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Valorisation of agro-food: Case study of the effects of traditional and oven roasting processes on the quality of date seed coffee

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Abstract: This research explores the potential of using roasted date palm seeds from three Moroccan varieties (Boufeggous, Bouslikhen and Mejhoul) as a substitute for coffee. The focus is on the roasting step of the manufacturing process and its impact on the acceptance of the date seed coffee. The study involved a combination of infrared spectroscopic analysis (IR) and principal component analysis (PCA) for physicochemical characterization, as well as organoleptic testing for comparison of coffee quality. The goal is to find an alternative to coffee that carries no health risks.The study found that the roasting process has a strong impact on the quality of date seed coffee from the three varieties, Boufeggous, Bouslikhen and Mejhoul, using a combination of infrared spectroscopy and principal component analysis (PCA). The results of the organoleptic testing showed that consumers preferred the Mejhoul variety for both roasting methods. Furthermore, the study presents the potential of using date seeds as an alternate source of dietary fiber, phenolic compounds, and antioxidants, by using an agro-waste.

Keywords: Date seed coffee, FT-MIR spectroscopy, Principal component analysis, Roasting process, Organoleptic test.

1. INTRODUCTION

The Phoenix dactylifera L has a long history of cultural and economic significance. The tree has been cultivated for thousands of years and is deeply ingrained in the history, culture, and economy of the Middle East and North Africa.The date palm is also considered as an important agricultural crop and is grown in many regions of the world with similar climates such as California, Arizona, and Florida in the United States, Iraq, Iran, Saudi Arabia, Egypt and Pakistan are the largest date producer countries in the world.

Dates can be consumed fresh or dried, and can also be used to make date syrup, which is a popular sweetener in many Middle Eastern cuisines. Dates are also used in traditional medicine to treat a variety of ailments, such as constipation and anemia.Overall, the date fruit is a versatile and valuable crop that is enjoyed for its taste, nutritional value, and cultural significance [1], [2].

The date fruit is a single-seeded that composed of a thin epicarp, which is the outermost layer of the fruit, a fleshy mesocarp, which is the middle layer and the most fleshy and juicy part of the fruit and a hard endocarp that encases the seed [3], [4]. Studies have also found that the average percentage of date seeds is around 10% of the overall weight of the fruit when it is fully ripe [6].

Morocco is one of the top producers of dates, with over 4.8 million date palms distributed across various regions such as Errachidia, Goulmim, Tata, Ouarzazate, Tiznit, Figuig, Agadir, and Marrakech [7]. The yearly production of dates in Morocco can fluctuate greatly due to changes in weather conditions, particularly rainfall or drought. Typically the total production is more than 100,000 tonnes, of which 25% is considered high quality, 35% is medium quality, and the remaining 40% is considered low quality [8].

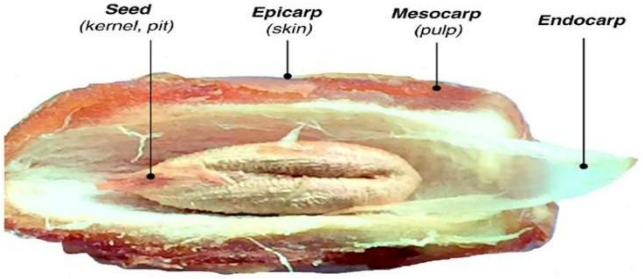

Figure 1- The anatomy of the date fruit at the Tamr phase, displaying the seed, mesocarp, epicarp and endocarp

Date seeds are a by-product generated during the direct consumption or during the treatment of the dates industry [9]. These by-products are often disposed of, which poses environmental problems, or used as fodder

for animals. However, date seeds contain a significant amount of dietary fiber, and phenolic compounds, and antioxidants, which can be extracted and utilized for therapeutic purposes [10]. Studies have found that dietary fiber has been shown to have therapeutic effects on diseases such as hyperlipidemia, obesity and diabetes, and can also offer protection against cardiovascular disease, intestinal disorders, and high cholesterol [11]

In addition, phenolic compounds and antioxidants found in date seeds may also have protective effects against chronic diseases such as cardiovascular disease and cancer, and aid in treating conditions such as renal stones, respiratory disease, coughing, hyperactiveness, and poor memory [12].

The chemistry of date seeds has been studied for several decades, with early reports dating back to 1936 when Grant and colleagues [13], described the characteristics and composition of DegletNour date seed oil. They have described the oil as a yellowish-green liquid with a sweet odor. The study also noted that date seeds have been used as livestock feed since the early 1900s. More recent studies such as that by EL-Shurafa et al [14] have highlighted the potential uses of date seed waste, with earlier analyses primarily focused on utilizing date seeds as animal feed [15] in the cattle, sheep, camelina and poultry industries [16] as well as for goats and horses, or other industrial uses.

Recent research on date seeds has focused on finding new ways to use them for human consumption. Studies by researchers such as Devshony et al. [17], Almana and Mahmoud [18], and Ali-Mohamed and Khamis [19] have aimed to use date seeds for pharmaceutical, cosmetic, and nutraceutical applications [20], [21], [22], [23]. This shift in focus from using date seeds for animal feed to using them for human consumption reflects a change in ideology towards finding more sustainable and nutrient-rich food sources in light of current global challenges to food safety and agricultural efficiency.

Scientists in the field of agriculture and food are investigating new ways to incorporate plant by-products, such as date seeds, into the human diet as sources of nutrients. As a result, new food products have been developed that incorporate date seed as an ingredient, including ground beef [24], bakery products [25], [26] chocolate [27], and non-caffeinated drinks [28], [29]. In the Arabian region, roasted date seed powder is used as a caffeine-free alternative to coffee [30] due to the potential negative health effects associated with caffeine consumption, such as increased blood pressure, insomnia, and cardiovascular disease. An infusion made from roasted date palm seeds can be consumed. as an alternative to traditional coffee for those who are allergic to caffeine but still want to enjoy the aroma and flavor of coffee without the adverse effects [31], [32], [33].

The potential of date seeds as a caffeine-free alternative to coffee has been gaining attention in recent years due to the discovery that roasted date seeds contain similar aromatic compounds (aldehydes and alcohols) found in Arabica coffee [34], [35] and are also caffeine-free [29], [30]. To study the quality of date seed coffee, researchers use methods such as chemometrics and spectroscopic techniques.

Chemometrics is a branch of chemistry that uses statistical and mathematical methods to analyze chemical data [36]. When combined with FTIR spectroscopy, chemometricscan be used to extract additional information from the spectra, such as the concentrations of different chemicals in a sample. This can be useful for applications such as quality control, process control, and the identification of unknown compounds.

There are many different chemometric techniques that can be used in combination with FTIR spectroscopy, including multivariate calibration, principal component analysis (PCA), and partial least squares (PLS) regression [37]. These techniques can be used to analyze large sets of spectra and extract information that would be difficult to obtain using traditional methods [38], [39].

FTIR spectroscopy is a technique that uses infrared light to analyze the vibrations of chemical bonds in a sample, while chemometrics is a branch of chemistry that uses statistical and mathematical methods to analyze chemical data. Combining the two can provide greater insights and more accurate results than using either method alone [40].

The goal of this study is to conduct a comparative analysis of coffee extracted from different varieties of date seed using different roasting methods, using FTIR combined with chemometrics and an organoleptic test.

2. MATERIALS AND METHODS

2.1 The studied dates

In the current study, three different varieties of dates were analyzed: Mejhoul, Boufkousse, and Bouslikhene.

Mejhoul, also known as Medjoul or Al Majhoul, is considered the most prized variety. Originally from Morocco, it was first introduced in California in the 1930s before being decimated by Bayoud and reintroduced in Morocco. Mejhoul is a large, soft, and sweet date, weighing between 20 and 30 grams, compared to other varieties that weigh between 6 and 11 grams. The harvest for Mejhoul starts in late July-early August and finishes in October-November. Freezing to between 0° and -2°C in the early season and then to -18°C during the production peak, makes it available year-round [41].

Boufkousse is a variety that is known for its scented and slightly caramelized taste. It is considered the best variety in the Ouarzazate and Zagora region and is believed to have fortifying virtues for women after childbirth. In southern regions, it is also used as baby pacifiers [41].

Bouslikheneis characterized by its medium-dry consistency and pleasant sweet taste [41]. Table 1 shows the different characteristics of each variety of dates, including their geographical distribution, shape, color, and tree productivity. The three varieties are located in Tafilate, with a generally ovoid shape for Mejhoul and opposite for Bouslikhene. Mejhoul has a dark brown coloration, while Bouslikhene has a light coloration. Both Mejhoul and Bouslikhene have a high tree productivity and low fibrous nature.

Table 1- Comparison between the three varieties of studied dates [41]

Characteristic varieties	Mejhoul	Boufkousse	Bouslikhene
Division Geographical	Ziz,extended to theDaraa, Tafilalet, oriental	Draa,Tafilalet, Gerisguir, Anti atlas, Bani, Todra, Ferkala,	Saghro, Tafilalet
Form	Lying ovoid	Ovoid	Opposite ovoid
Color	Dark brown	Dark brown	Light brown
Consistency	Semi-soft	Very high	Semi-dry
Tree productivity	Very high	High	Average
% protein (g / 100g)	2.75	3.35	2.69
Fibrous nature	Low fibrous	Low fibrous	High fibrous

2.2 Date seeds

In this study, palm date fruits of three varieties (Mejhoul, Bouslikhene, and Boufkousse) were collected from a farmer in the Drâa-Tafilalet region of Morocco. A total of 15 date fruits were picked randomly from each type to identify the dimensions and weight (diameter and length) of the seeds.

Dates are single-seeded fruits that are typically ovoid, cylindrical or rounded in shape, with a sweet, fleshy mesocarp coated with a thin epicarp, and a yellowish to brown color [42]. The color of the seeds of Monocotyledonae dates can vary from light brown to dark brown, and they are odorless with a bland taste and slight bitterness [43]. Depending on the variety and quality grade, the weight of the seed in the fully ripe date fruit can range from 5.6-14.2%, 6-12%, 10%, 18.34% [44], [45]. On average, date seeds make up about 10% of the weight of the whole fruit [46], [47].

The weight of date seeds can vary, with a range of 0.5 g to 4 g. Additionally the diameter can range from 0.6 to 1.3 cm, the length of the seeds from 1.2 to 3.6 cm. The shape of the seed is typically oblong, and it contains an embryo. The inside of the walls is made up of hard endosperm, composed of cellulose [48].

2.3 Experimental approaches

The In this study, date seed powder is produced by roasting and grinding the date seeds in a similar manner to coffee beans [49]. The process includes four steps: cleaning, drying, roasting, and grinding. After the date seed powder is ready, an organoleptic test is conducted.

Cleaning: The date flesh and pit are separated, and the seeds are washed to remove any adhering date flesh and to remove the small white film that sometimes remains between the fruit and seed.

Drying: The seeds are dried by removing water through direct contact with ambient air (natural drying) [50].

Roasting: The dried date seeds are roasted, with each variety divided into two parts. One part is roasted in a traditional way using a pottery pan, and the other part is roasted using a modern method using an oven. The roasting time using the traditional method is 8 hours, while the modern method is 20 min at a temperature of 250°C.

Figure2- Traditional roasting

Grinding: After the toasted date seeds are well carbonized, they are crushed in a grinder or blender. The palm date seeds are ground into two fractions: coarse and fine [51]. The final product is date seed powder (fine), but sometimes the coarse powder can also be used.

Figure3- Modern roasting

2.4 Fourier Transform Mid Infrared Spectroscopy (FT-MIR)

It is a technique used to analyze the infrared spectra of a sample. Infrared (IR) spectroscopy is a powerful tool for the characterization of chemical compounds, as different functional groups in a molecule will absorb light at specific wavelengths, known as absorption bands. Is based on the principle of Fourier Transform (FT) spectroscopy, which allows for the conversion of a signal from the time domain to the frequency domain. In FT-MIR, an infrared beam is passed through a sample, and the amount of light absorbed by the sample is measured at different wavelengths. This data is then transformed using a Fourier transform algorithm, which converts it into a spectrum that displays the absorption bands of the compound.

FT-MIR is useful in many fields such as chemistry, biology, pharmaceuticals and materials science. FT-MIR is used for the identification and quantification of chemical compounds, and for the study of the structural and chemical properties of materials. It is also used for the analysis of a wide range of samples, including gases, liquids, and solids, and can be used for both qualitative and quantitative analysis.

The advantage of FT-MIR is that it provides high spectral resolution, and is able to detect even very small amounts of a substance. Additionally, FT-MIR spectra can be easily compared to reference spectra, making it a useful tool for identifying unknown compounds.

The functional groups present in date seed coffee were determined using FT-MIR. The spectra were acquired using a Bruker Vector 22 FT-IR Spectrophotometer with an Attenuated Total Reflectance (ATR) equipped with a DTGS detector, Globar (MIR) Source, and KBr Germanium separator, accessory (Diamond, incident angle 45°, Pike Miracle, Pike Technologies, Madison, USA). The spectra were gathered in the absorbance mode at a resolution of 4 cm-1 with 80 scans, and a total of 21 samples were analyzed in the range of 4000 to 400 cm-1.

2.5 Chemometrics methods

Chemometrics is a field of study that involves the use of mathematical and statistical techniques to analyze chemical data. It is used to extract meaningful information from complex sets of data, such as those obtained from analytical instruments like Fourier Transform Infrared Spectroscopy (FTIR), Nuclear Magnetic Resonance (NMR) and mass spectrometry (MS). Chemometrics methods can be used in various fields, including analytical chemistry, process control, environmental monitoring, and bio-medical research [52].

There are several different chemometric methods that are commonly used, but we will use in this study Principal Component Analysis (PCA) This technique is widely used for data reduction and visualization. It is used to identify patterns in data and to reduce the dimensionality of the data set. PCA is used to identify the underlying factors that explain the variation in the data, and to generate a new set of variables that are uncorrelated and ordered by the amount of variation they explain [53].

2.6 Organoleptic test

The sensory analysis was conducted by a panel of 10 people from the community of teachers and students of the Beni-Mellal Higher School of Technology. The panel underwent a two-hour training session before conducting the study. The panel then identified six main attributes that were used to characterize the studied coffees. Different samples of date seed coffee were distributed in white polystyrene cups and presented to the panel in a randomized order. The experiments were conducted in a dedicated room for evaluation. Water was provided for the panelists to clean their mouths between samples.

The sensory evaluation was conducted according to guidelines outlined in standard norms [54]. After preparing the coffee using an electric coffee maker, the panel evaluated the coffee using a 6-point organoleptic test for color, taste, odor, viscosity, residual taste, and overall acceptability. A numerical scale was used, where zero indicates no intensity and five corresponds to an extreme intensity. A comparison was made between the

three studied varieties and the two roasting methods. A test sheet was prepared to compare the organoleptic characteristics of each coffee variety.

3. RESULTS AND DISCUSSION

3.1 Morphological comparison between studied date seeds

The average diameter of date seeds was found to vary between 0.98 cm for the Boufkousse seed to 1.1 cm for the Mejhoul seed. Additionally, the Mejhoul seed had the highest date seed length at 2.51 cm, while the lowest length of 2.25 cm was observed in the Bouslikhene seed. These results are consistent with previous research by Bouhlali et al. [55] who reported that the length and diameter of date seeds ranged between 2.58-2.75 cm and 0.71-1.15 cm, respectively. The study also revealed that the average weight of 15 samples of date seeds varied from 1.05 to 1.24 g, with the highest seed weight observed in the Mejhoul seed and the lowest in the Boufkousse seed, which is coherent with the findings of Mahawar et al [56].

Table 2- Physical characteristics of date seeds

Varieties	Weight (W) g	Diameter (D) cm	Length (L) cm
Mejhoul	1,55±0.16	1,11±0.07	2,51±0.18
Bouslikhene	1,24±0.15	1±0.06	2,25±0.12
Boufkousse	1,05±0.11	0,98±0.07	2,35±0.11

3.2 Physicochemical characterization of studied date seed coffee by FTIR spectroscopy

This study aims to investigate the chemical composition of three distinct varieties of date seeds through the use of (FTIR), with a specific focus on examining the impact of different roasting methods on the chemical structure of the seeds. It is known that date seeds are composed primarily of hemicellulose, cellulose, and lignin, along with minor components such as proteins and oil. The FTIR spectra of unprocessed date seeds are expected to contain specific functional groups and species as outlined in Table 3 [57]. The findings of the FTIR analysis of the date seeds are in line with previous literature and are presented in Table 4.

Table 3- Chemical composition of date seeds

Constituents	Present (%)
Proteins	5
Oils	8.8
Moistures	8.
Carbohydrates (hemicellulose, cellulose and lignin)	61
Fibers	15.7
Inorganics present	1.4

Table 4- Peak wave numbers of FTIR bands for date seeds, with their assignments based on the literature

Peak wavenumber (cm-1)	Band origin
3367	O–H hydroxyl groups [58]
2924	C–H methyl and methylene groups [59], [60]
2855	C–H methyl and methylene groups, waxes, cutin [61]
1746	C=O either the acetyl, and uronic ester groups of hemicelluloses or the ester linkage of carboxylic groups of the ferulic and p-coumaric acids of lignin and/or hemicelluloses [62], [63]
1616	C=C or C=N vibrations in aromatic region [60], [64]
1522	C=C aromatic skeletal mode [59], [60]
1443	C=C aromatic skeletal mode [59], [60]
1377	C–H s cellulose [60], [65]
1248	C–O–H and C–O of phenolics [66], [67]
1151	C–O–C cellulose and hemicelluloses [68]
1061	C–O cellulose and hemicelluloses [66-68]
870	C–H cellulose [69]

In general, the FTIR spectra of the date seed samples analyzed in this study are similar to each other, with some variations due to the botanical origin and roasting method of the seeds. The FTIR spectrum displays a prominent band in the range of 3600-3100 cm-1, which is assigned to the stretching vibrations of hydroxyl (OH) groups and indicates the presence of water in the date seeds. Strong bands observed between 2970 cm-1 and 2800 cm-1 are associated with symmetrical and asymmetrical C-H bonds in the methyl and methylene groups, and are primarily contributions from hemicellulose and lignin.

The presence of an absorption band in the 1700-1600 cm-1 range is indicative of carbonyl groups in esters, ketones, aldehydes, and acetylated derivatives. The bands at 1616 cm-1 may indicate C=N or C=C vibrations in the aromatic region. In the range of 1300-1080 cm-1, the bands are attributed to O-H and C-O vibrations. The bands around 1050 cm-1 represents the C-O stretching vibrations of hemicellulose and cellulose. The absorption at 870 cm-1 is linked to C-H. A later band observed at 600 cm-1 is associated with O-H in the OH groups, which is lower than the expected region (650 cm-1) where it appears to be non-free and involved in hydrogen bonds.

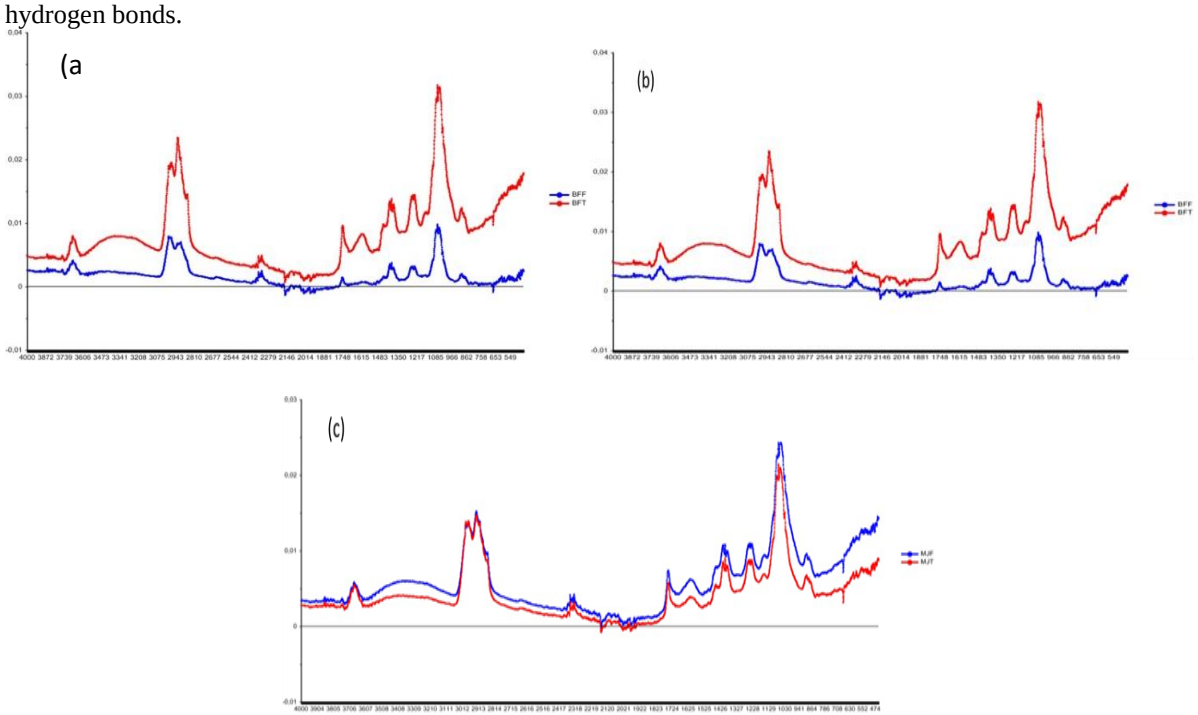

Figure4- ATR-FTIR spectra of roasted date seed samples of each cultivar: (a) Boufkousse “BF”; (b) Bouslikhene “BK” and (c) Mejhoul “MJ”; in two modes of roasting: Traditional “T” and Modern “F”; at MIR region of 4000–400cm-1.

The FTIR spectrum of BFT, as shown in Fig. 4(a), displays strong bands at 3341 cm-1, 2926 cm-1, 2870 cm-1, and 1640 cm-1, which are absent or very weak in the BFF spectrum (Fig.4(b)). This suggests a decrease in the content of water and aliphatic compounds, which is consistent with previous research by El-Hendawy. A strong band at 1520 cm-1 is attributed to C=C vibrations in olefinic double bonds, while the bands at 2900 cm-1 and 1435 cm-1 are attributed to CH species and aromatic stretching structures, respectively. This indicates an increase in aromaticity, possibly due to the decomposition or reinforcement of unsaturated chemical structures.

The bands in the range 400-1400 cm-1 have a smaller intensity than in the BFF spectrum. This change in intensity is likely resulting of the activating action of H2O + N2 at high temperatures. In Fig. 4(b), the disappearance of the strong band at 3400 cm-1 and the decrease in intensity of other bands between 4000 and 400 cm-1 for both roasting modes may explain the lower taste and overall acceptability of the BK variety compared to other date varieties. In Fig. 4(c), the FTIR spectra of the MJ variety show that the O-H stretch functional group are visible by the intense band at 3309 cm-1 for MJT and weak for MJF.

The bands observed between 3018 and 2814 cm-1 have the same intensity for both types. From 1742 cm-1 to 400 cm-1, we see the presence of the same bands for both spectra, but the intensity is higher for MJT than MJF. However, the results are closer to each other than those found for BF.

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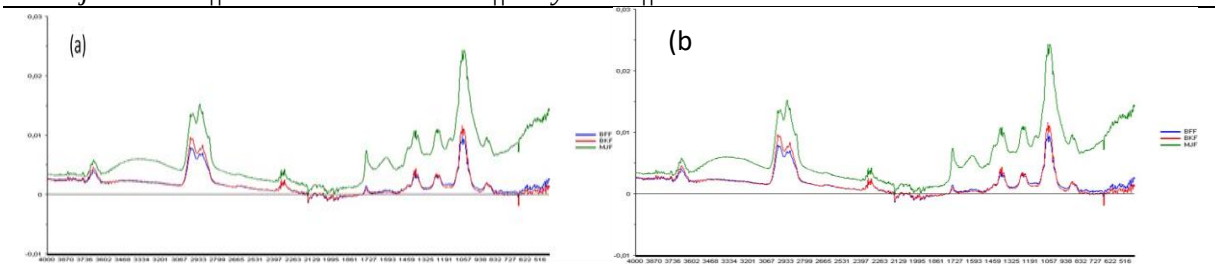

Figure- 5 FTR-FTIR spectra of roasted date seed samples using; (a) modern mode "F", (b) traditional method "T"; at MIR region of 4000–400 cm-1

Fig. 5 (a) illustrates the differences between the FTIR spectra of date seed samples roasted using an oven, specifically BFF, BKF, and MJF. Significant variations were observed in the spectrum of MJF compared to BFF and BKF. The peak of OH groups in the spectrum of MJF got broadened at 3334 cm-1 due to the presence of flavonoids and polyphenolics which are rich in OH groups and glycosides. An intense band at 1523 cm-1 in the aromatic region is also present in the spectrum of MJF but not in the other samples, and other bands of MJF have a higher intensity compared to the spectra of BFF and BKF.

Fig. 5 (b) shows the spectra of date seeds roasted using a traditional method. It can be observed that this mode of roasting improves the intensity of all bands compared with oven roasting. Additionally, the traditional method increases the intensity of bands in BKT samples compared to MJT.

3.3 PCA modeling

3.3.1 Boufkouse samples

The first two principal components explain 91% of the variance, with 76% accounted for by PC1 and 15% by PC2. The results are depicted in the score plots of Fig. 6(a) and loading plots of Fig. 6 (c) and (d). The score plots indicate a clear separation between BFF and BFT, with BFF samples forming a tight cluster compared to BFT samples. The first principal component is the one that differentiates the two groups best. This component is likely related to the quality of roasted date seeds, as can be inferred from the loading plot.

The loading of PC1 (Fig. 6 (c)) has the strongest contribution in the region from 2700-3100 cm-1, specifically at 2919, 2946 and 2852 cm-1. This region is characteristic of O-H in the hydroxyl groups. The bands seen at 2924 cm-1 are attributed to the symmetric and asymmetric C-H bands of the methylene and methyl groups, which are contributions from cellulose, lignin and hemicellulose. In the region 1879-1688 cm-1, an intense band at 1744 cm-1 is attributed to the carbonyl C=O, due to either the uronic ester and acetyl groups of the hemicelluloses or the ester bond of the carboxylic groups.

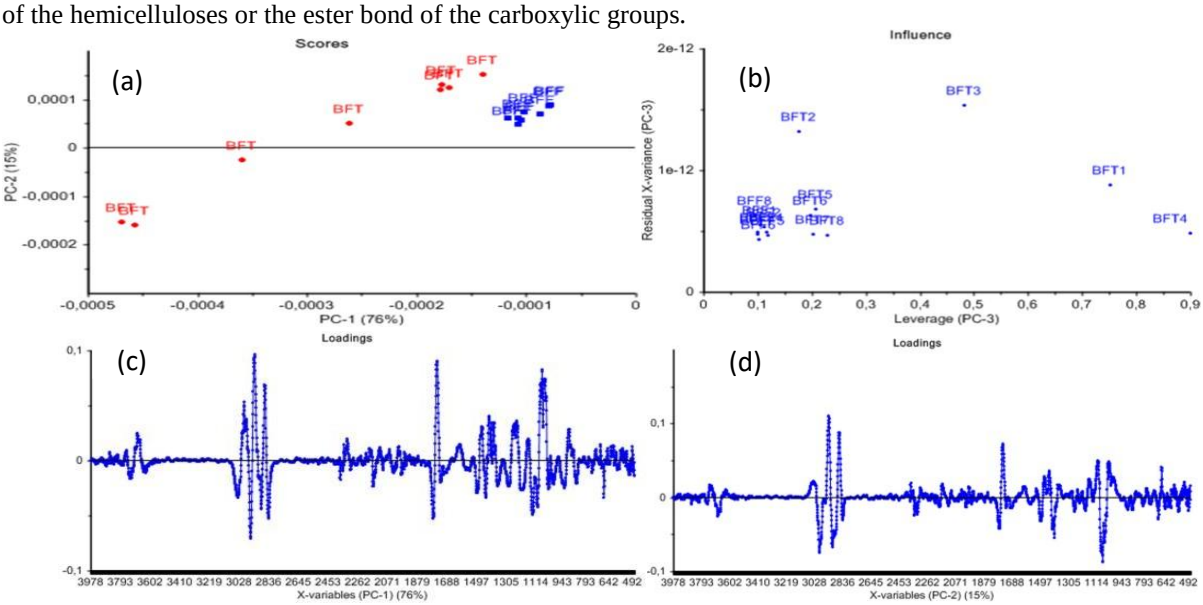

Figure6- a) PCA 2D-score plot of date seed Boufkousse cultivar "BF", (b) Influence PC3, (c) PC1 loadings of BF, (d) PC2 loadings plot of BF

3.3.2 Bouslikhene samples

Principal component analysis (PCA) of FTIR spectra revealed that two principal components explained 97% of the spectral variance. The first component accounted for 96% of the variance, while the second explained1%. The score and loading plots are shown in Fig. 7(a) and (c) respectively. The score plot (Fig. 7(a)) illustrates a clear separation between the two classes of samples, with the first principal component effectively differentiating the two groups. The samples of BK all have negative scores.

The FTIR spectra of BK samples were further analyzed using the PCA loading plot (Fig. 7(c)). The PC1 loading shows similar bands as found in BF Fig. 6(c), however, the intense band at 1744 cm-1 is missing.

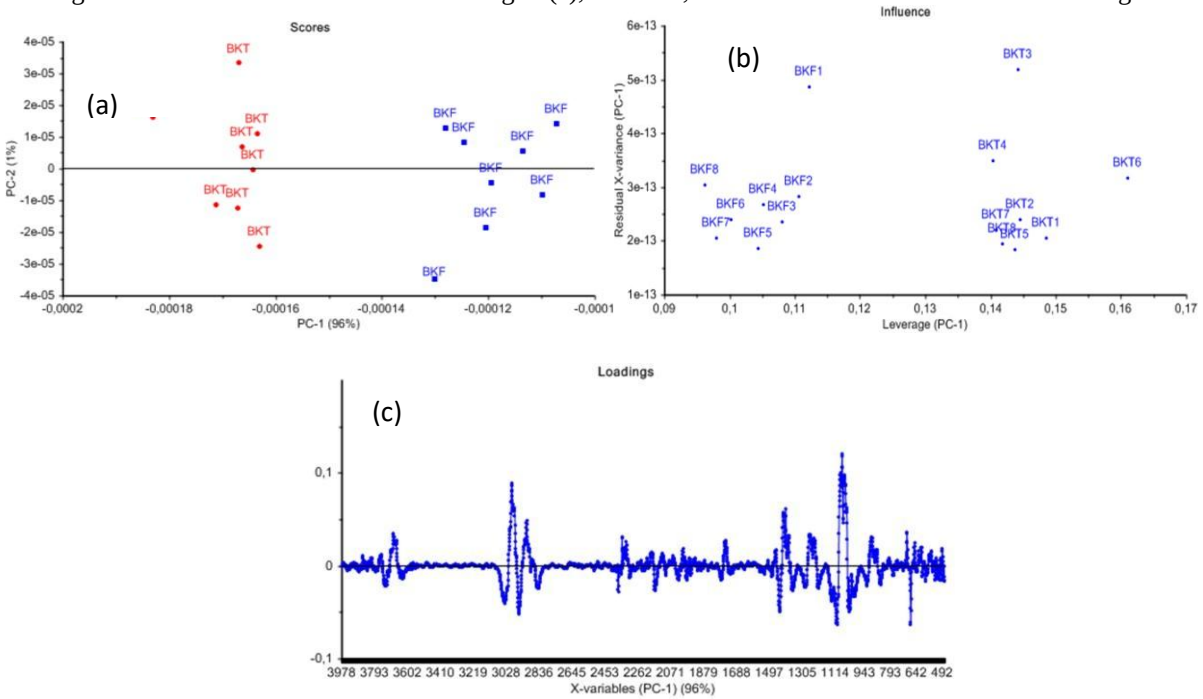

Figure7- (a) PCA 2D-score plot of date seed Bouslikhene cultivar "BK", (b) influence PC1, (c) PC1 loadings of BK

3.3.3 Mejhoul samples

Results of principal component analysis (PCA) for MJ samples are visualized using score and loading plots. Score plots in 2D and 3D (Fig. 8(a) and (b)) were constructed to observe the principal groupings among observations and to identify and remove outliers. The loading plot (Fig. 8 (d) and (e)) indicates the importance of each variable in the model, and is used to interpret the relationships among variables and clusters observed in the score plot. PCA revealed that three principal components explained 99% of the spectral variance. The first component accounted for 82%, while the second and third components explained 16% and 1% respectively.

The results shown in Fig. 8(a) are confirmed by the 3D score plot (Fig. 8(b)) of PCA score plots, and Fig. 8(c) illustrates the influence of the data set on the outliers. The Fig. 8 (d), is a 1D correlation loading plot. The 1D correlation loading plots are especially helpful for the analysis of the important wavelengths in FTIR. PC1 and PC2 show strong bands at (2986, 2988,2921cm-1), (1742 cm-1), and (1065 cm-1) which are associated with cutine and wax, hemicellulose and lipids, and cellulose respectively [70].

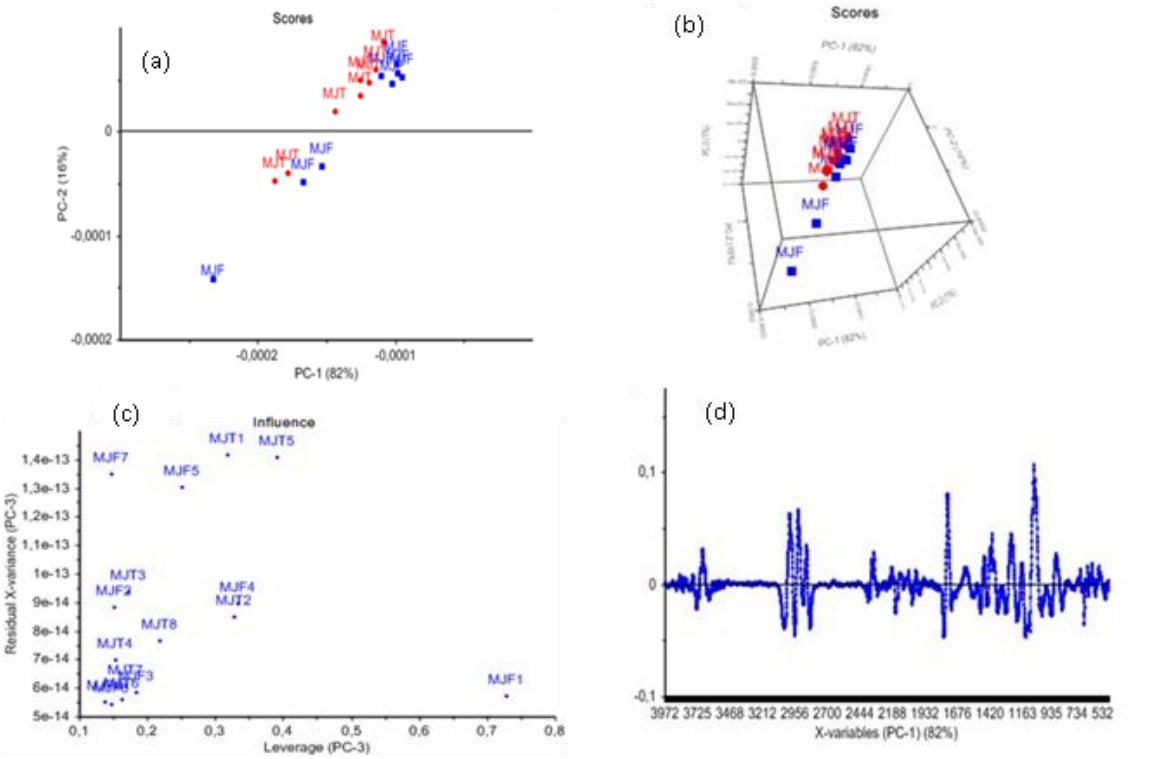

Figure8. (a) PCA 2D-score plot of date seed Mejhoul cultivar "MJ", (b) 3D -score plot of date seed, (c) influence PC3; (d) PC1 loadings of MJ.

3.3.4 Date seeds roasted by oven

The first two principal components explained 99% of the variance, with 83% accounted for by PC1 and 16% by PC2. The results are shown in the score and loading plots, respectively. The score plots clearly separate all the samples, BFF, MJF, and BKF. The majority of samples have negative scores; we mention the presence of an outlier MJF1, which can be clearly seen in Fig. 8 of influence. Both Fig. s 8(a) and 8(b) show a 1D correlation loading plot. These plots are useful for interpreting important wavelengths in spectroscopy analysis. As previously mentioned, a strong band at 1734 cm-1, assigned to the C=O group of hemicellulose and lipids, is absent on the loading of PC1.

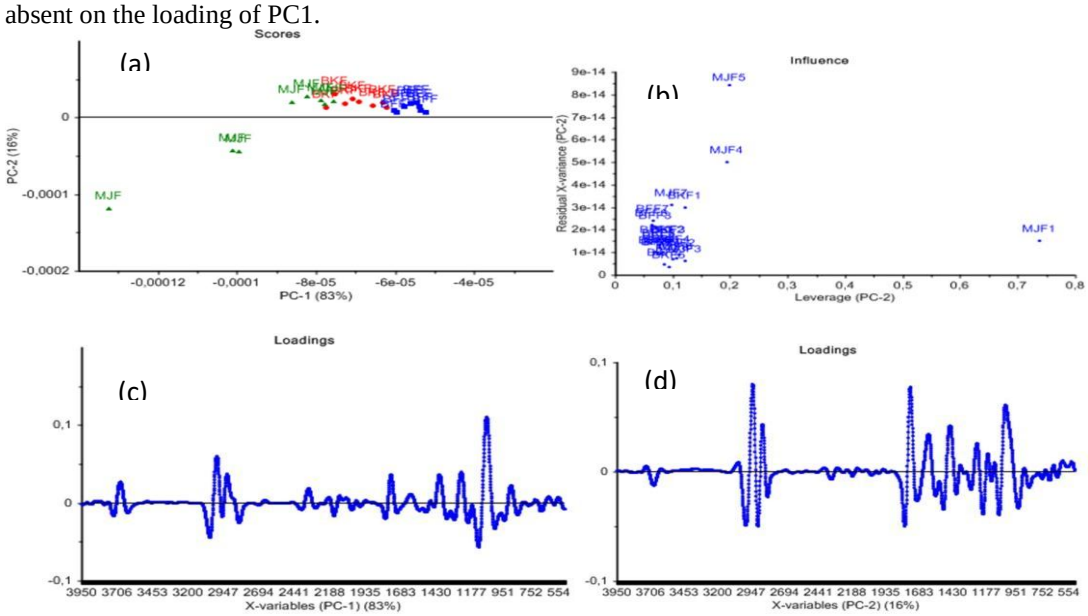

Figure-9 (a) PCA 2D-score plot of oven roasting mode; (b) PC2 influence; (c) PC1 loadings;(d) PC2 loadings

3.3.5 Date seeds roasted by traditional method

As shown in the 3D score plot (Fig. 9), the separation between the three samples is clearly evident. The explained variance (%) obtained from the full cross-validation of the PCR model and three PCs was 100% (86% by PC1, 11% by PC2, and 3% by PC3). The samples of MJT and BKT are grouped together, but BFT samples are spread out in the model. Fig. 9(b) of influence shows that certain samples maybe outliers (BFT1, BFT3, and BFT4).

The ATR-FTIR spectra of traditionally roasted samples were examined using the loading curve (Fig. 9(c), (d), and (e)) of PCA to determine the bandwidths that can be used to distinguish between the samples studied. From the loading plots corresponding to the first three components, we can clearly identify the peaks responsible for the distinctions. The results indicate that PC1 has a strong band at 1053 cm-1 in the region of cellulose, PC2 shows 3 strong bands at 2922 cm-1 (cutine, wax and pectin), 1733 cm-1 (hemicellulose, lipids), and 1006 cm-1 (wags, vinyl), and finally PC3 has an intense band at 2921 cm-1 (cutine, wax and pectin).

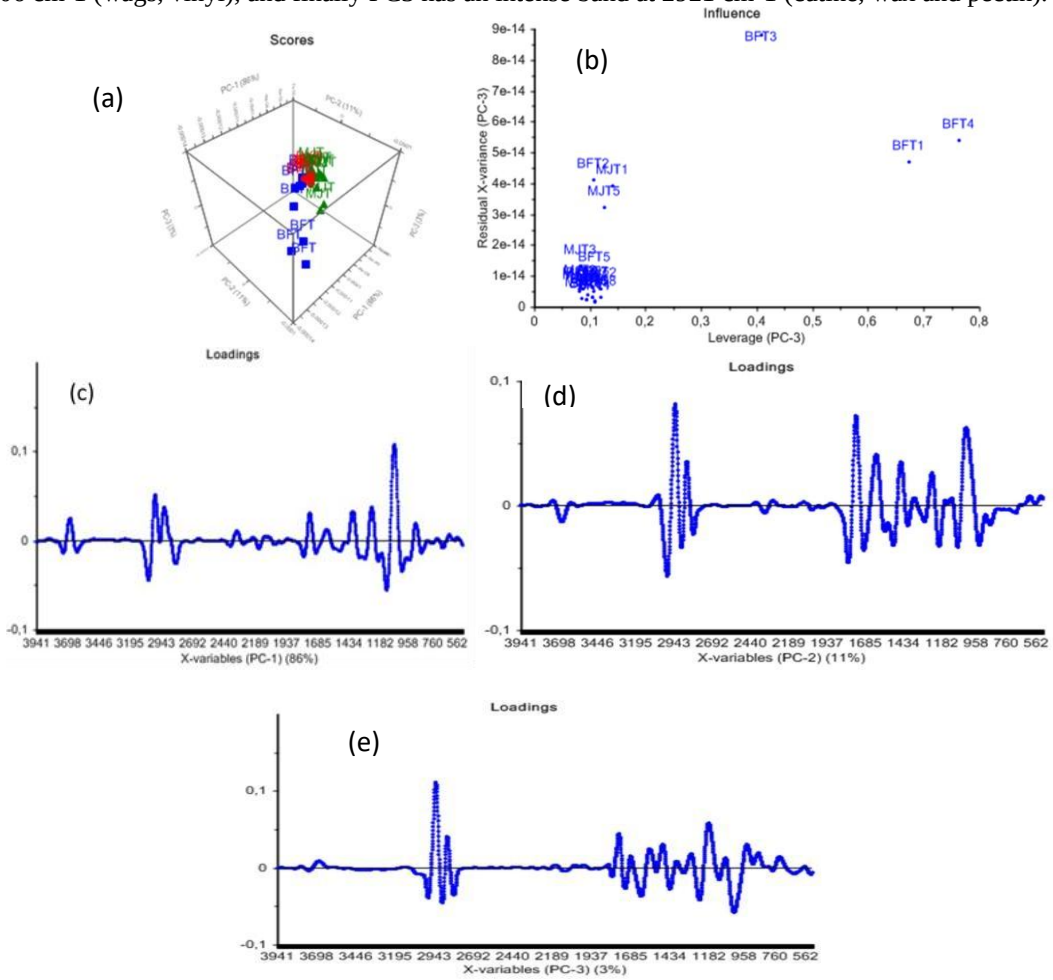

Figure-10 (a) PCA 3D-score plot of traditional roasting mode; (b) PC2 influence; (c) PC1 loadings; (d) PC2 loadings; (e) PC3 loadings

3.3.6 Organoleptic characterization of studied date seed coffee

3.3.6.1 Date seeds roasted by traditional method

Sensory evaluation is an important measure of potential consumer preferences. The differences in sensory quality attributed to the coffee made from date seeds are shown in Fig. 11. The data indicate that the modern roasted date seed drink (Fig. 10(b)) is stronger in color, odor, and viscosity compared to the coffee drink made from date seeds using traditional roasting methods. The coffee made from traditionally roasted date seeds had better taste and overall acceptability (Fig. 10(a)) with some variations due to the different types of date seeds used.

During the traditional roasting process, it was found that panelists preferred coffees made from "Mejhoul" and "Boufkousse" varieties (Fig. 10). Additionally, sensory analysis generally indicates that parameters vary between varieties, with the exception of viscosity, which remains consistent across the three varieties studied.

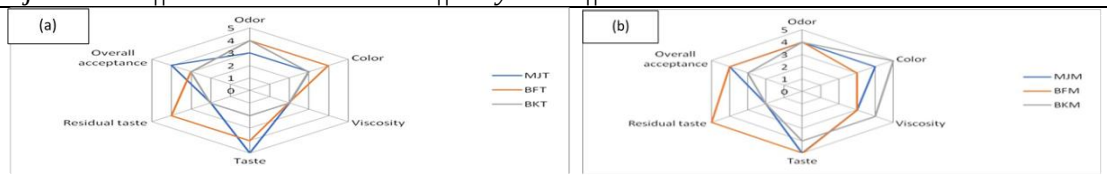

Figure 11-Organoleptic test results for date seed coffee according to roasting mode; (a) traditional method, (b) modern mode.

3.3.6.2 Comparison between the three varieties of coffee

The results of the organoleptic test for the three varieties of date seeds, grouped by roasting methods, are shown in Fig. 11. The first graph (a) shows the results for the "Bouslikhene" variety, which indicate that the taste and overall acceptability are lower than the other varieties. However, the color and viscosity values are considered very important, but only for the coffee roasted using the modern method. This suggests that the Bouslikhene variety provides a date seed coffee with a good color and viscosity.

In Fig. 11 (b), the results for the "Boufkousse" variety reveal that the taste and residual taste are more significant than the other varieties, and that the modern roasting method produces better results than the traditional method.

Finally, in Fig. 11 (c) for the "Mejhoul" variety, the panelists agreed that the odor, color, and viscosity are better for the modern roasting method compared to the traditional method. Additionally, they all recognized that the taste and overall acceptability are good for this variety, regardless of the roasting method.

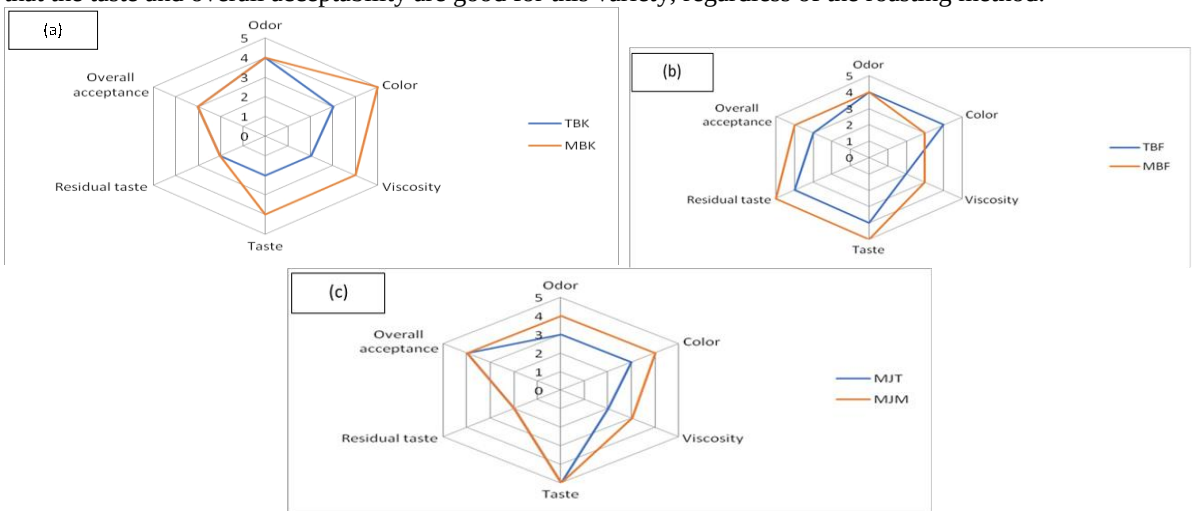

Figure-12 Organoleptic test results for each date seed coffee variety according to roasting mode; (a) Bouslikhen, (b) Boufkousse, (c) Mejhoul.

4. CONCLUSION

The results of this study indicate that the roasting process has a significant impact on the quality of date seed coffee made from three different varieties. Specifically, the use of modern roasting methods resulted in higher scores for certain organoleptic characteristics, such as color and viscosity, compared to traditional roasting methods. Additionally, the use of ATR-FTIR spectroscopy and chemometric tools was successful in characterizing and distinguishing the two roasting modes for the three studied varieties of date seed coffee.

It is important to note that date seeds, which are often considered as agro-waste, have the potential to be used as a source of dietary fiber, phenolic compounds, and antioxidants. Utilizing these by-products for human consumption can help to alleviate both nutritional and economic losses. Future research is needed to further evaluate the potential of date seeds as a source of functional food ingredients.

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