Sugar Beet in the Three Harvest Dates. The results of the various analytical and statistical data, obtained during three harvest dates, are summarized in Table 1 and presented in a graph form in Figure 1.

According to Table 1, the comparison of the mean and median of each variable (studied parameter) shows that the distribution of each variable was asymmetric, which suggests the presence of outliers with respect to each of the variables. But, from a multivariate point of view (considering all parameters at the same time), these values may not be outliers. Thus, the range (maximum-minimum) and standard deviation of each variable, at the three harvest dates, were relatively high. This may later explain the large dispersion of samples within each variable (see Figure 1).

This univariate descriptive study of variables in the raw state made it possible to suspect the presence of outliers. Also, it made it possible to justify the application of the PCA on centered-reduced data. That is to say, a multivariate descriptive analysis is carried out, independent of the measurement scales of the parameters studied.

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3.2. Descriptive Analysis of Sugar Beet Quality Parameters in Three Harvest Dates by ACP. The objective of principal component analysis (or PCA) is purely descriptive: it is a question of "exploring" a set of observations gathered in the form of a table of data indicating for each statistical unit (here, the sample beet) the observed values of a certain number of quantitative variables (here, the quality parameters studied).

Principal component analysis is one of the most important multivariate analysis techniques. It allows a good visualization of the structures present in the data. In fact, the interpretation of PCA results is usually provided by visualizing plot scores and loadings plots [30]. The score of a

Table 1: Analytical and statistical data related to the parameters studied in the three harvest dates.

	Samples	Sucrose %	Nitrogen	Potassium	Sodium
			The concentrations were expressed in mmol per 100 g of sugar juice		
First date of harvest: 30 May 2012	A1	18.32	0.96	2.46	1.61
	A2	18.64	0.63	2.69	1.9
	A3	18.98	1.63	2.31	1.61
	A4	18.3	1.46	2.72	0.77
	A5	17.95	1.09	2.97	1.84
	Average	**18.43**	**1.15**	**2.63**	**1.54**
	Standard deviation	**0.38**	**0.39**	**0.25**	**0.45**
	Minimum	**17.95**	**0.63**	**2.30**	**0.77**
	Maximum	**18.98**	**1.63**	**2.97**	**1.9**
	Median	**18.32**	**1.09**	**2.69**	**1.61**
Second date of harvest: 06 June 2012	E1	16.09	1.62	3.45	2.64
	E2	15.95	2.06	3.87	2.95
	E3	16.57	1.57	3.3	2.65
	E4	17.5	1.61	4.06	2.59
	Average	**16.52**	**1.71**	**3.67**	**2.70**
	Standard deviation	**0.7**	**0.23**	**0.35**	**0.16**
	Minimum	**15.95**	**1.57**	**3.3**	**2.58**
	Maximum	**17.5**	**2.09**	**4.05**	**2.95**
	Median	**16.33**	**1.60**	**3.65**	**2.64**
Third date of harvest: 14 June 2012	J1	17.72	2.21	2.85	2.72
	J2	18.71	2.41	3.12	3.29
	J3	17.65	1.77	2.38	3
	J4	18.16	1.83	2.46	2.58
	J5	18.88	2.14	2.77	2.53
	Average	**18.22**	**2.07**	**2.71**	**2.82**
	Standard deviation	**0.55**	**0.26**	**0.30**	**0.31**
	Minimum	**17.65**	**1.77**	**2.38**	**2.53**
	Maximum	**18.87**	**2.41**	**3.11**	**3.29**
	Median	**18.16**	**2.14**	**2.77**	**2.72**

sample is the value on the principal components axis, where it is projected [31]. Loadings of the initial variables can be interpreted as correlations between these variables and the principal components. The greater the contribution (loading) of a variable on a principal component, the more the variable is linked to this component. Briefly, the loadings plot allows determining and defining the most important variables according to their distribution with respect to the principal components.

When a PCA procedure is used, the quantity of original variables is reduced to a few principal components (PCs) which still represent the main information of the original dataset. The PCs are fetched so that the first PC carries most of the information, followed by the second PC carrying less information, and so on, in descending order. After a certain number of PCs, variation modeled by a new PC can be attributed mainly to noise.

After importing the data into the Unscrambler software, first, principal component analysis (PCA) was applied to the raw analytical data. Then, a centered-reduced data matrix was calculated to work with the correlation matrix so that the descriptive analysis was independent of measure units.

Therefore, Principal Component Analysis (PCA) was performed on analytical data (raw and centered-reduced) from 14 beet samples, where the interpretation of the results is based on visualization of the biplot (Figure 2) and correlation loadings (Figure 3).

Figure 2 (samples/variables representation) is a graphical representation in which the projection of variables and samples is juxtaposed on the PCs axis. This representation makes it possible to visualize the samples having high (or low) values of a given variable. Generally, there is a grouping of samples according to the harvest date. According to Figure 2(a), this grouping is strongly linked to the sucrose composition (richness). While it is, respectively, related to the composition of potassium, sucrose, and sodium (see Figure 2(b)), these results were confirmed by the "correlation loadings" plot (Figure 3).

Figure 3(a) presents 1D correlation loadings. There are red dotted lines for the bounds of the 50 and 100% explained variance for the given principal component. Variables that lie within the upper and lower bounds of the plot are modeled by this main component. Those between the two inner terminals are not. When interpreting this figure, the sucrose composition (richness) was the most important variable. So, it contained a very large variation; also, it was responsible for grouping samples according to the harvest date.

To have an independent interpretation of the effect of scale between variables, the analytical data were centered-

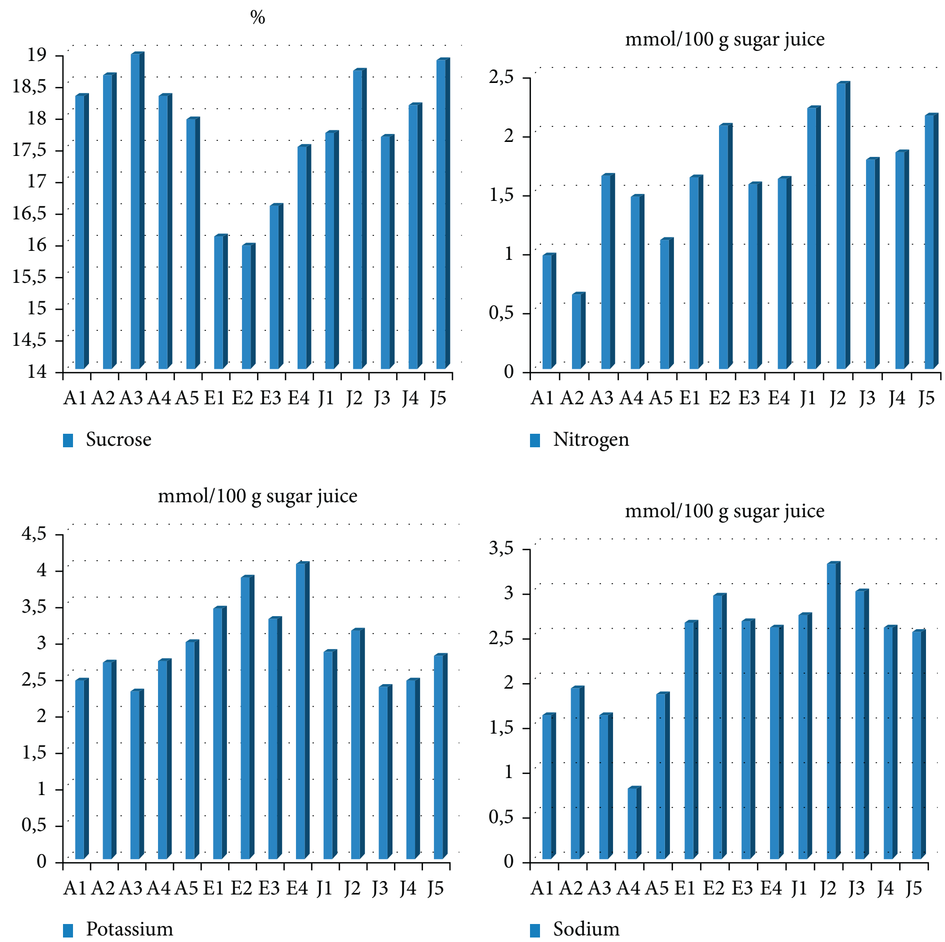
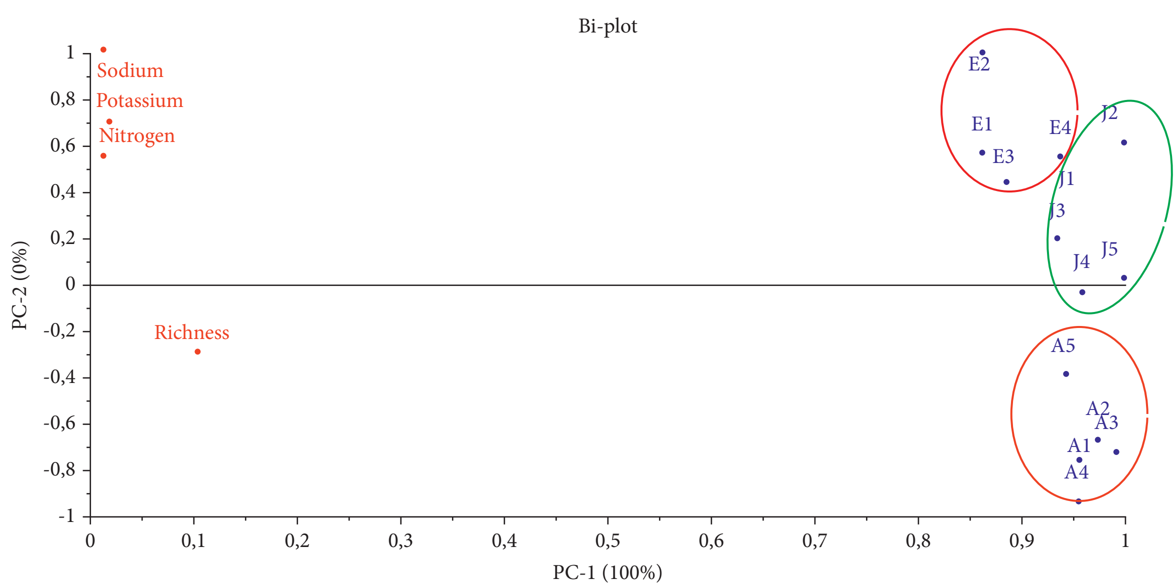
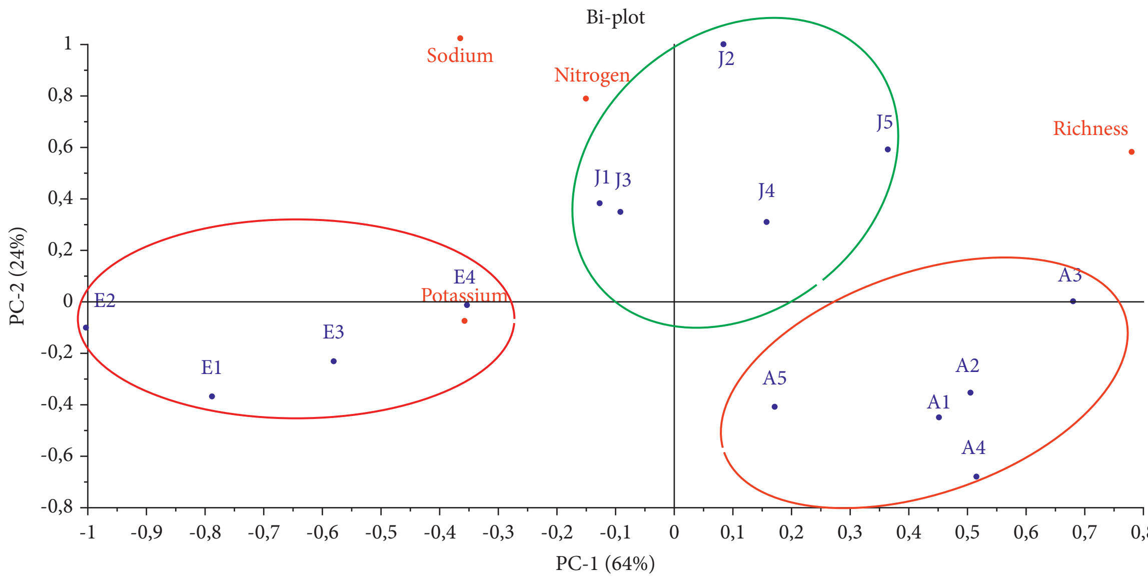


Figure 1: Sucrose, nitrogen, potassium, and sodium composition of beet in 3 harvest dates.



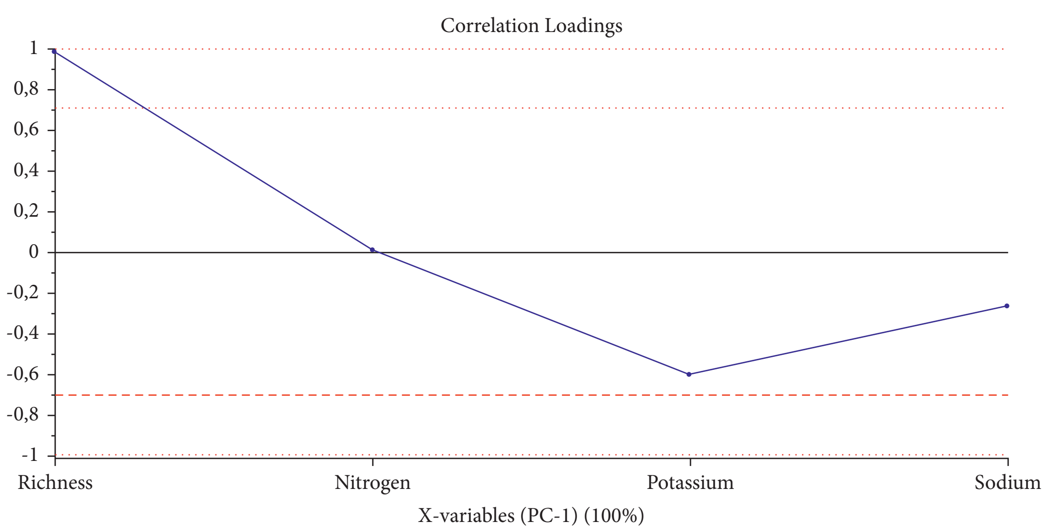
(a)

Figure 2: Continued.



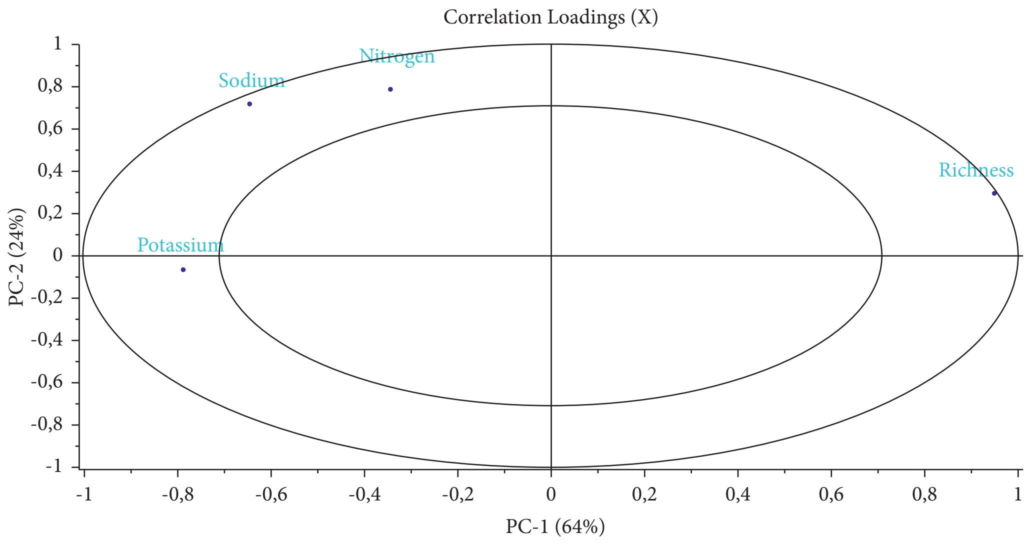
(b)

Figure 2: Biplot (PC1 vs. PC2) of analyzes of beet quality parameters and samples in 3 harvest dates: (a) in the raw state; (b) on standardized centered data.



(a)

Figure 3: Continued.



(b)

Figure 3: Correlation loading of beet quality parameters: (a) in the raw state; (b) on standardized centered data.

reduced. Figure 3(b) is a correlation circle defined by two principal components. It is the graphical representation of the variables according to their correlation coefficients with the principal components. All parameters were located in the radius between the two ellipses, thus explaining more than 50% and less than 100% of the variance in the data. So, the four parameters studied contain a variation structured enough to be discriminating for the samples of beet according to the date of harvest.

In this study, the harvest date proved its influence on various qualitative parameters of sugar beet, and this is also proven in the bibliography. Moreover, there are researchers who have studied the influence of different harvesting times on the productivity and technological quality of sugar beet as a function of contamination and root freezing [32] and who have found that there is a dependence on the productivity and quality of the beet roots (potassium, sodium, alpha-amino nitrogen, and sugar) and the harvest date, and they also estimated the degree of dependence. Other researchers have studied the influence of harvest on storage losses [33] and have shown that the quality of the harvest is of critical importance in order to further optimize the value chain. Others have relied on multispectral imaging collector drones capable of determining the vegetation index to estimate the dates of sugar beet harvests [34]; they found that the early harvest dates reduced the yield of recoverable sugar by comparing to late harvest dates. Another study looked at the interactions between the planting date and sugar beet genotypes for different harvest dates [35]; analytic results revealed that genotypes, planting date, and harvest date significantly affected sugar yield.

4. Conclusions

Sugar beet cultivated for its fleshy root which forms in the first year of the agricultural cycle is mainly used for the production of sugar. In the sugar industry, the overall quality of beet is evaluated by measuring the following compounds: sucrose, total nitrogen, sodium, and potassium. The present study was able to demonstrate the influence of the harvest date on the quality parameters of sugar beet. The extension of the harvest date, seven and fifteen days after maturity estimated, made it possible to say that there is a significant effect, in particular, on the sucrose content and the two melassogenic elements potassium and sodium, while the nitrogen composition shows negligible variation.

Data Availability

The data used can be acquired from first author (lamia.alami@usms.ma) upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

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