Research article

Postharvest quality assessment of apple during storage at ambient temperature

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ABSTRACT

In this study, the physical and chemical quality attributes of apples were measured experimentally during the storage after harvesting, using well-defined procedures and techniques. Overall quality index (OQi) models were formulated in terms of measured quality attributes. Firmness (F) and total soluble solids (TSS) varied from 11.88 ± 0.25 to 7.68 ± 0.24 N and 14.1 ± 0.1 to 12.7 ± 0.1 % Brix, respectively, whereas acidity and density varied from 0.163 ± 0.003 to 0.081 ± 0.001 % and 0.995 ± 0.003 to 0.951 ± 0.004 gm/cm^3, respectively. The gloss values at $45°$ and $60°$ angles of incidence were found to be in the range of 7.9 ± 0.2 to 4.1 ± 0.3 and 6.8 ± 0.1 to 2.5 ± 0.3, respectively whereas, the Hunter color values *L, a, b* were found to be in the range of 51.75 ± 1.33 to 57.01 ± 0.98, 24.20 ± 0.86 to 30.12 ± 1.13, and 19.53 ± 1.61 to 22.96 ± 1.12, respectively. Formulated models were validated with the sensory scores. OQi predicted by the Model ML2 was found to be in consonance with the variation in the sensory overall quality scores. The OQi, as per the model ML2, was estimated as the ratio of the product of the constant C (265.5), acidity (A), and firmness (F) to the mod of the product of Hunter color values *a* and *b*. Finally, the predicted values of OQi were correlated with the measured quality parameters to check the possibility of predicting OQi non-destructively by using any one of those measured attributes during the storage.

1. Introduction

Apple (*Malus domestica* Borkh) is one of the highly ephemeral and important fruits of the world, mainly grown in temperate regions. It belongs to the family of *Rosaceae* and sub-family *Pomoideae* [1]. More than 7500 apple cultivars are known, but only a few of them are commercially important. Some varieties like Red Delicious, Golden Delicious, Granny Smith, Rome Beauty and McIntosh are commonly produced worldwide. A low percentage of apples produced are consumed immediately after harvesting, and most of the time, a large part of them is stored for a long period to keep them available for their further utilization [2].

Two terms namely, quality and acceptability play an important role in the selection of fruits. The term quality can be defined as the combination of characteristics of fruit and the consumer's recognition. On the other hand, the feedback to those characteristics is referred to as acceptability [3]. The quality of most of the fruits varies with time as well as the quality of the individual fruit may also differ extremely from the average. For example, apple is one of those fruits whose quality changes rapidly with

time during the storage period, due to which its acceptability among consumers also varies [4, 5]. The quality of an apple or any fruit can be predicted by various properties or attributes like sensory, physical, chemical, mechanical, etc. In the first instance, it is judged by its appearance, including size, gloss, and color, and thereafter by its firmness, density, acidity, and total soluble solids content [6]. These physical and chemical attributes may help consumers to recognize the nutritional value of fruits [7]. Consumers do not like light weight, colorless, and shriveled fruits. In the past several years, numerous studies have been conducted to improve the quality of apples during storage using various treatments [8, 9, 10, 11, 12, 13]. Moreover, consumers generally purchase apples on the basis of their appearance, only because at that time, their other quality parameters such as taste, acidity, total soluble solids content, etc. are not accessible. To estimate these parameters, several methods have been extensively used, but they are highly time-consuming and require laboratory testing. Therefore, nowadays, non-destructive methods have gained more popularity. Several studies [14, 15, 16, 17, 18] have reported the quality parameters of various fruits and vegetables like strawberry, blueberry, apple, tomato, and chili pepper by using

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various non-destructive methods such as computer vision system, hyperspectral imaging, acoustic impulse resonance frequency sensor, etc.; but each of them anticipates either a single, or double quality attribute such as shape and color, firmness or acid to Brix ratio [19, 20]. Furthermore, some authors have also determined the freshness index and maturity index by using machine vision systems [21, 22, 23]. The machine vision system is also associated with several limitations such as it determines only a single parameter like other methods; it also has a high cost and needs to be employed each time separately to assess the parameters.

Moreover, some of the sensor-based testing methods such as near infrared (NIR) spectroscopy [24], magnetic resonance imaging (MRI) [25], and X-ray [26] have also been tried by some researchers to assess the internal and external quality or defects of fruits and vegetables non-destructively but again the limitations are that they are also costlier, inaccessible to most stakeholders and are not feasible for routine quality testing. Other than these, Jha et al. [27] have also formulated the models to assess the quality of apple non-destructively. But they have formulated the models by selecting the quality parameters manually. However, like other methods this manual method of selecting parameters is equally time-consuming; sometimes, it takes hours or days as well as it does not show accuracy and reflects uncertainties in the result. This is because the minor changes in the quality parameters may disturb the whole expression. Therefore, as of now in the literature, no computational method or equations are available to assess the internal, external, and overall quality of apple. The main objective of this work was to formulate the computational models in the R software in terms of quality attributes to assess the overall quality of apple during 30 days of its storage at ambient temperature. This work also included the study of the variation in the physical and chemical quality attributes of apples during storage. Furthermore, all the formulated models were validated by the sensory scores, and then, the predicted values of OQi were also correlated with the measured quality parameters.

The fruit storage after harvesting is one of the biggest real time problems in the world in general and in particular. In comparison to the production of fruits, very limited cold storage facilities are available, which subsequently lead to an increase in the cost of the fruits. Further, it has also been estimated that more than 60–70 % of consumers in India procure the fruits from the local market, where generally the fruits are stored at ambient temperature.

Therefore, the assessment of the quality of the stored apple during storage at ambient temperature assumes great importance. Suggested models and the relationship of the overall quality index with the quality parameters help the consumers to assess the quality of fruit during purchasing. Generally, consumers purchase apples based on their appearance only because the other quality parameters such as taste, acidity, total soluble solids content, etc., are not accessible to them. However, through this study, consumers can easily and quickly judge the quality of apples by measuring gloss or any other quality parameter and thus make an intelligent decision. The results of this study can be utilized by the food processing industries to assess the quality of apples non-destructively during storage at ambient temperature before processing. Moreover, the results of this study would also be helpful for the researchers who are working in the areas of food packaging and also for those who want to improve the shelf life of fruit during storage at ambient temperature through modified atmosphere packaging.

2. Material and methods

Fresh "Red Delicious (Royal)"variety of apple fruit (*Malus domestica* Borkh) was purchased from the local market of Aligarh, India, which is cultivated in Shimla, India. Apples that are at the commercial maturity stage were selected. Samples of approximately similar shape and size (Horizontal diameter $= 63.72 \pm 1.30$ mm, and Vertical diameter $= 66.37 \pm 1.06$ mm), gloss, color, and free from any external damage or defects were sorted manually and stored at ambient storage condition (24 ± 1

°C) for a period of 30 days. Three apples were reserved and placed separately for measuring the consistent and accurate data of weight loss, density (D), and gloss (G_{45} and G_{60}) throughout the storage period. From the remaining apples, three apples were taken randomly at an interval of 0, 2, 4, 6, 10, 14, 18, 22, 26, 30 days for measuring the physical and chemical attributes, such as firmness (F), acidity (A), total soluble solids content (TSS), and Hunter color values (*L, a, b*). The whole experiment was performed in triplicate as well as all measurements of physical and chemical quality attributes in each experiment on each apple were also performed in triplicate. On the day of the experiment, ten apples were selected and subjected to sensory evaluation to know the overall acceptability of the apple during storage.

2.1. Measurement of density (D)

The density of each apple was calculated by dividing the weight of the apple by its calculated volume. The weight of the apple was measured using an electronic weighing balance (BL 220H weighing balance, Shimadzu, Kyoto, Japan) having the least count of 0.001g. The height, width, and thickness of the apple were measured using the vernier caliper (500-181-30 ABS Digimatic Caliper, Mitutoyo Corporation, Kanagawa, Japan) having the least count of 0.01 mm to calculate the geometric mean diameter. Finally, the volume of the apple was calculated on the basis of the geometric mean diameter.

2.2. Measurement of gloss (G_{45} and G_{60})

Gloss was determined using a digital and handy gloss meter (PCE-RM 100, PCE Instruments, UK and IG-331, Horiba, Japan) at 45 and 60° angles of incidence of light. The gloss measuring surface of the gloss meter was put on the surface of the apple in a manner that light discharged/released by the gloss meter could not leak. The gloss of each apple was recorded from three equally distant places across the height of the apple, and mean values of gloss were then noted.

2.3. Measurement of hunter color values (L, a, b)

The spectrophotometer (Color Flex EZ spectrophotometer, Hunter Lab, Virginia, USA) was used to measure the surface color of the apple in terms of Hunter color values *L, a, b*. Before measuring the color of the sample, the colorimeter was standardized with black and white color calibration tiles provided with the instrument. The surface of the apple was placed on the nose cone of the colorimeter in a manner that the light emitted by the colorimeter could not leak. The color of each apple was measured at three equally distant places across the height of the apple, and mean values were recorded. '*L*' indicated the lightness or darkness, '*a*' indicated the redness or greenness, and '*b*' indicated the yellowness or blueness of the samples, respectively.

2.4. Measurement of firmness (F)

The firmness of the apple was measured using a texture analyzer (TA.HD plus, Stable Micro System Ltd, UK) supported by the software "Exponent Lite". 2mm diameter cylindrical probe (SMS P/2) and flat fixture (HDP/90 Heavy Duty Platform) were used to perform the penetration test. Before measuring the firmness, the height of the probe and the texture analyzer were calibrated by performing the calibration test. The penetration test was carried out on both sides of the apple with a penetration distance of 5 mm and a speed of approach of the probe of 2 mm/s. Then the apple was cut into two parts along the height of the apple, and then one part was placed in the center of the platform in such a way that the probe easily penetrated in the middle of the sample without striking the surface of the platform. A force-distance curve was recorded for each sample. The firmness was measured at two distant places (near the center) on each side of the apple, and average values were reported. The value of the firmness for each sample was recorded from the

elaboration of the force-distance curve in terms of peak force (N). Peak force indicated the maximum force registered during the penetration which was related to the entire fruit firmness (peel and flesh) [28].

2.5. Measurement of total soluble solids (TSS) and acidity (A)

Initially, for the measurement of total soluble solids content and acidity, the juice of the apple was extracted using a domestic juice extractor and was filtered through a cotton muslin cloth. The hand held refractometer with automatic temperature compensation (RHB-32ATC, Bombey Scientific ERMA, Tokyo, Japan) having the least count of 0.2 % Brix was used for measuring the TSS of the filtered juice. The acidity of the apple juice was measured by using the standard titration method (AOAC 1990) [29], and the results were expressed as a percentage of malic acid. The TSS and acidity values of the juice were measured in triplicate and recorded.

2.6. Sensory evaluation

During each interval of the storage period, ten apples were subjected to sensory evaluation by the semi-trained panel of 15 judges including males (9) and females (6) in the age group of 20–50 years [30]. Sensory evaluation was done according to the procedure and guidelines recommended by Ranganna [31] by Hedonic rating test and as per the method recommended by Indian Standard (BIS IS: 6273-2: Guide for Sensory Evaluation of Foods, Part II: Methods and Evaluation Cards). The semi-trained panelists were invited from the faculty members and students of other departments of the Faculty of Agricultural Sciences, Aligarh Muslim University, Aligarh, India. On the day of sensory evaluation the required numbers of panelists were present to appear for the sensory evaluation, their voluntary presence itself shows their consent. Before the sensory evaluation, the selected members of the panel were instructed to give their sensory score only under four categories viz. like extremely, like moderately, dislike moderately, and dislike extremely. Furthermore, they were also informed about the microbial status of the sample, sensory procedure, and the 9 points Hedonic scale (like extremely = 9, like very much = 8, like moderately = 7, like slightly = 6, neither like nor dislike = 5, dislike slightly = 4, dislike moderately = 3, dislike very much = 2, dislike extremely = 1). Responses of all the panelists were recorded in the questionnaire or in the format of sensory evaluation as shown in Table 1. Finally, the percentage of the respondents was computed in order to check whether the trends of acceptability level and overall quality index to be formulated were in line or not [32].

2.7. Computation of overall quality index (OQ_i) models

On the basis of the increasing or decreasing trend of physical and chemical quality attributes of the apple that were observed during the experiment, 12 OQi models were computed for the fresh and stored apples by using the R software in the linear and exponential forms. All the 12 models were computed in terms of the quality parameters by assuming the overall quality of apple to be one on the zero-day of storage. But out of the 12 models, only 6 (3 linear and 3 exponential) models gave the OQi values near to one on the zero-day of storage. All the selected six models are represented in Table 2. Thereafter, for the selection of the best and appropriate model, the overall quality index values at each interval of storage were matched with the likeness patterns of the sensory panel. Out of the six, one model was selected on the basis of sensory evaluation. Furthermore, the computed OQi from the selected model was also correlated to the storage period, and other measured quality attributes to know its predictability using them non-destructively.

2.8. Statistical analysis

The whole experiment was performed in triplicate, and all the quality attributes in each experiment on each apple were also measured in triplicate and are reported as mean [n = 27 (3 × 3 × 3)] and standard deviation. Data were analyzed by one-way analysis of variance (ANOVA) using IBM SPSS Statistical Analysis Software, version 24. Significant differences between mean combinations values were assessed using the Post-hoc test (Duncan multiple range test). The level of significance was defined as $p \leq 0.05$.

2.9. Software used

During the study, four software namely R, Minitab, SPSS, and Excel were used. The open-source R software was used to formulate the overall quality index models, SPSS was used for statistical analysis, while the Minitab and Excel were used to plot the graphs.

3. Results and discussion

3.1. Behavior of measured quality parameters during storage

3.1.1. Total soluble solids (TSS)

The TSS value of the apple generally increases, but in our case during the storage period of 30 days, initially it significantly ($p \leq 0.05$) decreased from 13.10 ± 0.01 to 12.90 ± 0.09 % Brix, and after that, it again significantly ($p \leq 0.05$) increased up to the 22nd day of storage from 12.90 ± 0.09 to 14.00 ± 0.08 % Brix, as shown in Figure 1. The initial decrease in TSS may be attributed to the conversion of sugar into starch during the initial period of two days leading to a decrease in the sweetness of the apple [33]. Later on, an increase in TSS was observed, which may be due to the re-conversion of starch into mono-saccharides [34]. In the later stages of storage, a slight decrease was observed in the content of TSS. Overall, three phases of changes were observed in TSS during the storage. The maximum value of 14.00 ± 0.09 % Brix TSS was attained during the storage. A third-order polynomial with a coefficient of determination, R^2 of 0.932 faithfully, explained the variation in the total soluble solids of the apples during storage. The same trend for TSS has also been reported in the literature [27]. The regression equation is given in Table 3.

3.1.2. Acidity (A)

The acidity of the apple declined from 0.163 ± 0.003 to 0.081 ± 0.001 % malic acid during storage. This might be because, during the storage, the starch content decreases, and sugar content increases, as a result, the acidity of the apple decreased (Figure 2). The fruits continue to respire after harvesting, which promotes ripening. The same type of pattern for acidity during the storage was also reported in the literature [35]. A third order polynomial was fitted to the data with the coefficient of determination, R^2 as 0.956. The regression model is listed in Table 3.

3.1.3. Firmness (F)

The firmness of the fruit is considered as a major quality parameter that indicates the respiration and evaporation rates. In this study, a continuous decline was observed in the firmness of the apple from 11.87 ± 0.25 to 7.68 ± 0.24 N during the storage period at ambient temperature (Figure 3). This change may be attributed to the fact that at the ambient temperature, the moisture loss, flesh weight loss, and the fruit softening occurred very rapidly as compared to the fruit which is placed in the cold storage. In this case, around 35 % of the firmness of the apple decreased during the storage period of 30 days, but in another study [28] around 21 % decrease in the firmness was recorded during the period of three months in the cold storage for the same variety of apple. This shows that the firmness of the apple decreases very fast at ambient temperature. A similar type of decreasing trend towards the firmness of apple during the storage at different temperatures and conditions has also been observed by other authors working in the same area [28, 36, 37]. The polynomial of third order with the coefficient of determination, R^2 of the 0.982 represented the variation in the firmness of the apple during the storage, and the corresponding regression equation for the firmness is

Table 1. Sensory evaluation score card.

SENSORY SCORE CARD FOR APPLE ON 9 –POINT HEDONIC SCALE

Product: *Apple during storage (0 – 30 days)*

Method: *9-Point Hedonic Rating Test (According to BIS IS: 6273 (Part II) – 1971, and Ranganna, S. 1974)*

Name of the Panellist: **Designation:**

Dated:

Note: You are requested to evaluate the following samples of apple by using 9 point hedonic scale after carefully reading the instructions given below:

Instructions

- You have to give your sensory scores only under four categories liked extremely (9), liked moderately (7), disliked moderately (3), and disliked extremely (1).
- Samples from 1 to 7 are microbiologically safe, so evaluate the sample in terms of all quality attributes like color, texture, taste, flavor, juiciness and overall acceptability.
- Samples from 8 to 10 are not microbiologically safe (may have a growth of bacteria and fungus) so evaluate these samples only in terms of color, texture, and overall acceptability.

Sample No.	Storage Period (Days)	Color	Texture	Taste	Flavor	Juiciness	Overall acceptability
1	0						
2	2						
3	4						
4	6						
5	10						
6	14						
7	18						
8	22						
9	26						
10	30						

9 –Point Hedonic Scale

9	Like Extremely	4	Dislike Slightly
8	Like Very Much	3	Dislike Moderately
7	Like Moderately	2	Dislike Very Much
6	Like Slightly	1	Dislike Extremely
5	Neither Like nor Dislike		

Signature of the Panellist

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given in Table 3. During the storage periods, variation in the firmness of apple was found to be significantly ($p \leq 0.05$) different.

3.1.4. Density (D)

During the storage, the density of the apple decreased from 0.995 ± 0.003 to 0.951 ± 0.004 gm/cm^3. This could be due to the reduction in volume is lesser compared to the rate of weight loss during storage. At the ambient temperature, the evaporation rate of moisture from the fruit is faster, and it causes rapid weight loss and wrinkling [38]. At the initial period of storage, the weight of the apple decreased swiftly, and at the later stage, it decreased slowly (Figure 4). The density of the apple was

significantly ($p < 0.05$) decreased up to the 8th day of storage. The polynomial of fourth order with a coefficient of determination, R^2 of 0.912 is perfectly represented the density of apple during storage. The corresponding regression model is given in Table 3.

3.1.5. Gloss values (G_{45}, G_{60})

At 45° and 60° angles of incidence of light, the gloss values of the apple varied from 7.9 ± 0.2 to 4.1 ± 0.3 and 6.8 ± 0.1 to 2.5 ± 0.3 gloss unit (GU), respectively. The higher values of gloss were observed at 45° as compared to the gloss values at 60° (Figure 5). This might be because according to the basic principle of reflectance, at a lower angle

Table 2. Formulated models in R for computing overall quality index of apple during the storage.

Model No.	Model Code	Model Equation
1.	ME1	$OQi = e^{-\left(\frac{G60 \times G45 \times d}{L + a \times b}\right)}$
2.	ME2	$OQi = e^{-\left(\frac{A \times TSS \times G60 \times G45 \times d}{a \times b}\right)}$
3.	ME3	$OQi = e^{-\left(\frac{TSS + D + A + F + G60 + G45) \times d}{L + a \times b}\right)}$
4.	ML1	$OQi = (G_{60} \times G_{45} \times D)/L$
5.	ML2	$OQi = (265.5 \times A \times F)/|a \times b|$
6.	ML3	$OQi = (G_{60} \times G_{45})/(a + b)$

F: Firmness (Peel strength); TSS: Total soluble solids; D: Density; A: Acidity; d: Storage periods (Days); L, a, b are the hunter color values; G_{60} and G_{45} are the gloss values at 60° and 45°.

of incidence of light the diffused reflectance is more than that at the higher angle. Several studies conducted on the storage of fruits have observed that during storage, the water present in the fruit continuously evaporates [35, 38]. Thus, the skin of the fruit shrinks and produces rough surfaces, resulting in decreased gloss values [12]. Further, it has also been observed that the skin of the fruits remains soft and firm in the initial days of storage, and later on, it became loose and shriveled, as a result of which it is less acceptable. Similar types of results have also been observed in the present study. Initially, the gloss values of apple decreased steadily up to the 10th day of storage, and thereafter, the values decreased gradually. This might be due to the fact that in the early days of storage, the water present in the apple evaporates at a fast

rate and later on, it evaporates slowly. The gloss values of the apple at 45° and 60°angles of incidence of light were found to be significantly different up to the 8th day of storage. The fourth-order polynomial with the coefficients of determination of 0.893 and 0.938 represented the variation in the gloss values at 45° and 60°, respectively. The regression equations are given in Table 3.

3.1.6. Hunter color values (L, a, b)

Color is also an important quality parameter that directly affects appearance and consumer acceptability [39]. During the period of storage, positive and significant changes were observed on color parameters (L, a, and b), and they were found in the range of 51.75 ± 1.33 to 57.01 ± 0.98, 24.20 ± 0.86 to 30.12 ± 1.13, and 19.53 ± 1.61 to 22.96 ± 1.12, respectively. Overall, the ambient temperature had a significant ($p \leq 0.05$) effect on color parameters during the storage. The "L" value, indicates the darkness of the skin, whereas a and b values indicate the red and yellow color of the skin of the fruit. Initially, the darkness (L value) on the surface of the apple decreased slightly up to the 2nd day of storage, but after that, it increased up to the 16th day of storage due to the appearance of redness, and later on, it again decreased up to the last day of storage. Overall the a value, increased from 24.20 ± 0.86 to 30.12 ± 1.13 up to the 16th day of storage, and later on, it decreased slightly from 29.92 ± 1.31 to 28.12 ± 1.51 (Figure 6). The b value increased from 20.71 ± 0.72 to 22.96 ± 1.12 throughout the storage period with a slight decrease in the middle of the storage (Figure 6). During the storage period, it was observed that the apples appeared dull, less reddish, more yellowish, and less acceptable during the course of time. Other studies on the different varieties of apple have also observed the same variation in the values of L, a, b [5, 40]. The regression equations and their corresponding coefficients of determination that perfectly represented the Hunter color values L, a, b are given in Table 3.
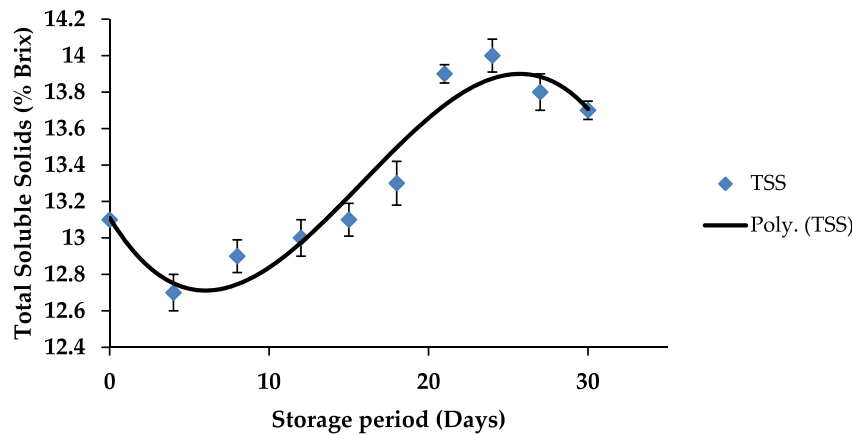

Figure 1. Effect of ambient temperature on the total soluble solids content (TSS) of fresh apple during storage.

Table 3. Regression equations in terms of storage period (S) with their corresponding coefficient of determination (R^2) for measured quality parameters.

| Regression equations	Coefficient of determination (R^2)
$F = -0.00001S^3 + 0.0037S^2 - 0.232S + 11.744$	0.982
$D = -0.0000003S^4 - 0.00003S^3 + 0.008S^2 - 0.0085S + 0.9966$	0.912
$A = -0.000002S^3 + 0.002S^2 - 0.0069S + 0.159$	0.956
$TSS = -0.0003S^3 + 0.0148S^2 - 0.1439S + 13.11$	0.932
$G(45°) = 0.00007S^4 - 0.0047S^3 + 0.1091S^2 - 0.9708S + 7.7209$	0.892
$G(60°) = 0.00009S^4 - 0.0065S^3 + 0.1534S^2 - 1.3418S + 6.55$	0.938
$L = -0.00006S^5 + 0.004S^4 - 0.0138S^3 + 0.2143S^2 - 0.9259S + 53.205$	0.974
$a = 0.00009S^5 - 0.0006S^4 + 0.0133S^3 - 0.1028S^2 + 0.4607S + 24.323$	0.890
$b = -0.00001S^5 + 0.0008S^4 - 0.0195S^3 + 0.1675S^2 - 0.2979S + 20.733$	0.970
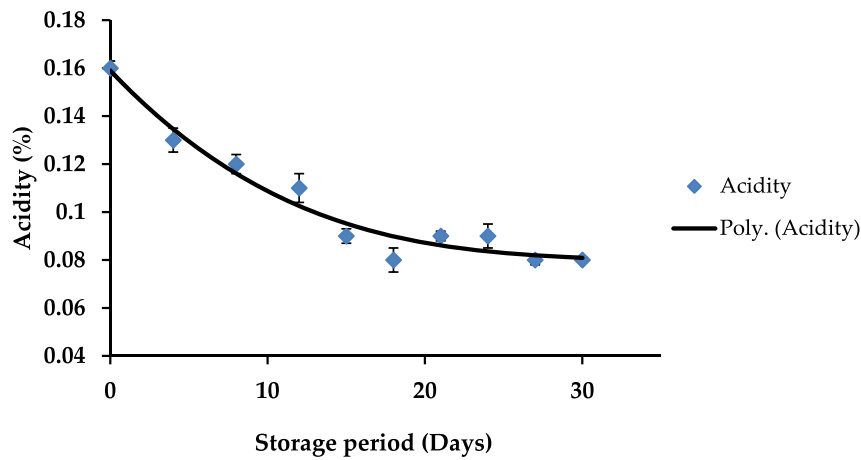
Figure 2. Effect of ambient temperature on the acidity of fresh apple during storage.
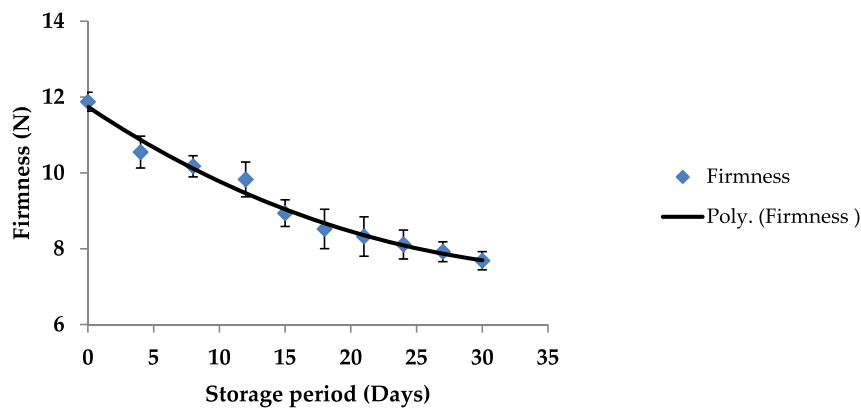

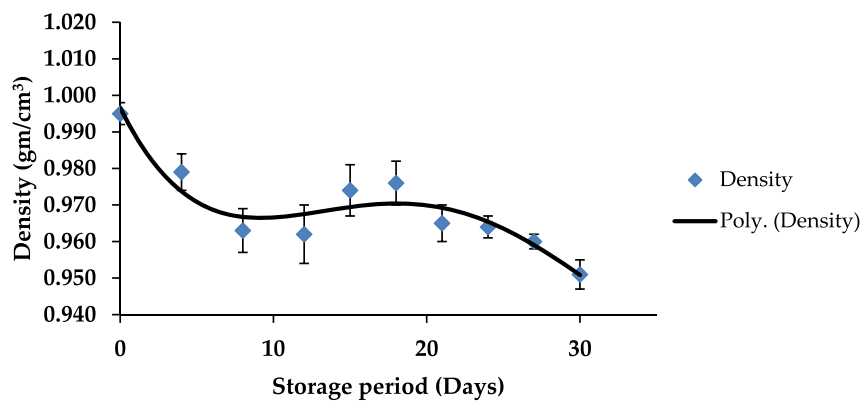**Figure 3.** Effect of ambient temperature on the firmness of fresh apple during storage.

Figure 4. Effect of ambient temperature on the density of fresh apple during storage.

3.2. Overall quality index models (OQi)

Three linear and three exponential OQi models were developed in the R software using the measured quality parameters such as firmness, acidity, density, total soluble solids, gloss, and Hunter color values (Table 2). It was presumed that the quality of the apple brought from the market was perfect initially. Therefore its OQi was taken to be equal to 01. The OQi of the apple samples calculated using the formulated model equations varied from 1.005 to 0.188 (Table 4). All the three exponential models ME1, ME2, and ME3 perfectly gave the initial values of OQi exactly equal to 01, and all the three linear models ML1, ML2, and ML3

also gave the initial values of OQi near to 01, as shown in Table 4. It was observed that the values of the models ME1, ME2, and ME3 declined very slowly for the storage period of 30 days (Figure 7). After the 30th day of storage, models ME1 and ME2 showed overall 60 % quality of the apple that was not visually apparent. Also, the model ME3 did not predict the decline in OQi as actually obtained. Hence, these three models were rejected. It was seen that the models ML1 and ML3 predicted a sudden decline in quality within two to four days of storage (Table 4), but this condition in the quality of apple was not visible actually within two and four days. The likely cause of this poor prediction by these two models could be that only the physical parameters were considered in the
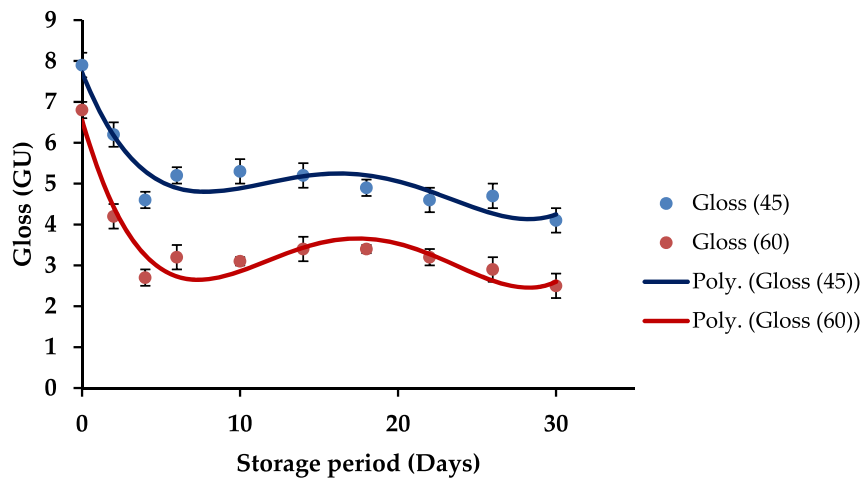
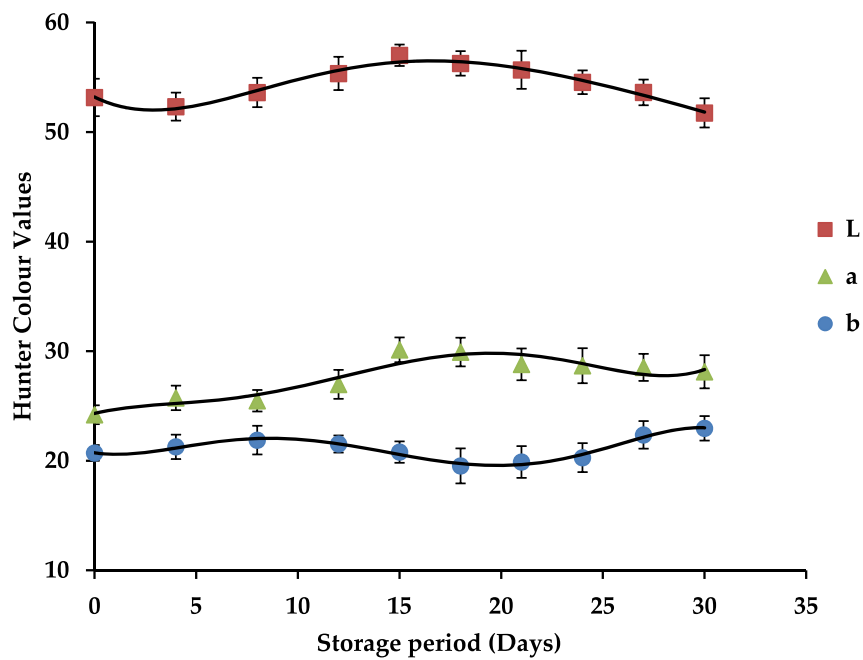**Figure 5.** Effect of ambient temperature on the gloss values of fresh apple during storage.

Figure 6. Effect of ambient temperature on the Hunter color values of fresh apple during storage.

Table 4. Computed overall quality index of apple during storage using model equations.

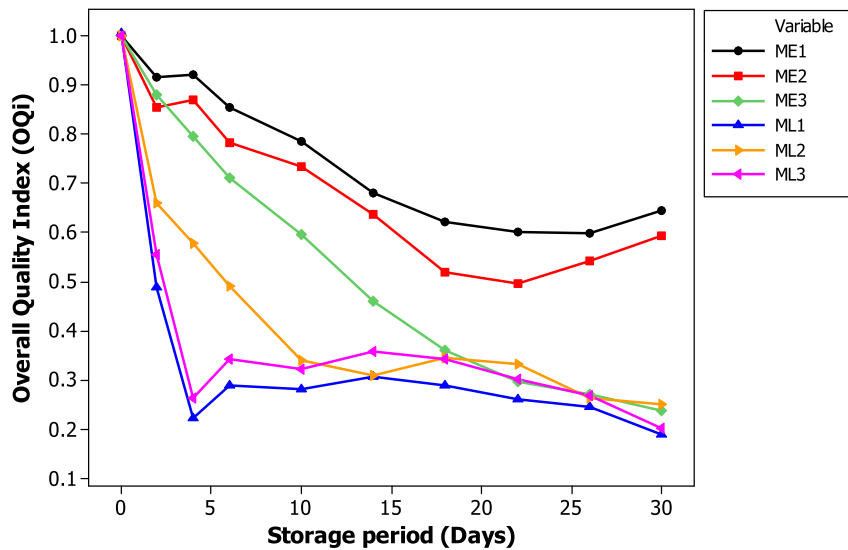| Storage Period (Days)	Models/Overall quality index values					
	ME1	ME2	ME3	ML1	ML2	ML3
0	1.0000	1.0000	1.0000	1.0055	1.0009	1.0009
2	0.9168	0.8547	0.8803	0.4873	0.6613	0.5539
4	0.9219	0.8711	0.7951	0.2231	0.5781	0.2622
6	0.8547	0.7820	0.7120	0.2892	0.4915	0.3431
10	0.7862	0.7339	0.5963	0.2807	0.3391	0.3227
14	0.6795	0.6372	0.4609	0.3067	0.3080	0.3575
18	0.6204	0.5193	0.3601	0.2887	0.3453	0.3422
22	0.6010	0.4957	0.2964	0.2601	0.3315	0.3007
26	0.5989	0.5415	0.2712	0.2440	0.2623	0.2679
30	0.6434	0.5933	0.2361	0.1884	0.2514	0.2007

Figure 7. Behavior of overall quality index of apple predicted by using different model equations with storage period.

Table 5. Overall acceptability of apple by the panelists during storage with the predicted overall quality index computed by the model ML2.

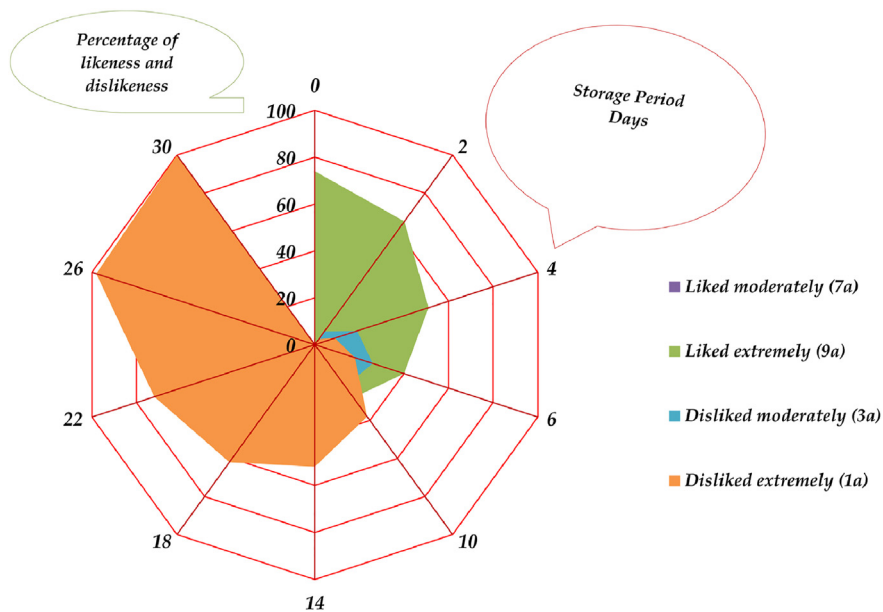| Storage period (days)	Predicted quality index (ML2)	Like extremely (9[a])	Like moderately (7[a])	Dislike moderately (3[a])	Dislike extremely (1[a])	Overall acceptability (%)
0	1.001	74	26	0	0	100 %
2	0.651	65	24	7	3	89 %
4	0.559	51	21	19	9	72 %
6	0.475	40	16	26	18	56 %
10	0.332	28	12	22	38	40 %
14	0.302	21	10	17	52	31 %
18	0.335	14	9	15	62	23 %
22	0.321	5	4	12	72	09 %
26	0.253	0	0	2	98	0 %
30	0.240	0	0	0	100	0 %

Figure 8. Variation in the percentage of likeness and dislikeness of apple during storage.

Table 6. Predicted values of OQi of Red Delicious (Royal) variety of apple.

| Days | Predicted values of OQi of Red Delicious (Royal) variety of apple by | | Deviation (%) |
	Jha et al. [27] Model	ML2 Model	
0	0.418	1.001	58.217
2	0.302	0.661	54.398
4	0.278	0.578	51.972
6	0.246	0.492	49.896
10	0.188	0.339	44.483
14	0.182	0.308	40.883
18	0.218	0.345	36.724
22	0.217	0.332	34.628
26	0.173	0.262	33.999
30	0.170	0.251	32.465

formation of these two models. However, in comparison to the other developed models, the values of OQi of the apple as computed by the model ML2 changed gradually (Figure 7). This gradual change may be attributed to the fact that this model comprised of parameters that depended upon both the physical and chemical changes occurring during storage. Therefore, on this basis, the model ML2 was selected tentatively as a model for computing the OQi of the apple.

3.3. Validation of tentatively selected model by sensory scores

Table 5 indicates the sensory scores in terms of the four parameters namely like extremely, like moderately, dislike moderately, and dislike extremely against the predicted OQi values computed by the model ML2, for the days of storage. The percentage of the likeness of the apples indicated that in the early days of storage most of the apples were either liked extremely or moderately. The data indicated that around 50 % of the panelists continued to like the apples extremely or moderately up to the 9th day of storage corresponding to the predicted quality index value of 0.332. After that, the percentage of overall acceptability decreased. Further, it was also noted that on the 26th and 30th day of storage 98 % and 100 % of the panelists extremely disliked the apples and the overall acceptability was zero. A similar type of likeness and dislikeness was also observed by Jha et al. [27]. Also, the sensory scores too showed that the degradation in apple during the storage was as slow as the predicted OQi. Trends of acceptability of apple as given by the sensory scores were found in good agreement with the predicted values of quality index computed by the model ML2. Thus, the model ML2 that was selected tentatively to

predict the OQi of apple was finally selected. The percentage of likeness and dislikeness of the apples by the panelists during the storage is depicted in Figure 8. The green color represents the percentage of panelists who liked the apple extremely. On the first day of storage, around 74 % of the panelists liked the apples extremely after that, the decrease in green color represents the decrease in the percentage of likeness with storage. Similarly, the orange color represents the percentage of panelists who disliked the apples extremely. From the first day of storage up to the 4th day of storage, no orange color is present, which means that no one disliked the apples extremely in the initial days of storage. After that, the orange color increases slightly, which means that some of the panelists disliked the apples after the 4th and 5th days of storage, and after that, subsequently the presence of orange color increases. In the period of 26–30 days of storage, maximum amount of orange color is reflected in Figure 8, which means 100 % of the panelists extremely disliked the apples.

3.4. Comparison of the prediction performance of model ML2 with an existing quality evaluation model (Jha et al. [27]) for Red Delicious (Royal) variety of apples

To compare the quality prediction performance of model ML2 with the model suggested by Jha et al. [27], the OQi of the Red Delicious (Royal) variety of apples was predicted by the model suggested by Jha et al. [27]. Table 6 represents the predicted values of OQi by both the models along with the percentage of deviation between them. It was observed that on the zero-day of storage, the model suggested by Jha et al. [27] predicted the OQi value to be 0.418 whereas the model ML2 predicted the OQi value to be 1.001 with the deviation of 58.21 %. Overall, the deviation between the predicted values of OQi by the two models varied from 58.21 % to 32.46 %. Over the entire storage period, the maximum deviation of 58.21 % was observed on the zero-day of storage followed subsequently by a gradual to a final deviation of 32.46 % on the 30th day of storage. Overall, the model suggested by Jha et al. [27] does not predict the OQi of Red Delicious (Royal) variety of apple inspite of having the same quality parameters except firmness, whereas the model ML2 predicted the quality more accurately (Figure 9). This difference may be because of Jha et al. [27] proposed their model for five varieties of apples, including Golden Delicious, Red Delicious, Ambri and two unknown varieties whereas, the Model ML2 has formulated, especially for the Red Delicious (Royal) variety of apple. The other reason behind the poor performance of the Jha et al. [27] model could be due to the fact that they have obtained wide-ranging Hunter color values,
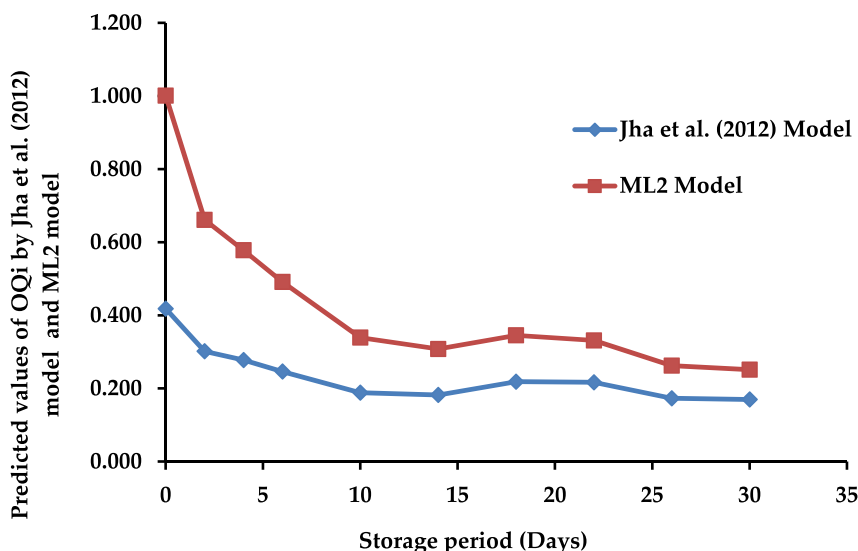

Figure 9. Behavior of predicted values of OQi by the model suggested by Jha et al. [27] and model ML2 of the present study.

Table 7. Regression equations with their coefficients of determination representing the relationship of predicted overall quality index of apple by the model ML2 with the storage period and measured quality attributes.

Equation No.	Regression equations	Coefficient of determination (R^2)
1	$OQi = -0.000112S^3 + 0.006307S^2 - 0.1121S + 0.9420$	0.996
2	$OQi = -0.0001F^3 + 0.035F^2 - 0.487F + 1.962$	0.989
3	$OQi = 1.821TSS^3 - 73.17\ TSS^2 + 979.2\ TSS - 4363$	0.865
4	$OQi = 181.1A^3 - 25.8A^2 + 7.16A - 0.2278$	0.996
5	$OQi = 11916D^3 - 34428D^2 + 33163D - 10651$	0.876
6	$OQi = -0.080G45^4 + 1.856G45^3 - 15.64G45^2 + 57.55G45 - 77.85$	0.847
7	$OQi = -0.167G60^4 + 2.758G60^3 - 16.11G60^2 + 40.11G60 - 35.85$	0.844
8	$OQi = 0.022L^3 - 3.666L^2 + 199.6L - 3618$	0.853
9	$OQi = -0.002a^3 + 0.188a^2 - 5.963a + 62.99$	0.948
10	$OQi = 0.007b^3 - 0.588b^2 + 15.06b - 124$	0.754

especially *a* and *b,* for different varieties of apple and then they have considered the average of each of these varieties. Thus, the model ML2 predicted the quality of red apple more appropriately as compared to the model suggested by Jha et al. [27]. The Model ML2 is also more appropriate as it could be used for the other varieties of apple that are produced in India, which are mostly red in color.

3.5. Regression analysis between computed OQi and measured quality parameters

After establishing that Model ML2 is the best suited OQi model, it was decided to predict the OQi non-destructively by using measured quality parameters. Several orders of regression equations such as linear, second, third order polynomial, etc., were fitted between the computed OQi values from the finally selected model ML2 in terms of the storage period and the measured quality parameters. The regression equations that fitted perfectly are represented in Table 7 with their coefficients of determination. Figure 10(a) shows a plot of OQi predicted by the model ML2 versus the storage period. It was observed that initially, OQi decreased at a fast rate as compared to the later stage. After the storage of 22 days the OQi value reached a minimum of 0.253 and after that it appeared almost constant. The corresponding regression equation is given by Equation 1 in Table 7. The results of the regression analysis between OQi values predicted by model ML2 and the TSS values

(Figure 10(b)) revealed that with the overall increase in TSS, the quality index of apple was found to decrease. With the increase in acidity (A) the OQi was found to increase (Figure 10 (c)) when this behavior was correlated with the sensory scores, it was deduced that during the period of storage the apples with the slightly acidic taste was preferred (very much liked) by the consumer whereas the order of likeness of apples got reduced with the increase in TSS during storage. Similarly, with the increase in firmness of the apple the OQi was found to increase (Figure 10 (d)). This increase in OQi with firmness may be attributed to the fact that the unwrinkled (non-shriveled), glossy, and dense fruits are always preferred. Further, with the increase in density (D) and gloss (G45 and G60) during the storage, the OQi of apple was found to increase (Figures 11 and 12). Notably, the density, gloss, and firmness of the apple decreased during the storage and the OQi values followed the same trend. The values of (*L, a, b*) were found to be correlated satisfactorily with the computed OQi values and were also in good agreement with the trends of the acceptability scores of the sensory analysis. Overall, the OQi values decreased with the increase in Hunter color values (Figure 13). The results of color values revealed that the reddish, less yellowish, and less green apples were very much liked by the consumers. Several other authors have also reported a similar trend of color values with strong acceptability of consumers [5, 7, 27, 41]. All the regression equations with their coefficients of determination representing the interaction of predicted OQi of apple by the model ML2 with the measured quality
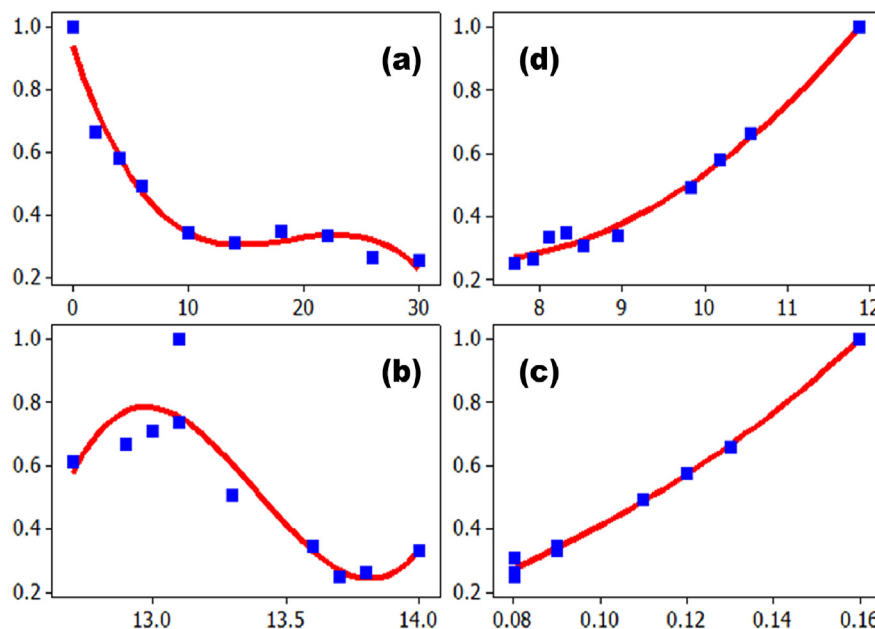

Figure 10. Relationship of overall quality index of apple (ML2) with (a) Storage (S), (b) Total soluble solids (TSS), (c) Acidity (A), (d) Firmness (F).
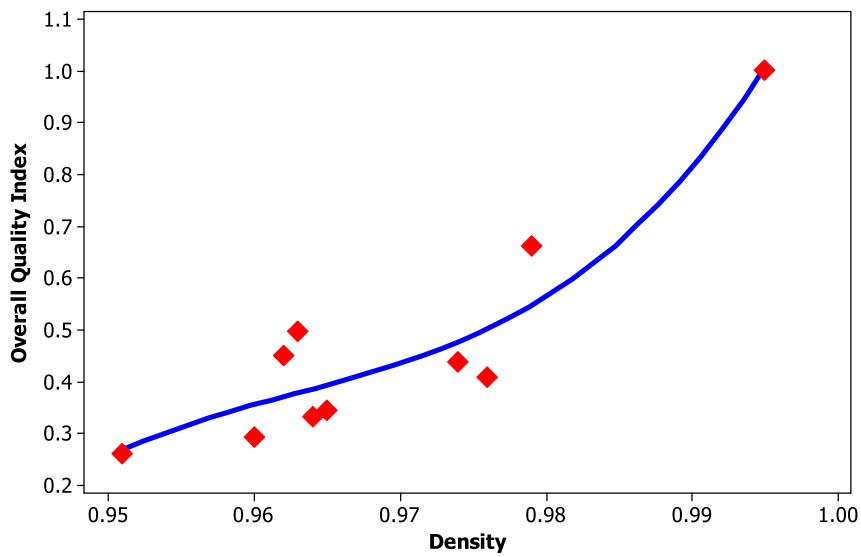
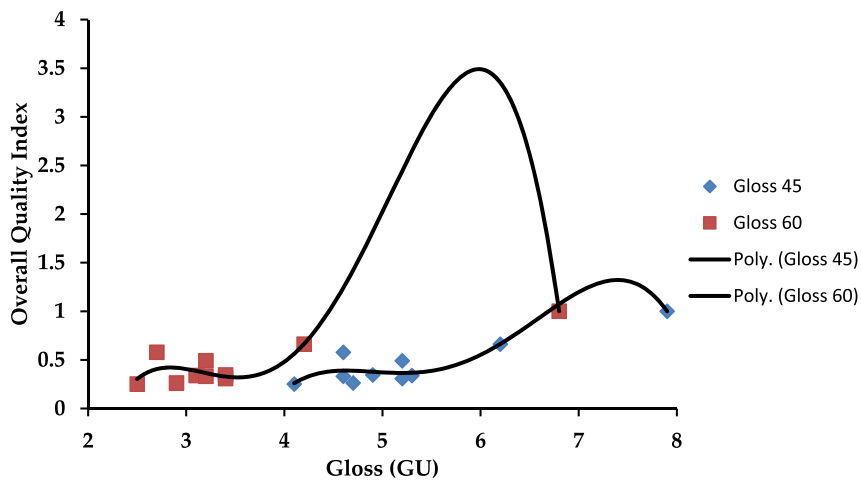**Figure 11.** Relationship of Density with the overall quality index of apple (ML2).

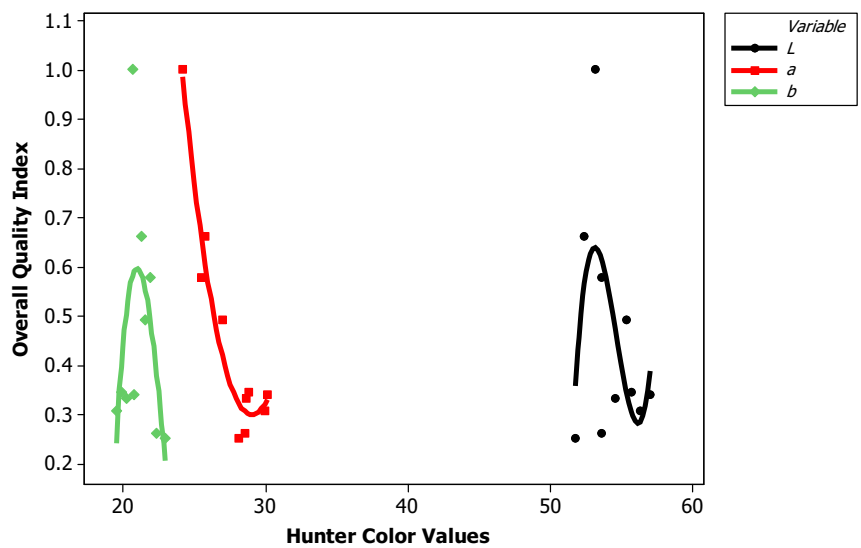**Figure 12.** Relationship of Gloss with the overall quality index of apple (ML2).

Figure 13. Relationship of Hunter Color Values with the overall quality index of apple (ML2).

parameters are given in Table 7. During the regression analysis, all the quality parameters were found to be significant in regression. It was observed from Table 7 that equations (1), (2), (4), and (9) exhibited R^2 values of 0.996, 0.989, 0.996, and 0.948 whereas the other regression equations have R^2 values below 0.9. From this, it can be deduced that the variance in the data for the quality parameters firmness, acidity, and Hunter color value '*a*' vis-à-vis OQi values is highly explained by the relevant equations.

4. Conclusions

During the study, all the measured quality parameters of the apple were found to be in variation during the storage. The firmness, density, gloss, acidity, and Hunter '*L' and 'b*' values decreased, although, the TSS and Hunter '*a*' values increased. The firmness and acidity varied from 11.88 ± 0.25 to 7.68 ± 0.24 N, and 0.163 ± 0.003 to 0.081 ± 0.001 % while, '*a*' and '*b*' Hunter color values were found to be in the range of 24.20 ± 0.86 to 30.12 ± 1.13, and 19.53 ± 1.61 to 22.96 ± 1.12, respectively. The formulated model ML2 was found to be in good agreement with the sensory scores and regression analysis. Thus, the OQi of the apple during storage could be defined as the ratio of the product of the constant C (265.5), acidity (A), and firmness (F) to the mod of the product of '*a*' and '*b*'. The OQi of apple was found to be around 0.240 at the end of 30 days of storage. This value is almost the same as those computed using the storage period and at the stage of rejection of apple by the sensory panel. Therefore, the overall results of the study showed that only 9 % of consumers liked the apples when the quality index came out to be 0.321 during storage and 100 % of the consumers rejected the apple even if the quality index came out to be 0.253 to 0.240. Furthermore, in the last section of the study, the OQi values computed by the model ML2 correlated well with the measured quality parameters such as TSS, gloss, density, and Hunter color values L and b. Moreover, firmness, acidity, and Hunter color value '*a*' satisfactorily explained the relationship between OQi with the coefficient of determination of 0.989, 0.996, and 0.948 respectively. Some of the measured quality parameters such as gloss and Hunter color values '*L', 'a',* and '*b*' could be measured non-destructively and from their graphs or regression equations, the OQi can be calculated. Therefore, it may conclude that the formulated quality index has the ability to judge the apple quality non-destructively and it could be used for the purpose of sorting and grading the apples.

Declarations

Author contribution statement

Faizan Ahmad: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Sadaf Zaidi: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Mohd. Arshad: Analyzed and interpreted the data.

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Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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