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Utilizing Near-Infrared (NIR) Technology to Predict the Quality Index (Q_i) Model of Barhi Dates Fruit at Khalal Stage Stored in a Controlled Environment

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Abstract: Saudi Arabia is a prominent producers of dates, with 1.6 million tons annually. There is a need to evaluate physical properties and quality of fruits non-destructively and then be modeled and predicted throughout the storage period. The aim of the current study was to generate a quality index (Q_i) and Near-infrared spectra (NIR) models non-destructively to predict properties of Barhi dates fruits including objective and sensory evaluations. The engineering properties of Barhi dates were measured and modeled with quality index (Q_i) based on NIR of fresh Barhi fruits (hardness, color, TSS, pH, and sensory evaluations) and during storage in cold, ambient, and controlled atmosphere (CA) for up to four months. The prediction of Q_i is non- destructively based on NIR utilizing PLSR and ANN data analysis. The results showed that the Q_i generated corresponds with high precision to the characteristics of the examined fruits through the duration of the storage period with R^2 of 0.96. The NIR spectrum proves to be an efficient method to evaluate the Barhi fruits' quality index. where ANN was found to be more suitable than PLSR analysis. Thus, NIR can be utilized to accurately predict the Q_i of fruits quality effectively throughout the handling, processing, transporting, storage, and retail sector supply chain.

Keywords: Barhi dates; Khalal; maturation; quality index; modeling; near infrared (NIR); storage

1. Introduction

Saudi Arabia produces more than 14% of the world's total production of dates, viewing the date palm as the most important fruit tree in country. Barhi dates fruits are tasty, physiologically mature, crisp and firm during the Khalal stage (yellow in color) of maturation [1]. They are also perishable and have a high moisture content of 66% to 75% (wet bases) and water activity 0.95 to 0.97. In this region, Barhi fruits during the Khalal maturation (Bisr) was mainly chosen because of their desirable texture, sweetness, and great flavors [2]. Researchers, food innovators and producers, consumers, and health experts are emphasizing the need for food quality for fruits to be more palatable, healthy, natural, and wholesome.

Fruit losses in farms reached 25% due to the huge production of Barhi dates over a short season and the lack of commercial means to maintain fresh Barhi at its Khalal maturation stage that caused drop of fruit prices during peak season. Towards approaching the end of the season, Barhi prices gradually rise reaching ten times that of average season [3].

Cooling plays a significant role in decreasing biological activities, respiration rate and enzymatic activities, during storage. Several studies have indicated that any delay in cooling harvested fruits leads to water losses of up to 50% [4]. Etiolation of the fruit surface as well as changes in physical qualities (e.g., weight, density, and color) resulted from this water loss. Furthermore, moisture losses may lead to an increase in sugar component [5].

Controlled atmospheric storage ((CA) is a postharvest preservation technique involving the meticulous regulation of the gaseous composition (oxygen, carbon dioxide, and nitrogen) and the environmental conditions (temperature and relative humidity) within enclosed storage facilities. CA storage slows ripening by lowering oxygen levels and increasing carbon dioxide levels, thus

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extending the shelf-life of various fruits and vegetables. Fruit stored in low O_2 atmosphere slow the ripening, but they continued to ripen when left in the air [6]. Successful CA preservation of Barhi fruits was achieved at storage temperature 0 °C where fruits kept fresh for up to 5 months [7] where best quality was attained within the first three months of storage.

Fruit ripening stages may be assessed using smart agriculture technologies, which might help with quality management. Routine measurements of physicochemical properties of foods are expensive and timely consumed to evaluate food quality during the whole chain from harvest to consumers. Frequently methods used to evaluate fruit quality includes: titrable acidity (TA), starch content, pH, soluble solid content (SSC), ratio of SSC to TA, tissue stiffness, and physical features including size, shape, color, and appearance [8]. However, evaluating these elements takes time and mostly causing damage to the sample. It is crucial for commercial management to avoid destructive tests through a quick prediction of food properties during various stages of processing.

The food quality index (Q_i) [9, 10] can describe a theoretical/empirical model developing to describe product general characteristics. In research and commercial applications, objective measures (instrumentally) are favored than sensorial tests. These technologies are more accurate, eliminate arbitrator discrepancies, and provide consumers, businesses, and academics with one standardized language[11]. It is important to track the food quality attributes over time with an effective prediction model such as a quality index to assist food manufacturers and consumers acceptance. After that, additional predictions for the quality index model can be made using a non-destructively testing, namely, near-infrared spectroscopy (NIR).

Using near-infrared spectroscopy (NIR) is a frequent non-destructive detection method for a fast assessment of fruit qualities [12]. In several studies, researchers employed near-infrared (NIR) spectroscopy in an attempt to predict the chemical and physical characteristics of many foods, both in their fresh state and after undergoing processing or storage [13, 14]. Furthermore, spectroscopy and food sensory evaluation have been correlated in a number of research studies [15]. The integration of appropriate statistical analysis with near-infrared (NIR) spectroscopy can be deemed an effective technique for communicating both quantifiable and qualitative aspects of food quality, including its inherent attributes and sensory characteristics. By establishing a comprehensive quality index model that incorporates NIR spectral data, the assessment of food quality can be facilitated and optimized across the entire food chain, from initial production through consumption, while simultaneously accounting for potential variations during shelf life.

NIR models (range 300-2000 nm) were used to estimate soluble sugar concentration in apple fruits with a relatively good R^2 (0.91 to 0.97) [16, 17, 18, 19]. Cherry fruits were assessed for soluble sugar content utilizing NIR spectra at (600–1100 nm) wave length with a standard error 0.75 of (SEP) prediction [20]. For kiwi fruits, physical parameters of SSC and Hue angle were conducted using near-infrared estimation with R^2 (0.82 and 0.93); respectively [21]. NIR spectroscopy was used [22] at (900-1700 nm) to classify Shahani dates into four maturity phases: Kimiri, Khalal, Rutab, and Tamr where R^2 values for moisture content and TSS were (0.98, 0.96; respectively) in the predicted models. According to Gómez [23], mandarin has (6) broadband peaks on its absorption curve. Spectroscopic analysis performed in the near-infrared (NIR) region reveals a significant absorption peak at 672 nm, suggesting the presence of pigments like chlorophyll. The presence of chlorophyll leads to the distinctive green color observed in the fruit.

While PLS (Partial Least Squares) is a classic linear tool in chemometrics, ANNs (Artificial Neural Networks) offer a powerful alternative for modeling complex nonlinear relationships between input and output data. Introduced relatively recently to the field, ANNs are finding diverse applications in chemometrics, including mapping, regression, modeling, clustering, and classification [24]. Notably, their ability to interpret and quantify overlapping peaks and reduce interference effects in mixed spectra makes them particularly valuable for food investigations [25].

There is a need to investigate and quantify both objective and subjective measurements of the fruits quality throughout the storage period of controlled atmospheric storage (CA). The objective of this work was to model a quality index (Q_i) for Barhi fruits that involve sensory and objective assessments, followed by investigating the possibility of forecasting the Q_i using a NIR non-

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destructively. This reduces the acquired money, time, and labor for routine work and sensory evaluation of fresh and stored produce throughout the processing and marketing chain.

2. Materials and Methods

2.1. Fruit samples preparation and storage

Barhi fruits, identified as having reached the Khalal maturity stage, were harvested from a date palm farm situated within the Riyadh region of Saudi Arabia. Thereafter, on the same day, the aforementioned fruits were transported to the food processing laboratory located at King Saud University. After being cleaned gently from dust with compressed air (3 bar), Barhi fruits were sorted to three stages of maturation, ranging from 80 to 100% yellowish. Quality attributes of Barhi fruits were measured and then combined with scanning fruits with NIR spectrum. The fresh Barhi fruits quality was evaluated, then stored at 3 systems; ambient (25 ºC), Cold (1 ºC), and CA (1 ºC with 5%:5% O_2:CO_2, 85% RH) for up to 4 months.

2.2. Sensory Analysis

The sensory quality of both fresh and stored Barhi fruits was assessed by 36 semi-trained panelists from King Saud Univ. at College of Food & Agric. Sciences. The sensory evaluation process were accomplished using the 9-point hedonic table [26, 27]. The selected sensory attributes were taste, texture, color, and general acceptance. The mark of responses were "1" denoting " extremely dislike " while "9" denoting " extremely like."

2.3. Objective Analysis

Digital refractometer (Abbe 5 Refractometer, Bellingham, Stanley (BS), Jena, Germany) was used at room temperature (25°C) to measure the total soluble solids of Barhi fruits (expressed as a percentage) [28]. The color of the Barhi fruits was assessed using a Hunter Lab scan XE and the fundamental color criteria L*, b*, and a*, where L* stands for (brightness/darkness), a* for (redness/greenness), and b* for (blueness/yellowness). Browning index (BI) and total color difference (ΔE) were derived from (L*, a*, and b*) values [29] according to:

$$\Delta E = \sqrt{\left(L^*_0 - L^*\right)^2 + \left(a^*_0 - a^*\right)^2 + \left(b^*_0 - b^*\right)^2} \quad (1)$$

$$BI = \frac{[100 \times (x - 0.31)]}{0.170} \quad (2)$$

where:

$$x = \frac{\left(a^* + 1.75L^*\right)}{\left(5.645L^* + a^* - 3.012b^*\right)} \quad (3)$$

To evaluate the fruits texture, (TA- HDi, Model HD_3128, Stable Micro Systems, Surrey, UK) texture analyzer was utilized. A whole fruit was compressed to a 5 mm depth at speed of 1.5 mm/s. Using the resulting deformation curves of the force-time, the hardness parameter was derived [1].

2.4. Evaluation of the Quality Index (Qi)

The overall quality index (Q_i), which has a range of 0 to 1, is a tool used to model and normalize the variables under study in relation to the controlled variable's minimal value. Normalizations would help to ensure that the data in the quality index is compatible [30]. The formula below can be implemented to normalize the parameters:

$$\hat{x_i} = \frac{x_i - x_{min}}{x_{max} - x_{min}} \quad (4)$$

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Where ($\hat{x}_i$) is defined as the normalized value of the quality parameter (x) where (x_i) is the quality parameter of the measured value, and x_{min} ; x_{max} are the minimum and maximum values of the quality parameter (x); respectively. Calculation of the quality index (Q_i) was according to:

$$Qi = \frac{\sum_{1=1}^{N} \widehat{x_i}}{N} \quad (5)$$

Consequently, normalized sample characteristics and overall sensory acceptability data will be combined in the generated Q_i. Subsequently, these quality index data would be further evaluated via non-destructive NIR spectra in order to predict Q_i and food properties.

2.5. NIR Technique for Assessing Quality Index

Using a portable NIR spectrometer (F- 750, Firmware v_1_2_0 build 7041, Felix Inst., Camas, USA), NIR spectrum of fruits would help to assess sample characteristics as well as Q_i non-destructively. Zeiss MMS1 VIS-NIR spectrometer with an interval of 3 nm was used to set the system. For every fruit sample, optical shot of the F750 were obtained prior to food measurements (sensory evaluation and objective attributes). The F-750 has a reference shutter that, while scanning with the lamp off, makes it possible to account for ambient light and dark current in each measurement. Three scans of the spectrum for each sample were collected and averaged. The three scans of each sample of the spectrum was captured then averaged. Spectra was acquired for a different group of samples at 5 °C for the same serving for the validation procedure. After spectra was recorded all data on F-750 SD card were transferred to a computer for further analysis. Using Data Viewer Software, the imported data was saved as (CSV format) and the spectra was pre-analysed utilizing the Savitzky-Golay 2nd derivative. Following the creation of the calibration model, the data set (272 spectra and 252 samples) were used.

Partial least squares regression (PLSR) and artificial neural network (ANN) analysis tools were used to generate the models of calibration. The spectra are examined as a linear multivariate connection using the PLSR method [31]. Prior to applying the multiple regression model, PLSR finds the high-dimensional vectors (latent variables, LVs) that are used to explain the data's most valuable variation. Exploring subspaces that boost predictor and response variable covariance leads to the discovery of latent variables [32]. The highly developed nonlinear pattern recognition technique known as artificial neural networks (ANNs) can simulate complex biodiversity as well as instrument and environmental variability [33]. In this study, App-Builder v.2.1.7 software (Felix Instr., Camas, USA) was used to examine the estimated data. Based on calibration and validation results, the performance of the prediction would be evaluated using correlation coefficient (R^2), square error of root mean in calibration (RMSEC), and cross validation (RMSECV) [14].

2.6. Statistics and analysis

Utilizing a statistical software (SAS, V. 9.2, Cary, NC, USA), all objectively measured attributes were examined. Felix F750 AppBuilder v.2.1.7 software)was used to predict the performance of both calibration and cross- validation findings. Microsoft Office 365 was used to create graphs, plots, and other calculations.

3. Results

Based on the Barhi dates characteristics, the fruits shelf life objectively and subjectively were evaluated, then the quality index and NIR spectra were modeled.

3.1. Sensory Evaluation

Sample Selection

Fresh Barhi dates fruits (80–100% yellowish) were sensory evaluated by thirty-six evaluators. To conduct the planned sensory evaluation, safety and health precautions were taken. The average

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sensory evaluations of Barhi fruit characteristics by judges were displayed in Table 1 which shows the significant variations determined utilizing Duncan multiple choice ($p < 0.05$)

Table 1. Sensorial analysis of fresh Barhi fruits at several maturity levels*.

#	Ripening stage	Texture	Taste	Color	Overall Acceptance
1	**(80% yellowish)**	8.9 ± 0.41[a]	7 ± 0.08[b]	6.9 ± 1.06[b]	6.8 ± 1.08[b]
2	**(90% yellowish)**	8.4 ± 1.01[ab]	8.7 ± 0.86[a]	8.9 ± 0.49[a]	8.5 ± 0.38[a]
3	**(100% yellowish)**	8.2 ± 0.21[b]	8.8 ± 0.97[a]	8.8 ± 0.69[a]	8.5 ± 0.44[a]

* Average values within a column with same letters are not significant different at $p < 0.05$.

Table 1 shows that the two most popular samples were 90% and 100% fruit yellowish. However, 90% yellowish dates would be favored compared to 100% yellow fruits to delay ripening and extending the shelf life of the stored fruits. Table 1 shows that harvesting time (stage of maturity) had a significant influence ($p<0.05$) for all sensory acceptance parameters in which 80% yellowish date fruits were the least liked taste, color, and overall acceptance. Therefore, the recommended 90% yellowish date fruits were selected for the shelf-life storage for up to three months (120 days (CA), 40 days (cold), and 20 days (ambient, marketing temperature) based on their physical and sensory characteristics.

Sensory assessment of fruits during storage

Table 2 shows average of sensory attributes of the Barhi samples during the storage period of up to 120 days (CA), 40 days (cold) and 20 days (ambient conditions). The periods of storage were determined based on when 50% of the samples deteriorated. During storage, the sensory scores for the qualitative attributes (taste, texture, color , and overall acceptance) for all samples decreased over time. This indicated that the Barhi fruits deteriorate with storage. At the end for each of the storage period, the color scores in CA, cold, and ambient decreased from 8.9 to 3.30, 3.45 and 3.52 while texture assessments decreased from 8.4 to 3.13, 3.06 and 3.20 where taste average scores decreased from 8.7 to 3.8, 4.05 and 3.89; respectively. Furthermore, the evaluations for (overall acceptance) decreased from 8.5 to 2.84, 3.83 and 3.70, respectively. It can be noted, however, that fruit quality was much better at CA during storage compared to cold and ambient conditions for the 40 and 20 days storage periods., respectively

Table 2. Variance analysis for the effect of storage period on the sensory assessment of Barhi fruits *,**.

Days	storage	texture	taste	color	Overall acceptance
0	CA	8.4 ± 1.01[a]	8.7 ± 0.86[a]	8.9 ± 0.49[a]	8.5 ± 0.58[a]
	Cold	8.4 ± 1.01[a]	8.7 ± 0.86[a]	8.9 ± 0.49[a]	8.5 ± 0.58[a]
	25 ºC	8.4 ± 1.01[a]	8.7 ± 0.86[a]	8.9 ± 0.49[a]	8.5 ± 0.58[a]
20	CA	7.02±0.61[a]	7.5±0.54[a]	7.12 ±0.05[ab]	7.42±0.79[ab]
	Cold	6.52±0.41[ab]	6.74±0.93[abc]	6.94±0.52[ab]	6.64±0.39[abc]
	25 ºC	3.20±0.64[de]	3.89±0.71[de]	3.52±0.29[e]	3.70±0.43[e]
40	CA	6.44±0.81[ab]	6.89±1.02[ab]	6.31±0.25[bc]	6.78±0.27[ab]
	Cold	3.06±1.04[e]	4.05±0.13[de]	3.45±0.69[e]	3.83±0.57[de]
	25 ºC	N/ A	N/ A	N/ A	N/ A
60	CA	5.64±0.97[bc]	6.31±0.52[bc]	5.53±1.12[cd]	6.44±0.87[bc]
	Cold	N/ A	N/ A	N/ A	N/ A
	25 ºC	N/ A	N/ A	N/ A	N/ A
80	CA	5.1±0.93[c]	5.70±1.62[c]	4.87±1.03[d]	5.63±1.62[c]
	Cold	N/ A	N/ A	N/ A	N/ A
	25 ºC	N/ A	N/ A	N/ A	N/ A
100	CA	4.14±1.07[d]	4.79±0.71[d]	3.93±0.94[e]	4.70±0.92[d]

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	Cold	N/ A	N/ A	N/ A	N/ A
	25 ºC	N/ A	N/ A	N/ A	N/ A
	CA	3.13±0.79^{e}	3.80±0.09^{e}	3.30±0.82^{e}	3.84±0.19^{de}
120	Cold	N/ A	N/ A	N/ A	N/ A
	25 ºC	N/ A	N/ A	N/ A	N/ A

* Average values within a column of a group with same letters are not significant different at $p < 0.05$. ** *(N/ A): not applicable due to fruit deterioration (50% or more).*

3.2. Evaluation of Barhi fruits physical properties during storage

Table 3 shows the influence of storage time on the physical properties of Barhi fruits. The TSS% scores for CA, Cold, and ambient (25 °C) increased from 20.31 to 24.12, 23.39, and 25.03 % respectively, at the end of storage duration which reflects the loss of moisture during storage. ΔE increased from 0 (control, fresh fruit) to 11.68, 11.28, and 12.16 where the average BI score increased from 83.31 to 89.45, 91.45, and 89.76, for CA, cold, and ambient storage; respectively. Furthermore, the hardness decreased from 99.81 to 73.59, 76.85, and 52.29 N where MC% decreased from 70.99 to 62.64, 62.58, and 60.91% for CA, cold, and ambient storage; respectively. This reflects the gradual deterioration of fruits during storage but at different rates based on storage conditions.

Table 3. Variance analysis for the influence of storage duration on the objective characteristics of Barhi fruits *, **.

Days	Storage	TSS	ΔE	BI	Hardness (N)	MC %
	CA	20.31±1.08^{d}	0^{g}	83.31±0.64^{g}	99.81±0.06^{a}	70.99±0.36^{a}
0	Cold	20.31±1.08^{d}	0^{g}	83.31±0.64^{g}	99.81±0.06^{a}	70.99±0.36^{a}
	25 ºC	20.31±1.08^{d}	0^{g}	83.31±0.64^{g}	99.81±0.06^{a}	70.99±0.36^{a}
	CA	20.46±0.35^{d}	6.80±0.79^{f}	83.33±0.06^{d}	98.52±0.63^{a}	68.35±0.91^{b}
20	Cold	21.56±1.21^{d}	9.06±0.02^{e}	87.21±0.39^{b}	83.65±1.20^{d}	65.25±0.89^{d}
	25 ºC	25.03±1.26^{a}	12.16±0.06^{a}	89.76±0.63^{g}	52.29±1.64^{g}	60.91±0.94^{g}
	CA	20.69±0.86^{d}	9.36±0.08^{de}	83.71±0.16^{a}	95.52±0.43^{b}	66.27±0.49^{c}
40	Cold	23.39±1.13^{bc}	11.28±0.04^{bc}	91.45±0.67^{f}	76.85±0.92^{e}	62.58±0.39^{f}
	25 ºC	N/ A	N/ A	N/ A	N/ A	N/ A
	CA	21.22±0.73^{d}	9.95±0.82^{d}	84.60±0.67^{e}	95.49±0.92^{b}	65.72±0.71^{cd}
60	Cold	N/ A	N/ A	N/ A	N/ A	N/ A
	25 ºC	N/ A	N/ A	N/ A	N/ A	N/ A
	CA	21.58±1.06^{d}	10.93±0.49^{c}	86.21±0.92^{c}	88.15±0.26^{c}	65.35±0.84^{d}
80	Cold	N/ A	N/ A	N/ A	N/ A	N/ A
	25 ºC	N/ A	N/ A	N/ A	N/ A	N/ A
	CA	22.64±0.96^{c}	11.48±0.63^{b}	87.94±0.08^{b}	84.18±0.07^{d}	64.13±0.53^{e}
100	Cold	N/ A	N/ A	N/ A	N/ A	N/ A
	25 ºC	N/ A	N/ A	N/ A	N/ A	N/ A
	CA	24.12±1.16^{ab}	11.68±0.37^{ab}	89.45±0.83^{ab}	73.59±1.21^{f}	62.64±0.19^{f}
120	Cold	N/ A	N/ A	N/ A	N/ A	N/ A
	25 ºC	N/ A	N/ A	N/ A	N/ A	N/ A

* Average values within a column of a group with same letters are not significant different at $p < 0.05$. ** *(N/ A): not applicable due to fruit deterioration (50% or more).*

3.3. Modeling of Quality Index (Q_i)

The fruits quality index (Q_i) for Barhi evaluates standard deviation of 10 characteristics, five of which are sensorial and five are physical. The Barhi fruits displayed consistent and ongoing changes for all assessed parameters during the storage period, as presented in Figure 1. The Barhi fruits index of modeled quality began with a value of 0.85 and decreased to 0.38 at the end of the storage time.

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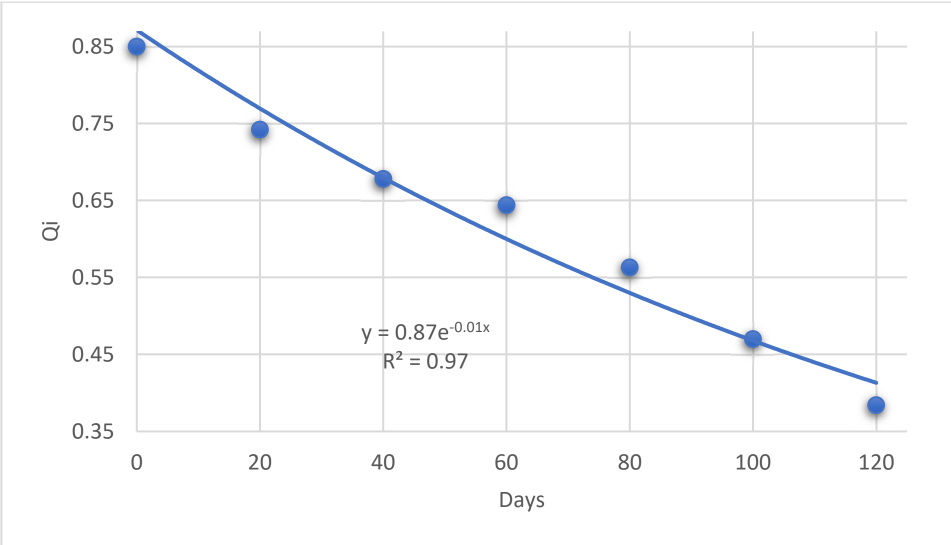

Figure 1. Normalized Q_i of Barhi fruits during controlled atmospheric storage.

The following model (with $R^2 = 0.97$) established a relationship of the normalized Q_i and with duration of shelf-life (days). The power law model could be used to analyze a food product's sensory evaluation [34]. Thus, the relationship between quality index (Q_i) and the shelf life is as follows:

$$\mathbf{Q_i = 0.87e^{-0.01\ Days}} \quad (6)$$

Once the power function's exponent approaching less than 1.0, the overall acceptance exhibited a downward curve in relation to the normalized quality index, and rose more slowly as the quality index increased.

It can be stated that the quality index aided in providing a reference for the actual shelf life of Barhi fruits. Furthermore, authorities may utilize Q_i as a powerful tool to evaluate and determine the actual quality during the shelf life of Barhi fruits throughout the production, transportation, storage, and retail chain at tolerable precision.

3.4. Quality Index Modeling (Q_i) with NIR spectra

The NIR technology has recently acquired popularity in food applications for linking the spectrophotometer waves absorbance and reflectance with the physiochemical characteristics of fruit ingredients. To gain superior performance and powerful models, NIR spectrum data must be pre-processed. These derivatives can be quite beneficial in near infrared spectrum to eliminate some improper signals from the spectrum [35]. The second derivative of NIR spectra was determined in this work. Figure (2) shows the average second derivative of spectra absorbance for date fruits shelf-life period within the wavelength shown.

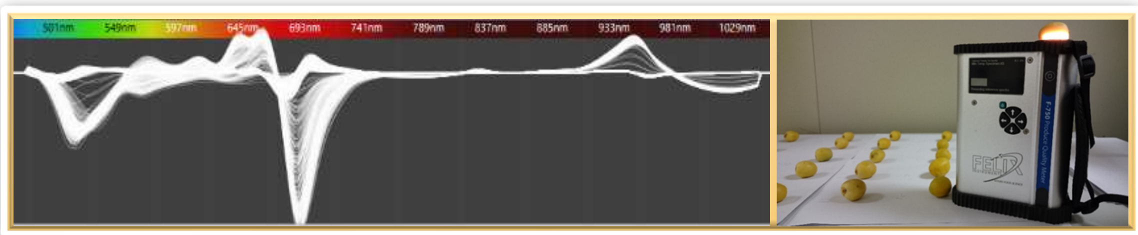

Figure 2. Spectra view of 1000 samples of Barhi dates at the different maturity stages utilizing the Flex F750 instrument.

The spectrum reflectance were typically in the visible region (from 475 to 650 nm) [36]. Figure 3 depicts the spectra (reflectance (R)) with the longest storage span being 120 days where Figure 4

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shows the 2nd derivative of Barhi fruit spectra absorbance at different storage periods along the storage span of 120 days. It can be seen the distinctive variations of reflectance and 2nd derivative absorbance curves for the fruit quality along the wavelength spectra during storage periods.

NIR spectra will be further analyzed utilizing two powerful tools, namely PLSR and ANN, then will be modeled with quality index (Q_i).

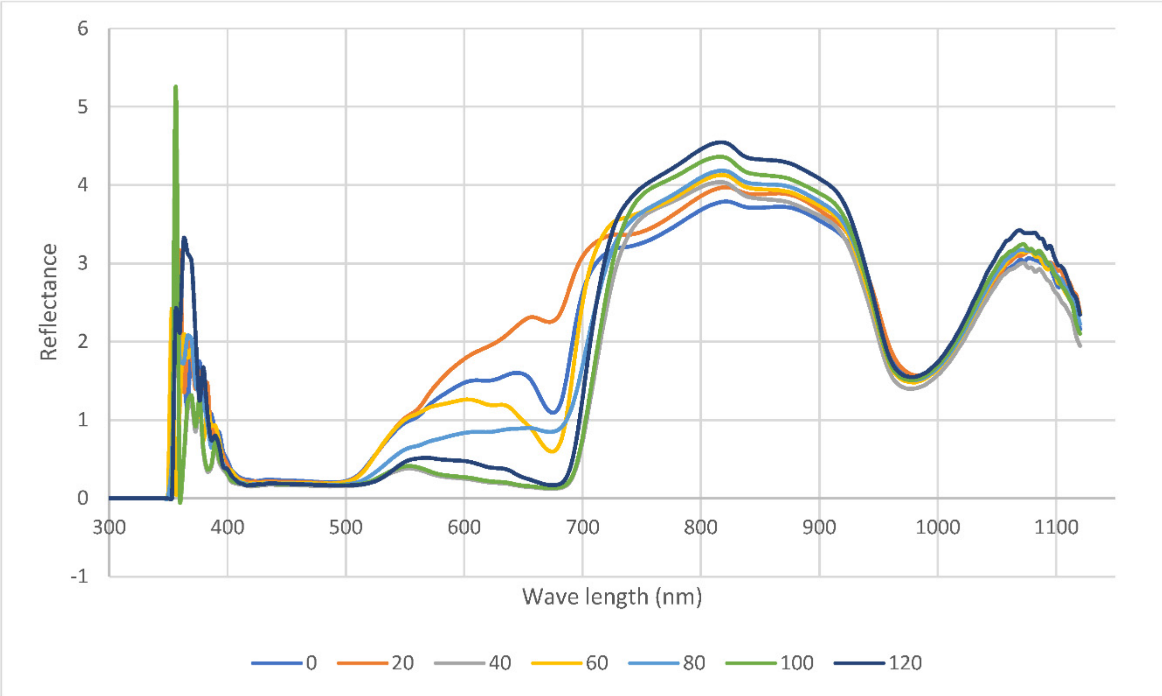

Figure 3. Reflectance spectra of different storage periods from fresh (0 days) to 120 days of Barhi fruit.

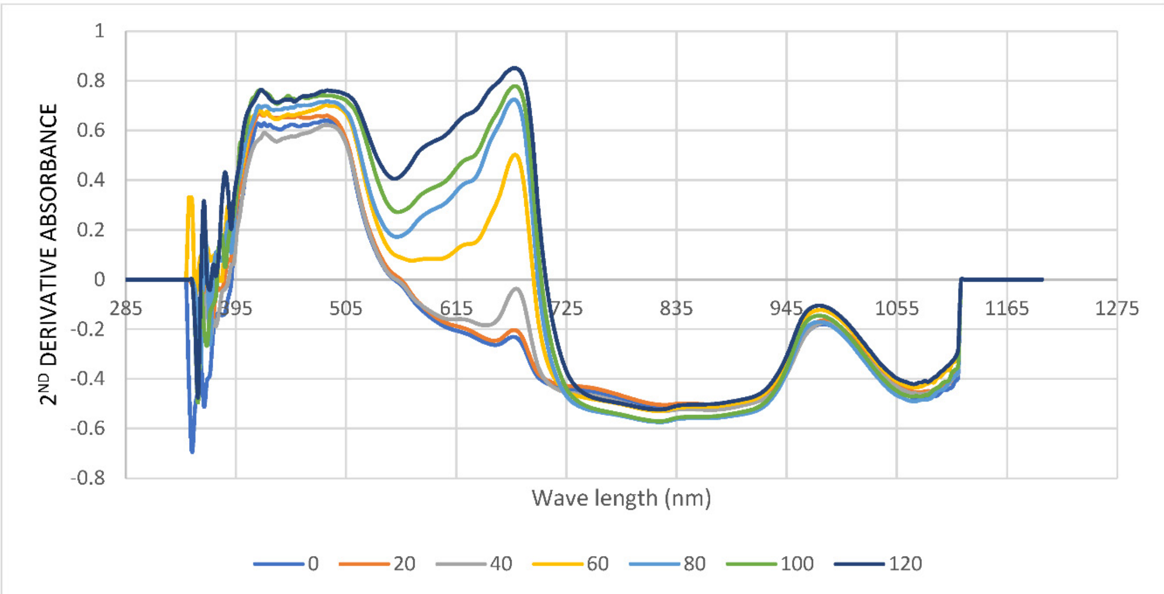

Figure 4. The 2nd derivative absorbance of Barhi date fruits at different storage periods from fresh (0 days) to 120 days.

Partial Least Squares Regression (PLSR)

Table 4 presents cross-validation analysis and the calibration of PLSR for the Barhi fruits physical properties of TSS, ΔE, BI, Hardness, MC, as well as Q_i characteristics. In the calibration models, R^2

and RMSEC were 0.979, 0.659 for TSS, 0.961, 0.994 for ΔE, 0.881, 0.978 for BI, 0.903, 0.708 for hardness, 0.902, 2.119 for MC%, and 0.793, 0.110 for Q_i; respectively.

Table 4. Performance of PLSR for Barhi fruits for both cross-validation models and calibration for TSS, ΔE, BI, Hardness, MC, and Qi.

Parameter	Calibration		Cross- validation	
	R^2	RMSRC	R^2	RMSECV
TSS	0.979	0.659	0.910	0.758
ΔE	0.961	0.994	0.912	0.979
BI	0.881	0.978	0.882	0.902
Hardness	0.903	0.708	0.893	0.777
MC	0.902	2.119	0.901	1.921
Q_i	0.793	0.110	0.783	0.298

In cross-validation analysis, R^2 and RMSECV were 0.910, 0.758 for TSS, 0.912, 0.979 for ΔE, 0.882, 0.902 for BI, 0.893, 0.777 for hardness, 0.901, 1.921 for MC%, and 0.783, 0.298 for Q_i; respectively. The coefficient of correlation (R^2) data was in range between 0.793 and 0.979. Such range proves a powerful performance of the model, with R^2 greater than 0.70 regarded satisfactory in NIR models [37, 38]. This implies that the PLSR analysis is an effective statistical means for predicting both subjective and objective Barhi fruit quality indicators.

Artificial Neural Networks analysis(ANN)

The performance analysis of ANN for each calibration and cross-validation of the Barhi fruits characteristics is showed in Table 5. In the calibration models, R^2 and RMSEC were 0.981and .0.857 for TSS, 0.950, 1.093 for ΔE, 0.891,0.681for BI, 0.891, 0.747 for hardness, 0.901, 1.82 for MC%, and 0.912, 0.308 for Q_i; respectively. Moreover, cross-validation performance, R^2 and RMSECV were 0.979, 0.705 for TSS, 0.949, 0.989 for ΔE, 0.889, 0.605 for BI, 0.893, 0.708 for hardness, 0.901, 1.129 for MC%, 0.912,0.308 for Q_i; respectively. The results showed that the ANN analysis is a powerful tool for estimation Barhi dates properties. It is interesting to note that compared to the PLSR model, the ANN model is typically better suited for predicting Barhi characteristics, as shown by the higher correlation coefficients of the ANN analysis.

Table 5. The model performance of ANNs for both calibration and cross-validation for ΔE, TSS, BI, Hardness, MC, and Qi of Barhi fruits .

Parameter,	Calibration,		Cross- validation,	
	R^2	RMSRC	R^2	RMSECV
TSS	0.981	0.857	0.979	0.705
ΔE	0.950	1.093	0.949	0.989
BI	0.891	0.681	0.889	0.605
Hardness	0.891	0.747	0.893	0.708
MC	0.901	1.822	0.901	1.129
Q_i	0.912	0.308	0.912	0.308

RMSEC is a parameter that indicates how well the calibration model coincides with the calibration set. With the increases number of components, RMSEC decreases. The RMSECV, on the other hand, grows as more components are included. Compared to RMSEC, RMSECV is a more accurate prediction of future model performance [39]. Therefore, in terms of calibration and cross-validation, the two analysis methods (PLSR and ANN) can be useful tools for modeling NIR data.

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3.7. Performance of Prediction Models of Barhi Quality during Storage

As indicated above, an excellent model performance is achieved with R^2 values greater than 0.70, in which values ranging from 0.50 to 0.69 indicated a fair model performance [40]. The findings of this study indicate the feasibility of correlating non-destructive parameters (Q_i, and NIR) with sensory estimating and texture parameters (Hardness, N) of Barhi samples at any storage time. This can be utilized in a commercial online fruit sorting instrumentation using NIR instrumentation and Q_i to predict the texture of fruit non-destructively.

Figure 5 shows a comparison of subjective (sensory predicted by Q_i) and objective TPA hardness tests. Both tests' curves showed a similar trend in a decrease with storage time. This indicates a link between the sensory, objective utilizing Q_i and NIR spectrums can be implemented in automation process of quality assurance.

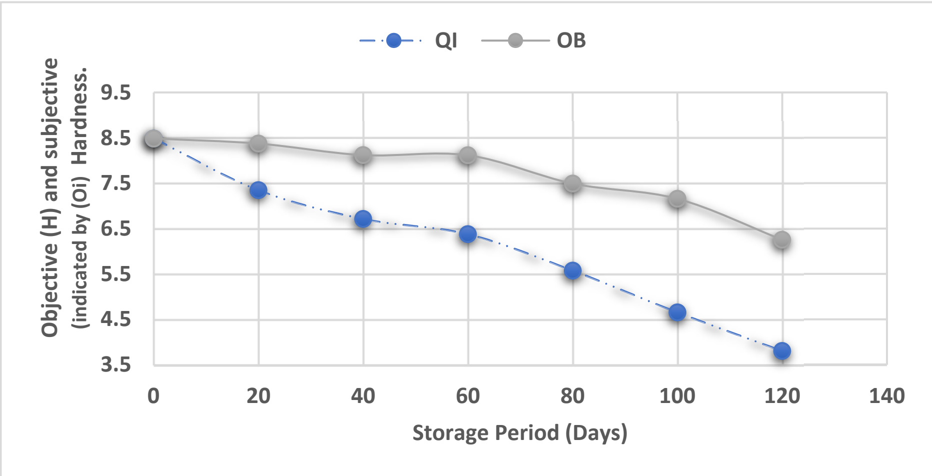

Figure 5. Subjective (Qi) and objective hardness during storage at CA (5%O2, 5%CO2, 80%RH), H: hardness × 1/11.76 ; Q_i: quality index*10.

Figure 6 (a) showed predicted Q_i and measured objective hardness. The correlation between these parameters was particularly good with a correlation coefficient of R^2 = 0.902. Figure 6 (b) showed a good relation between sensorial and objective texture (hardness estimation) with a correlation coefficient of R^2 = 0.850.

Figure 5 (c) showed the relation between NIR estimation and measured objective hardness with a correlation coefficient R^2 = 0.905. This result proves how well NIR spectroscopy can correlated with textural measurements of Barhi fruits at different stages of maturity. Furthermore, this suggests that automated sorting of Barhi dates non-destructively based on fruit firmness is applicable using a near infrared spectroscopy. This can be used to help for marketing; for example fruit of less mature and relatively hard texture assigned to long-distance/international markets, while intermediate mature (mild texture) fruits assigned to intermediate distances, where soft fruits for immediate marketing in regional/local stores.

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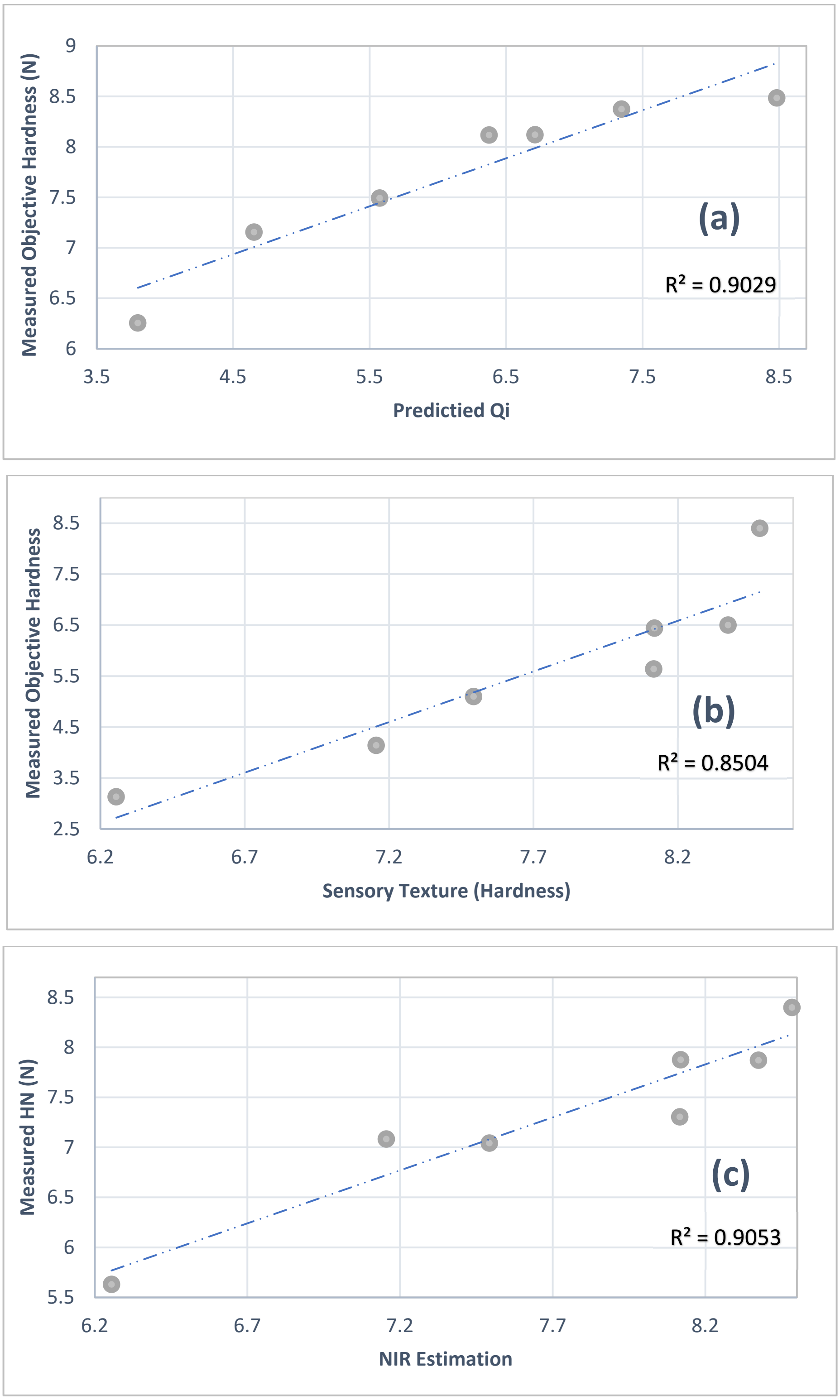

Figure 6. (a) Predicted Q_i and measured objective hardness, (b) sensory texture and measured objective hardness, and (c) relation between NIR estimation and measured objective hardness (H). H: hardness × 1/11.76 Q_i: quality index*10.

4. Discussion

According to the samples sensory analysis results , the acceptability of the arbitrators increases with fruit maturation. This is consistent with an increase in fruit maturity effect on sweetness (and, consequently, taste). These results agreed with earlier studies on the influence of harvesting stage on the storage duration of Barhi fruits [41] with ranges 60 to 80% MC, 20 to 35% TSS, and yellow to green color based on sensory estimation that affect consumer acceptance of Barhi fruits during maturation process.

The preservation in the CA storage achieved the longest shelf-life compared to cold and ambient storages based on Barhi fruits sensory assessment in which CA can delay the deterioration up to 120 days. At ambient environment, the samples had the shorted shelf-life. This could be attributed to the accelerated enzyme activities and texture softening at room temperature that affect Barhi fruits quality during such storage [42].

The increase of TSS of fruits throughout the storage probably due to the loss of moisture and more polysaccharides being enzymatically converted to simple sugars [43]. The observed color variations and alterations may be related to differences in the enzymatic oxidation of phenolic chemicals. The cell structure of date flesh changes due to dehydration during storage and thus increases various enzymatic oxidation of phenolic compounds [44]. Several studies [45, 46, 44] showed comparable results to this study. Hardness weakened during storage might related to cellular disintegration, which causes membrane porosity, or to the conversion of insoluble particles into soluble solids [47].

In NIR cross-validation performance, (R^2) were higher than 0.79 which indicates a strong model performance, in which R^2 greater than 0.70 regarded satisfactory in NIR models [37, 38]. The ANN model's correlation coefficients are clearly greater than that of PLSR model, especially when considering the normalized quality index parameter. Therefore, it is advised that Q_i estimation would be dependent on the ANN technique with (R^2 = 0.891-0.981) rather than PLSR technique (R^2 = 0.792-0.979).

The quality index (Q_i) of sensory and physical attributes simplified the assessment and comparison of products qualities, utilizing a non-destructive and simple NIR technique As a result of the analyses in this work, NIR interrelated well with quality index and hence with the Barhi fruits unique features. In general, Q_i can predict the fruit quality throughout the storage duration of Barhi dates and set by standard authorities [48]. Thus, portable NIR spectra meter can be a helpful tool in the field by producers, manufacturers, storage, transportation, market, authorities, and throughout the entire chain to confirm the "quality" and "shelf life" of the commodities.

5. Conclusions

The generated Barhi quality index (Q_i) in this study provides an approximate estimation of fruit quality during its storage duration. This approach provides a quick, non-destructive, and reliable method for evaluating quality that is simple to apply across the entire chain of processing, storage, and marketing chains. The NIR analysis correlated the absorbance and reflectance of spectrophotometer waves to the physical characteristics of food products. During the shelf life, both sensory and objective measurements can be followed and evaluated with the quality index (Q_i) and immediately measured by an NIR analyzer. Both (PLSR) partial least-square regression and (ANN) artificial neural network analyses were helpful to examine NIR validity.

NIR successfully predicted Q_i and fits well with normalized measured sample properties (total soluble solids (TSS), color (ΔE and Bi), texture (hardness), moisture content (MC%) and sensory evaluation during the shelf-life period. NIR spectroscopy was helpful in estimating the quality index of Barhi fruits in calibration and cross validation with an R^2 range (0.891 - 0.981).

In conclusion, NIR spectrophotometry can predict Q_i non-destructively and can thus be used successfully by authorities, product manufacturers, processors, and throughout the entire production, processing, transport, preservation, and retail market chain to assess the "quality" along the "shelf life" of the commodity.

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