Physico-chemical quality parameters and overall quality index of apple during storage

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Abstract Physico-chemical quality parameters of apple were measured during storage using standard techniques and fitted to model expressions for developing an overall quality index (I_q). Predicted I_q was validated with the trends of sensory scores. Total Soluble Solids (TSS) and acidity varied from 13.2 to 12.3 ºBrix and 0.161 to 0.079%, respectively whereas, Hunter colour values L, a, b and yellowness index were 48.7–56.1, 11.0–19.4, 18.8–20.2 and 84.6–98.2, respectively. The gloss at 45 and 60º incidence angles, density and I_q varied from 7.5 to 4.3 and 6.7 to 2.6 GU, 1.01 to 0.96 kg m^{-3} and 0.26 to 1.02, respectively. The variation in sensory overall quality scores with storage period was found to be in line with computed overall quality index. The I_q thus, could be defined as the ratio of product of acidity and TSS to the mode of product of a and b Hunter colour values. The polynomial regression equations for I_q with TSS, acidity, a, b, and storage period yielded the correlation coefficients of 0.8443, 0.9838, 0.7130, 0.7183 and 0.9665, respectively; which indicated that overall quality index could be predicted nondestructively using any one of these parameters during storage.

Keywords Apple · Storage · Acidity · Total soluble solids · Prediction · Nondestructive

Introduction

Apple (*Malus domestica* Borkh) is highly remunerative deciduous fruit grown in temperate region. Among various

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apple cultivars only about 20 are commercially important and of which only five varieties (Red Delicious; Golden Delicious; McIntosh; Rome Beauty and Granny Smith) account for major production of apple in the world.

Quality of apple changes rapidly during storage and thus, substantially affects the acceptability by the consumers (Vieira et al. 2009). At first instance, it is judged by appearance comprising colour, gloss, size and secondly by texture, total soluble solids (TSS) content and/or titrable acidity. These parameters may supply important information to the consumers in recognizing a more nutritional fruit (Drogoudi et al. 2008).

The effect of various treatments on the quality of apple during storage has extensively been studied by Ali et al. (2004), Ullah et al. (2004), Hayat et al. (2005), El-Anany et al. (2009) and Ghafir et al. (2009). Consumers do not prefer shriveled and light weight fruits. Generally fruits are selected on the basis of appearance only, because it is not possible to know the sweetness or sourness of apple during purchase. To predict these parameters, various techniques are employed, which are time consuming involving laboratory based analysis. Of late, nondestructive techniques for quality evaluation have gained popularity. Determination of various quality characteristics of fruits and vegetables using nondestructive techniques have been reported (Lesage and Destain 1996; Kato 1997; Nussinovitch et al. 1996; Jha et al. 2005, 2006, 2007), but each of them predicts only a single or in some cases double parameters such as acid to Brix ratio (Jha and Matsuoka 2004). A few reports on determination of maturity index (Sirinnapa et al. 2004; Lakshmi et al. 2006; Jha et al. 2007), freshness index (Jha and Matsuoka 2002; McGlone et al. 2002) and physical appearances using machine vision systems (Blasco et al. 2003) are also available. These techniques determine single quality

parameter using relatively costlier techniques and needed to employ as many times as the number of parameters required to be estimated. No expression or technique is available to compute the overall quality that can tell about external as well as internal quality of apple. The objective of this study was to study the changes in physico-chemical quality parameters of apple during storage and formulate an index to predict nondestructively the overall quality of apple.

Materials ad methods

Freshly harvested apples (*Malus domestica Borkh*) variety "Golden Delicious", "Red Delicious", "Ambri" and 2 unknown varieties were procured from local market. Apples of almost similar size, colour, gloss and free from any external injury/blemish were sorted manually and stored at ambient storage conditions (32± 1 °C and RH 65±7%) for 28 days. Three apples of each variety were taken randomly at an interval of 0, 2, 4, 6, 8, 11, 21, 23, 26, 28 days, for measurement of TSS, acidity, gloss, density, Hunter colour values (*L, a, b*) and yellowness index. Some portion of each apple was subjected to sensory evaluation to know the overall acceptability during storage.

Measurement of TSS and acidity The juice was extracted using domestic juice extractor at ambient temperature (32±1 °C) and was filtered through muslin cloth. The TSS of the filtered juice was measured thrice using a hand held digital refractometer (Pal-1, Atago, range 0–53°Brix, least count 0.2°Brix, Japan) and acidity was determined using standard titration method (AOAC 1990).

Measurement of gloss It was measured using a digital gloss meter (RSPT-20, Rajdhani, India, least count±1 GU) at 45° and 60° angles of incidence of light. The nose cone was positioned on the apple surface in such a manner that light emitted by the gloss meter could not leak. The gloss was measured at four equally distant places along the major axis (height) of each sample and average values were recorded.

Determination of density Height, width and thickness of apple were determined using vernier caliper (Mitutoya, Japan) having the least count of 0.02 mm to compute geometric mean diameter. The volume of apple was initially computed using geometric mean diameter. The weight was determined using digital balance (Avery, India) having least count of 1 g. Density was computed by dividing weight of apple by its computed volume.

Measurement of colour The surface colour of apple in terms of Hunter *L, a, b* values and yellowness index (Y_i) were determined using Hunter lab Miniscan XE plus colorimeter (Model No. 45/0-L, Hunter lab, USA). '*L*' denotes the lightness or darkness, '*a*' green or redness and '*b*', blue or yellowness of the samples. Yellowness index is a derived parameter from *L, a, b* and was noted directly from the digital colorimeter. Before measuring the colour, the colorimeter was standardized with black and white calibration tiles provided with the instrument. The nose cone of colorimeter was positioned at the apple surface in such a way that leakage of light thrown by the colorimeter was minimized. The colour of each apple was measured at four equal distant places along the major axis (height) and average values are reported.

Sensory evaluation A portion of the apple for which the above quality parameters were measured was subjected to sensory evaluation by semi-trained panel of judges including ten males and females each in the age group of 25–45 selected from within the organization during each interval of storage period (Verma and Joshi 2000). Semi-trained panel means the group of selected panel members who were instructed about the tasting procedure and 9- point Hedonic scale (Liked extremely=9, Liked very much=8, Liked moderately=7, Liked slightly=6, Neither liked nor disliked=5, Disliked slightly=4, Disliked moderately=3, Disliked very much=2, Disliked extremely=1) before sensory evaluation. The judges were instructed to put their sensory score only under four categories viz. 'liked extremely", 'liked moderately', 'disliked moderately' and 'disliked extremely' and percentage of respondent was computed to check that whether the trends of acceptability level and overall quality index to be formulated were in line or not as previously done for maturity index determination of mango by Jha et al. (2007).

Formulation of quality index (I_q) The quality index (I_q) of selected fresh apple was assumed to be one and then 14 model expressions (Table 1) in terms of above measured quality parameters were formulated in such a manner that their values at zero day of storage yielded near to one. Expressions were formulated taking ideas from the increasing or decreasing trends of physico-chemical quality parameters based on previous experience (Jha et al. 2007). The I_q values were thereafter computed at each storage interval and matched with the likeness patterns of the sensory panel for selecting the best expression. The computed overall quality index from selected expression was also correlated to storage period and other measured quality parameters to know its predictability using them nondestructively.

Table 1 Possible models for computing overall quality index (I_q) of apple

Model no.	Model equations
1.	$D \times T_S \times G_{60}/Y_i$
2.	$G_{45} \times T_S/(L + a + b)$
3.	$G_{60} \times T_S/(L + a + b)$
4.	$T_S \times G_{60}/(T_S/A)$
5.	$A \times T_{S(°Brix)}/|(a \times b)|$
6.	$A \times T_{S(°Brix)} \times D/|(a \times b)|$
7.	$T_S \times G_{45}/Y_i$
8.	$T_S \times G_{60}/Y_i$
9.	$T_S \times G_{60}/(T_S/A \times D)$
10.	$T_S \times G_{45}/(Y_i \times D)$
11.	$A \times T_{S(°Brix)} \times D \times G_{45}/b \times Y_i$
12.	$G_{45} \times G_{60} \times D/L$
13.	$A \times G_{60}/b + Y_i$
14.	$Y_i/(D \times T_S/A)$

T_s: Total soluble solids, A: acidity; G_{45} and G_{60} is gloss value at 45° & 60° angle, respectively; D: Density; L, a, b are hunter colour values; Y_i: Yellowness index

Results and discussion

TSS acidity and density TSS generally increased, but two phases of changes in TSS content were visible during the storage period (Fig. 1). In the initial period, it decreased from 13.2 to 12.3°Brix. The decrease was probably due to conversion of sugar into starch (Wills et al. 1980), which shows that apple may become less sweet with the passage of time. Later on, it again increased due to re-conversion of starch into mono-saccharide (Duque et al. 1999). Therefore, the TSS in apple underwent cyclic changes under the storage condition. The maximum TSS attained during storage was about 14.2°Brix.

Acidity of apple decreased from 0.161 to 0.079% during period of storage under study (Fig. 1). The fruits continue to respire after harvesting, which leads to ripening. As starch content decreases and sugar content increases, so acidity of most fruits decreases. Similar type of variations for TSS and acidity were reported by Ghafir et al. (2009), Wills et al. (1980) and El-Anany et al. (2009) for apple during storage. The regression equations for TSS and acidity with their corresponding correlation coefficients are given in (Table 2).

Density of apple declined from 1.011 to 0.963 kg m−3 (Fig. 1). This might be due to the fact that the rate of weight loss was higher than volume reduction during the storage period. The density of apple can be represented by third order polynomial during storage period with correlation coefficient of 0.8085 (Table 2).

Gloss, Hunter colour values and yellowness index The gloss values for apple varied from 7.5 to 4.3 and 6.7 to 2.6 gloss unit (GU) at 45° and 60°, respectively (Fig. 2). The

gloss values at 45° were higher as compared to gloss values observed at 60°. This was due to the fact that at 45° of incidence of light, defused reflectance is more than that at 60°. The decline in gloss values was gradual and steady initially but later on it declined drastically. Water present in fruit continues to evaporate during storage. Thus, fruit usually shrinks and produces relatively rough surface, which results in decreased gloss values. Khan and Ahmad (2005) also observed that in the initial days of storage, the fruit skin remained firm, soft and shiny, while with the passage of time it became loose and shriveled and was less acceptable. The correlation coefficients corresponding to
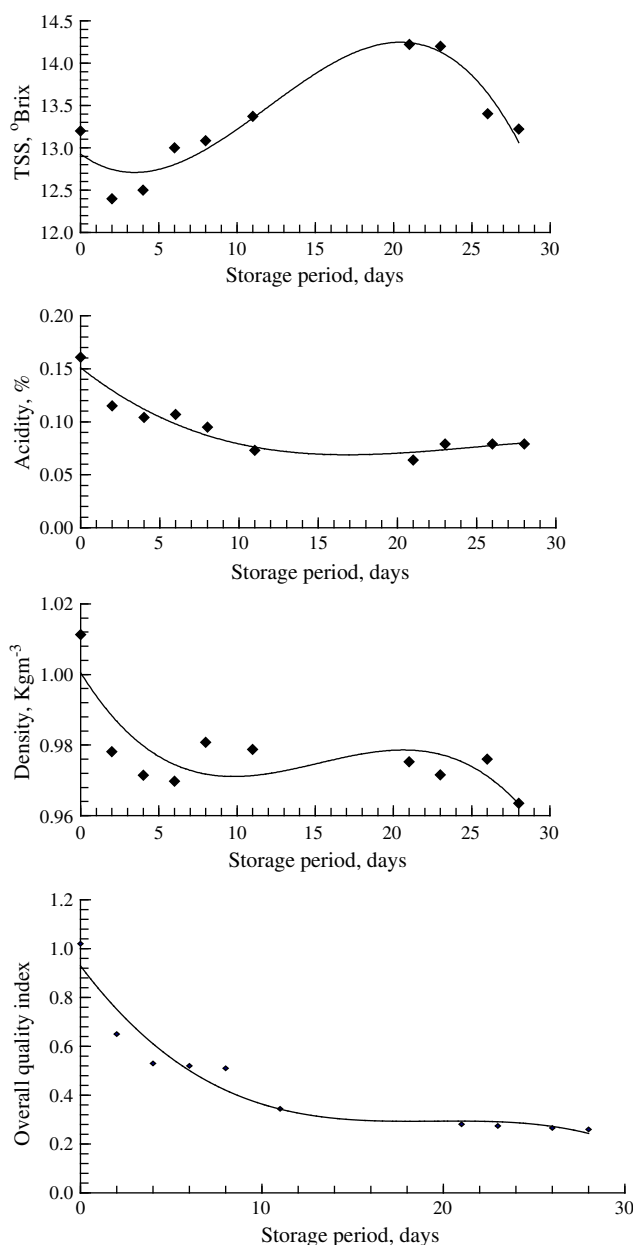

Fig. 1 Variation in physico-chemical quality and overall quality of apple during storage *TSS* Total Soluble Solids

Table 2 Regression equations with their corresponding correlation coefficient (r) for various measured quality parameters

Total soluble solids	$-0.0006\ S_p^3+0.0225\ S_p^2-0.1332\ S_p+12.927$	0.9402
Acidity	$-0.000007\ S_p^3+0.0005\ S_p^2-0.0118\ S_p+0.151$	0.9563
Gloss at 45°	$-0.0009\ S_p^3+0.0432\ S_p^2-0.6143\ S_p+7.136$	0.9183
Gloss at 60°	$-0.001\ S_p^3+0.0502\ S_p^2-0.7098\ S_p+5.8204$	0.8589
Density	$-0.00005\ S_p^3+0.0005\ S_p^2-0.0072\ S_p+1.0005$	0.8085
L values	$-0.0011\ S_p^3+0.0238\ S_p^2+0.3277\ S_p+49.319$	0.8586
a values	$0.0016\ S_p^3-0.0495\ S_p^2+0.419\ S_p+11.146$	0.9370
b values	$-0.001\ S_p^3+0.0243\ S_p^2+0.213\ S_p+18.317$	0.9389
Yellowness index	$0.0011\ S_p^3-0.0452\ S_p^2+0.8507\ S_p+86.032$	0.9150

S_p Storage period

gloss was found to be 0.9183 and 0.8589 at 45° and 60°, respectively (Table 2).

Colour directly affects the appearance and consumer acceptability of the fruit (Vieira et al. 2009). The Hunter colour values of apple changed appreciably during storage (Fig. 2). The L value decreased initially, but later it increased due to appearance of redness and later on it decreased in the last days of storage period (Jha et al. 2006). The a value, indicating green colour of the skin, increased from 11.0 to 19.4 during storage. The presence of yellowness i.e. b values on the surface of the fruit remained stable during initial stages, followed by a decrease in the middle and finally increased in the last stages. The yellowness index generally increased from 84.6–98.2 with 225 slight fluctuations (Fig. 2). The fruits become dull, less red, 226 more yellow and less acceptable with passage of time 227 during storage. Similar variations of L, a b values with 228 the strong correlation with the acceptability score were 229 observed by Vieira et al. (2009) for different apple 230 cultivars. The Hunter colour values L, a, b and yellowness 231 index in terms of storage period can satisfactorily be 232 represented by third order polynomial equation with 233 correlation coefficient of 0.8586, 0.9370, 0.9389 and 234 0.9150, respectively (Table 2).

Selection of expression for overall quality index The overall quality index (I_q) was computed using all the measured parameters such as TSS, acidity, gloss, density, Hunter colour values and yellowness index. The overall quality index calculated using various model equations (Table 1) ranged between 1.001 and 0.177 (Table 3). The trends of computed values of I_q of model number 5 and 12 indicated that the initial values of quality index were very near to one as assumed, but values computed by model 12 declined suddenly after two days. The sudden fall in quality within two days of storage was not visually apparent. It was probably because this model comprised of only physical parameters. The values computed by model 5, however, yielded gradual changes in quality index as compared to any other model and was comprised of both physical as well as biochemical parameters. Therefore, model 5 was tentatively selected as a model for computing overall quality index of apple.

Further, the range of quality index and percent of likeness of apple (Tables 3 and 4) indicated that initially, majority of apples were either liked extremely or moderately. The degree of likeness was assessed till 100% respondents indicated that they extremely disliked the
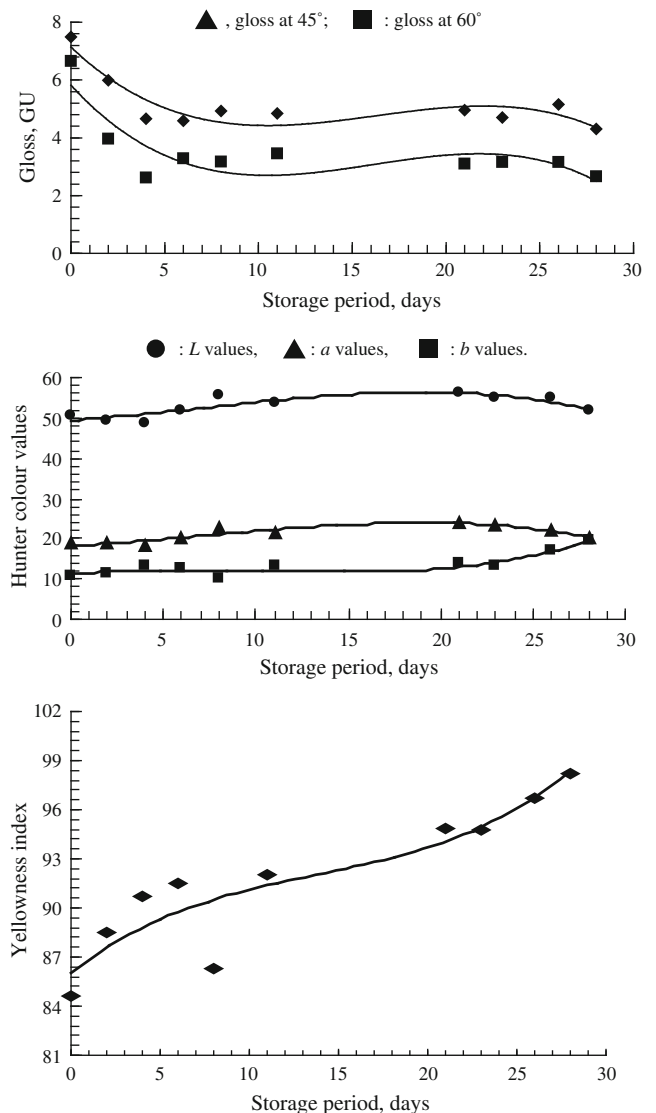

Fig. 2 Variation in gloss, Hunter colour values and yellowness index of apple during storage

Table 3 Computed quality index of apple using different model equations

Model no.	Storage period, days									
	0	2	4	6	8	11	21	23	26	28
1.	1.050	0.544	0.350	0.451	0.446	0.490	0.451	0.459	0.397	0.345
2.	1.233	0.931	0.726	0.708	0.685	0.732	0.755	0.733	0.682	0.622
3.	1.096	0.616	0.407	0.506	0.440	0.521	0.471	0.492	0.418	0.384
4.	1.072	0.456	0.272	0.351	0.301	0.250	0.198	0.249	0.249	0.210
5.	1.008	0.659	0.533	0.553	0.514	0.344	0.281	0.369	0.260	0.267
6.	1.040	0.645	0.518	0.537	0.509	0.337	0.273	0.358	0.254	0.257
7.	1.168	0.839	0.642	0.652	0.701	0.703	0.743	0.704	0.663	0.580
8.	1.039	0.556	0.361	0.466	0.451	0.501	0.465	0.473	0.407	0.358
9.	1.060	0.466	0.280	0.361	0.304	0.257	0.204	0.256	0.255	0.218
10.	1.155	0.858	0.661	0.672	0.709	0.718	0.765	0.724	0.680	0.602
11.	1.015	0.506	0.352	0.334	0.292	0.232	0.195	0.233	0.230	0.218
12.	1.001	0.469	0.243	0.283	0.277	0.304	0.266	0.263	0.289	0.212
13.	1.038	0.426	0.250	0.314	0.277	0.222	0.167	0.212	0.210	0.177
14.	1.020	0.839	0.776	0.776	0.674	0.513	0.439	0.542	0.628	0.609

apples. The data indicated that "liked extremely" decreased to 31% level when predicted I_q was in the range of 0.69 to 0.60. The sensory scores also indicated that deterioration in apple was as slow as the computed quality index. The trend of acceptability of apple was thus almost matching with the trend of predicted quality. Thus, the expression (model no. 5) which was tentatively selected to predict the overall quality index was finally selected among all the expressions. The quality index of apple thus may be defined as the ratio of product of acidity and TSS to the mode of product of a and b Hunter colour values of apple (Table 1).

Relationship between I_q and measured quality parameters Regression equations viz. linear, logarithmic, power, second order polynomial and exponential were fitted to computed I_q and measured quality parameters and storage period to see the possibility of predicting I_q nondestructively using either of these physico-chemical parameters. Best fitted expressions with their respective correlation coefficients are presented in Table 5. Figure 2 shows that quality index decreased during storage. Rate of decrease of quality index was initially faster than at later stages and I_q reached to the minimum value of 0.26 after storage period of 23 days, and thereafter it remained almost constant. The I_q decreased with increase in TSS whereas, it increased with increase in acidity (Fig. 3). This means that as the TSS increased with storage, the degree of likeness got reduced, whereas the apple with slightly acidic taste is preferred by the consumer. Similarly the I_q increased with increase in gloss and density of apple during storage period (Fig. 3). This is due to the fact that glossy surface and non-shriveled fruit surface is always preferred. Density and gloss actually

Table 4 Percentage of respondents for sensory scores with their predicted quality index (I_q) using model no. 5

Predicted quality index	Liked extremely (9[a])	Liked moderately (7[a])	Disliked moderately (3[a])	Disliked extremely (1[a])	Remarks
1.00–0.90	64	35	1	0	Good taste and appeal
0.89–0.80	58	33	7	2	Good taste but, not fresh
0.79–0.70	44	30	19	7	Fair appearance & taste
0.69–0.60	31	28	28	13	Dull colour and gloss
0.59–0.50	26	25	33	16	Shriveled, rotting spots
0.49–0.40	11	18	24	47	Partially rotten
0.39–0.30	0	0	8	92	Major portions rotten
0.29–0.20	0	0	0	100	Unacceptable, rejected

[a] Sensory scores (9 point Hedonic scale)

Table 5 Regression equations showing relationships of storage period & other measured quality parameters with overall quality index (I_q) calculated using best fitted model no 5

Parameter	Regression equation	Correlation coefficient, r
S_p	$-0.0009\ S_p{}^3+0.0051\ S_p{}^2-0.0989\ S_p+0.9298$	0.9665
T_s	$0.5386\ T_s{}^3-21.512\ T_s{}^2+285.79\ T_s-1262.5$	0.8443
A	$-1878.3\ A^3+645.05\ A^2-61.79\ A+2.0856$	0.9838
G_{45}	$-0.025\ G_{45}{}^3+0.4911\ G_{45}{}^2-2.911\ G_{45}+5.7998$	0.8712
G_{60}	$-0.1031\ G_{60}{}^3+1.355\ G_{60}{}^2-5.3429\ G_{60}+6.9566$	0.8958
D	$11810\ D^3-34703\ D^2+33998\ D-11104$	0.8343
L values	$0.0101L^3-1.5835L^2+82.574L-1432.1$	0.8661
a values	$0.0022\ a^3-0.088\ a^2+1.0416\ a-3.1296$	0.7130
b values	$-0.0039\ b^3+0.2629\ b^2-6.0074\ b+46.264$	0.7183
Y_i	$-0.0003\ Y_i{}^3+0.0722\ Y_i{}^2-6.9164\ Y_i+221.86$	0.9033

S_p: Storage period; T_s: Total soluble solids; A: acidity; G_{45} and G_{60} are gloss values at 45° & 60° angle, respectively; D: Density; Yi: Yellowness index; L, a, b are Hunter colour values
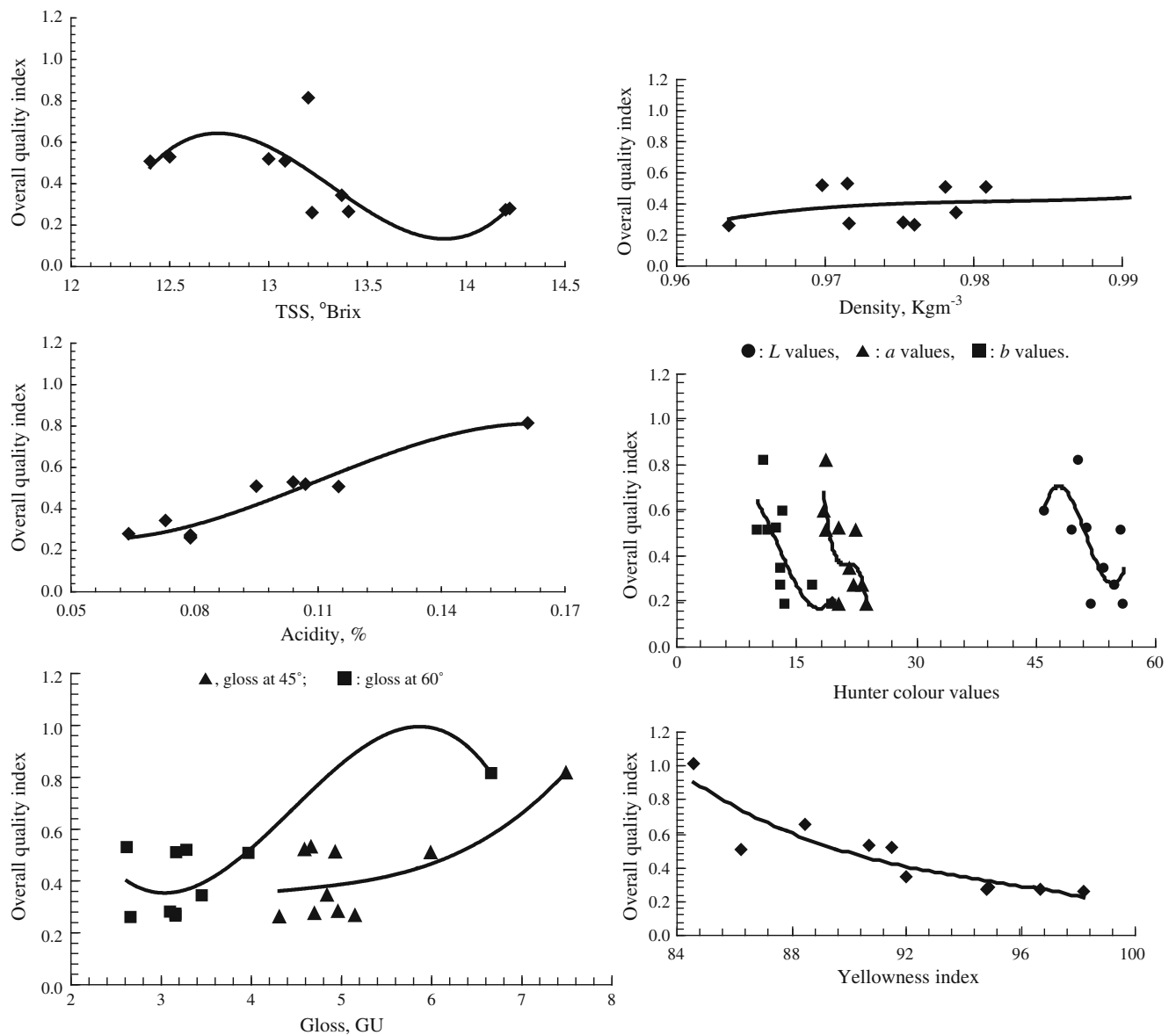

Fig. 3 Relationship of various quality parameters with overall quality index of apple

decreased with storage period and quality index followed the trend. At the end of storage period of 28 days the overall quality indices were found to be around 0.26 and 0.3 that are shown in Figs. 2 and 3, respectively. These values are almost the same as those computed using storage period, yellowness index and at stage of rejection of apple by the sensory panel. The Hunter colour values (L, a, b) and yellowness index were satisfactorily correlated with the computed quality index (Fig. 3). I_q decreased with the increase of these parameters. This is in line with the trend followed by the acceptability scores. This might be attributed to the perception that more red, less green and less yellow apples are liked by the consumers. Comparison of results indicated that consumers might reject the apple even if the quality index comes to about 0.3 to 0.25. Similar trends for the colour values with strong correlations with the consumer acceptability have also been reported by Orak (2007), Drogoudi et al. (2008), Iglesias et al. (2008), Vieira et al. (2009).

Conclusion

The TSS, Hunter a value and yellowness index increased while, acidity, gloss, density and Hunter L, b values decreased during storage period. TSS and acidity were 13.2–12.3 ºBrix and 0.161–0.079% whereas, Hunter colour a and b values were 11.0–19.4 and 18.8–20.2, respectively. An over all quality index was formulated and could be defined as the ratio of product of acidity and TSS to the mode of product of a and b Hunter colour values of apple. The computed overall quality index was correlated well with storage period, TSS, acidity, gloss, Hunter colour values and yellowness index, which could be measured nondestructively. Acidity and yellowness index best explained the relationship between I_q with correlation coefficient of 0.9838 and 0.9033, respectively. Thus, it could be inferred that the formulated quality index is having potential to be used for sorting and grading of apple nondestructively.

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