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A Dimensionless Index for Quantitative Evaluation of Apple Freshness

Y. J. Cho

Abstract: Though the freshness for agricultural products is an important factor related to their quality management, this terminology is being used restrictedly because it is very subjective. In this study, a dimensionless index which had the span of the maximum of 1 through the minimum of 0 was proposed to describe freshness of the product with time-variant quality and was applied to *Tsugaru* and *Fuji* apples. First, the compressive properties having the linearity in their change regarding time elapsed after harvest were selected. For *Tsugaru* apple, bio-yield and rupture forces had high correlation with time while for *Fuji*, bio-yield and rupture deformations had high correlations. When the slope, or ratio of force to deformation, was considered, the effect of cultivar could be neglected. When the linearly time-variant compressive properties for *Tsugaru* and *Fuji* apples were involved in the freshness indices, they described well freshness of apples. Also, the freshness decay constant depicted a characteristic which related to freshness decay rate. Therefore, the freshness index can be utilized to manage the quality during storage and distribution of apples.
Keywords: Freshness Index, Freshness Decay Constant, Apple, Compressive Property

Introduction

The apple is one of the most important commodities in Korea. It is harvested in the fall and stored even until early in the next summer. At this time, a quality inspection, for example, particularly freshness evaluation, is required, because during storage, the quality of the apple is degraded due to its irreversible metabolism.

Many parameters or factors are being used to objectively evaluate the quality and condition of apples. In the apple section of 'Market Inspection Instructions' published by USDA, there are many quality parameters and condition factors. The former includes immaturity, shape, cleanness, color and defects, and the latter does firmness, decay and other condition factors. The terminology related to freshness such as fresh skin is subjectively described in the section of other condition factors (USDA, 1978). Meanwhile, it is very common that the 'fresh' products are preferred with the consumers. Nevertheless, the parameter of 'freshness' may be so subjective and does not fit easily into any section of the manuals dealing with the major quality characteristics.

Arthey (1975) pointed out that freshness is an important positive quality characteristic and a major ingredient of quality factors of any agricultural products. He stated that this terminology could be interpreted in terms of time and state, so that it meant the period of time which elapsed between harvest and purchase of the consumer and also the extent to which the product had suffered as a result of time elapsed after harvest.

After harvest of an apple, its flesh softens due to loss of turgor, degradation of starch, or breakdown of the cell wall (Seymour et al., 1993). Also, the time elapsed after its harvest causes changes of apple cell structure such as separation of middle lamella (Ben-Arie et al., 1979), change of cell shape (Bolin and Huxsoll, 1987), change of intercellular space (Trakoontivakorn et al., 1988), and increase of surface roughness of cell walls (Cho, 1997). These phenomena may be closely related to decrease of freshness. Finally, if a parameter to linearly reflect the change of quality regarding time is selected for an apple, its freshness may be described quantitatively.

Cho and Hwang (1998) studied the change of some physicochemical factors such as total soluble solids content, uronic acid content, cell surface roughness, density, rupture deformation and rupture force after apple (cultivar: *Tsugaru*) and tomato (cultivar: *Momotaro*) harvest, and their relationship. They reported that for an apple, the cell surface roughness increased with the elapsed time and the rupture force decreased against it. When an index can describe the span of freshness for harvested apples using some physicochemical properties such as the above ones that can be measured with ease, it will be utilized for their post-harvest management.

The objectives of this study were, therefore, to:

1. Design a dimensionless freshness index having the span of the maximum of 1 through the minimum of 0.
2. Select some compressive properties of apples

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showing linear change with respect to time.

3. Describe apple freshness by using the index with a linear parameter.

Design of a Dimensionless Freshness Index

For an initial parameter, F_o, to correspond the quality immediately after harvest and a final parameter, F_f, to do the quality in infinite time, if the parameter shows a monotone, or linear, change in the time span, a general equation of its dimensionless value can be of the form:

$$I = \frac{(F-F_f)}{(F_0-F_f)} = \exp(-kt) \tag{1}$$

In equation (1), a dimensionless value, I, can be defined as a "freshness index" which has the maximum value of 1 at t = 0 and the minimum value of 0 at t = ∞. Here, k can be named as the "freshness decay constant" which describes a characteristic of freshness decay for a fresh product.

Materials and Methods

1. Test Apples

In this study, two cultivars of apples, *Tsugaru* and *Fuji*, which are two major varieties in Korea, were used. These cultivars have the different texture. The flesh of *Tsugaru* is so-called 'soft' while that of *Fuji* is 'hard'. The *Tsugaru* and *Fuji* apples were, respectively, harvested on Sep. 1, and Oct. 31, 1997 from two different commercial orchards in Korea and stored at room temperature of 25C.

2. Experimental Procedure

To obtain the data on the change of compressive properties with time, a compression tester mounted with a flat plunger in 5 mm diameter (Model Compac-100, Sun Scientific) was used. The apex of a hemisphere obtained by split of an intact apple was compressed at a loading speed of 5 mm/min. The *Tsugaru* apples were measured for one and one half month at 7-day intervals. 16 samples were tested at each stage. The *Fuji* apples were tested for 3 months at 10-day intervals using the sampling size of 10 individuals at each stage.

From the measured force-deformation data, bio-yield deformation and force, rupture deformation and force, the slope of the force-deformation curve at the origin ("initial tangent slope"), and the slope of a straight line from origin to bio-yield point ("secant slope") were obtained. Using the measured properties, the F values and coefficients of determination were analyzed through the ANOVA of linear models regarding time.

Meanwhile, the freshness decay constants, k, and asymptotic final values of parameters, F_f, were determined by the Marquardt method (Draper and Smith, 1981) using a non-linear regression analysis (NLIN procedure of SAS/STAT®).

Results and Discussion

1. Time-Variant Compressive Properties

Table 1 shows the F-values and coefficients of

Table 1 The F-values and coefficients of determination from the ANOVA of linear models of various compressive properties with time for apples

Cultivar	Compressive property	F value	Coefficient of determination
Tsugaru	Bio-yield deformation	1.85	0.092
	Bio-yield force	26.52**	0.585**
	Rupture deformation	1.20	0.061
	Rupture force	63.70**	0.778**
	Initial tangent slope	13.11**	0.419**
	Secant slope	23.55**	0.564**
Fuji	Bio-yield deformation	66.54**	0.866**
	Bio-yield force	0.37	0.034
	Rupture deformation	47.83**	0.823**
	Rupture force	5.35	0.342
	Initial tangent slope	57.24**	0.847**
	Secant slope	62.10**	0.857**

** highly significant at P=0.01.

Table 2 The initial and asymptotic final values of parameters and the freshness decay constants

Cultivar	Parameter involved in freshness index	Initial value	Asymptotic final value	Freshness decay constant (day^{-1})
Tsugaru	Bio-yield force (gf)	1474	889	0.1329
	Rupture force (gf)	2349	1087	0.1226
	Secant slope (gf/mm)	1389	688	0.07445
Fuji	Inverse bio-yield deformation (mm^{-1})	1.082	0.101	0.01923
	Inverse rupture deformation (mm^{-1})	0.555	0.027	0.01118
	Secant slope (gf/mm)	2192	61	0.01717

determination obtained from the ANOVA of linear models of various compressive properties with time for *Tsugaru* and *Fuji* apples. For *Tsugaru*, bio-yield and rupture forces had the linear relation with time at the significant level of 1% while for *Fuji*, bio-yield and rupture deformations showed the best results. This result may be due to the difference of texture between *Tsugaru* with 'soft' flesh and *Fuji* with 'hard' flesh.

Meanwhile, the initial and secant slopes showed high relationships with time at the significant level of 1%, regardless of cultivar. If these compressive properties are included in a linear model for describing the change of freshness regarding time, the effect of cultivar can be mitigated.

Therefore, the specific compressive properties of apples showed high correlation with the period of time which elapsed after harvest so that they can be utilized to describe the freshness.

2. Decay Constant and Index of Freshness

Table 2 shows the initial and asymptotic final values of parameters involved in freshness index having the form of equation (1). Also, it shows the freshness decay constants obtained from the equation (1). The initial and final secant slopes of *Tsugaru* apples were, respectively, 1,389 gf/mm and 688 gf/mm. In contrast with *Tsugaru*, *Fuji* had the initial and final secant slopes of 2,192 gf/mm and 61 gf/mm, respectively. This result means that the flesh of *Fuji* which was harder than that of *Tsugaru* at the initial stage became tenderer at the final.

But the freshness decay constant of *Tsugaru* derived from freshness index with secant slope was 0.07445 day^{-1} while that of *Fuji* was 0.01717 day^{-1}. That is, the freshness decay constant of *Tsugaru* was 4.3 times as large as that of *Fuji*. This result means that in the decrease of freshness, the *Tsugaru* apple was much faster than the *Fuji*.

Figs. 1 through 6 show the measured and predicted freshness indices for *Tsugaru* and *Fuji* apples. As all

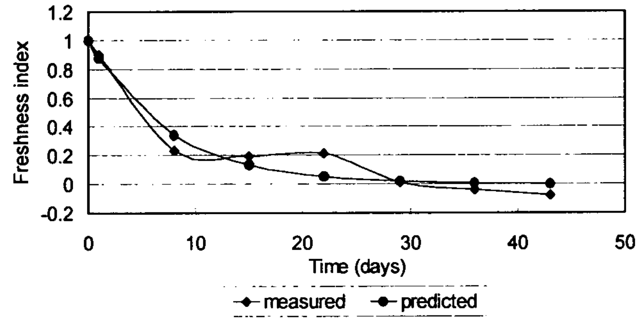

Fig. 1 Freshness indices with the parameter of bio-yield force for *Tsugaru* apples (R^2= 0.958).

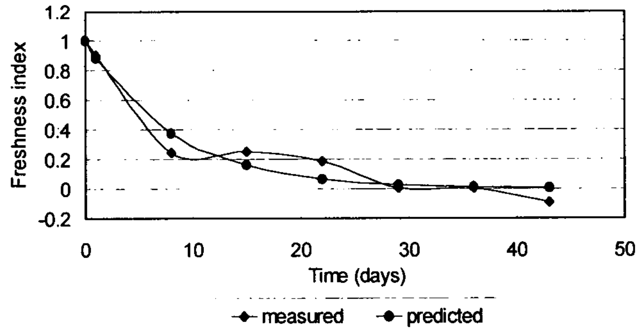

Fig. 2 Freshness indices with the parameter of rupture force for *Tsugaru* apples (R^2= 0.957).

the coefficients of determination were higher than 0.95, the measured freshness indices coincided well with the predicted ones. This means that these indices described well the freshness in the span of time during quality degradation of the harvested apple.

The freshness index proposed in this study can, therefore, be utilized to manage the quality during storage and distribution of apples.

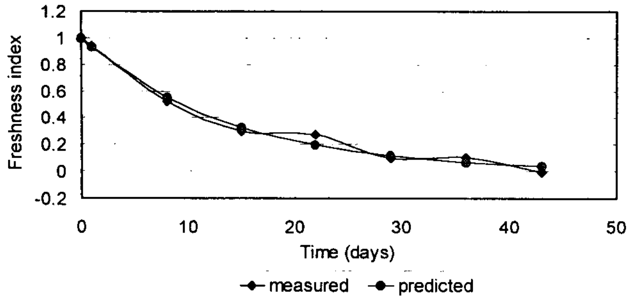

Fig. 3 Freshness indices with the parameter of secant slope for *Tsugaru* apples (R^2= 0.987).

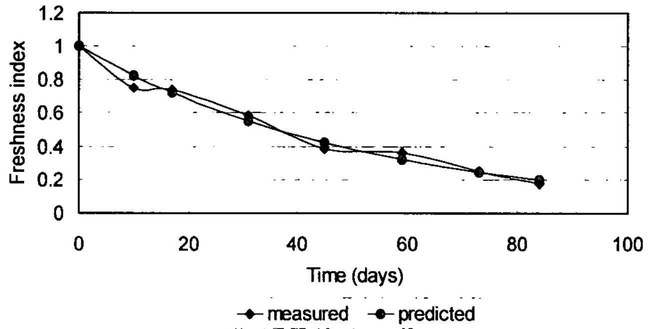

Fig. 4 Freshness indices with the parameter of inverse bio-yield deformation for *Fuji* apples (R^2= 0.981).

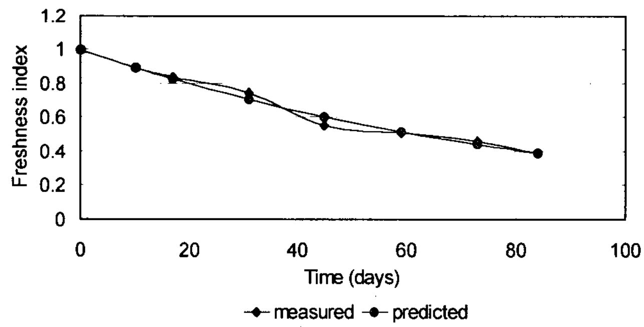

Fig. 5 Freshness indices with the parameter of inverse rupture deformation for *Fuji* apples (R^2= 0.987).

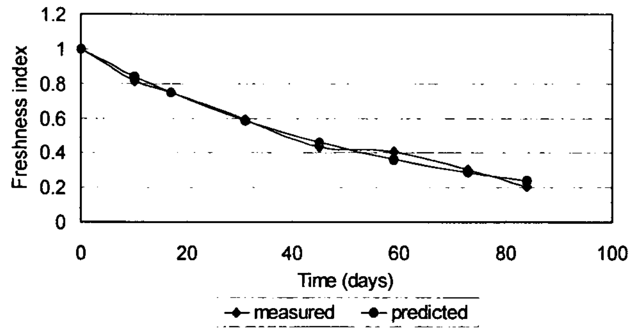

Fig. 6 Freshness indices with the parameter of secant slope for *Fuji* apples (R^2=0.9991).

Conclusions

Though the freshness for agricultural products is an important factor related to their quality management, this terminology is being used restrictedly because it is very subjective. In this study, a dimensionless index which had the span of the maximum of 1 through the minimum of 0 was proposed to describe freshness of the product with time-variant quality and was applied to apples.

The specific compressive properties of apples showed the linearity in their change with respect to time elapsed after harvest. For *Tsugaru* apples, bio-yield and rupture forces had high correlation with time while for *Fuji*, bio-yield and rupture deformations showed the best results. When the slope, or ratio of force to deformation, was considered, the effect of cultivar could be neglected.

When the linearly time-variant compressive properties for *Tsugaru* and *Fuji* apples were involved in the freshness indices, they accurately described freshness of apples. Also, the freshness decay constant depicted a characteristic related to freshness. Therefore, the freshness index can be utilized to manage the quality during storage and distribution of apples.

In the future study, the following topics should be investigated.

1) The actual meaning of freshness index should be interpreted. The value of freshness index should be related to physiological condition of agricultural products and their economic value.

2) The dependence of freshness decay constant on temperature, chemical potentials (i.e., concentrations of O_2, CO_2, ethylene) and so on should be revealed. These data can be utilized to establish some strategy during storage and distribution of fresh foods.

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