KEEPING QUALITY OF CUCUMBER BATCHES: IS IT PREDICTABLE?

Schouten R.E. and van Kooten O.
ATO-DLO P.O. Box 17, 6700 Wageningen, The Netherlands.
Fax: +31-317-475347, E-mail: R.E.Schouten@ato.dlo.nl

Keywords: Keeping quality, cucumber, prediction, distribution

Abstract

The prediction of the keeping quality for a cucumber, the time the colour remains acceptable, is until now not possible because of the unknown stage of maturity of the fruit. This is a fundamental problem common to all products that have a decrease of the limiting quality attribute according to the autocatalytic mechanism. For individual cucumbers this problem remains unsolved, but on a batch level an approach to obtain the stage of maturity of a batch is described. The stage of maturity of a batch of cucumbers can be obtained by observing the skewness of the colour distribution. This is demonstrated for four batches differing in growing conditions. The colour distributions obtained from high nutrient density treatments indicate an early stage of maturity because of the typical skewness. The approach to predict the stage of maturity from colour distributions was extended to predict the batch keeping quality, the number of days for which 95% of a batch has an acceptable colour. For four growing conditions the batch keeping quality for cucumbers was calculated by fitting colour data to a model that allows for biological variation between cucumbers. The hypothesis is that characterisation of the colour distribution provides sufficient information to specify the batch keeping quality. This is under further investigation.

Introduction

A generally accepted definition of keeping quality is the time a commodity remains acceptable. In a constant environment, with a given value of initial quality and of a quality limit, the first attribute to become unacceptable will always be the same. The four most common mechanisms of decrease of the quality attribute encountered are (Tijskens & Polderdijk, 1996):

a) zero order reactions having linear kinetics
b) Michaelis-Menten kinetics
c) first order reactions having exponential kinetics
d) autocatalytic reactions having logistic kinetics

The keeping quality in a constant environment can be represented as f(Q)/k with k as the reaction rate of the process of quality decrease. f(Q) contains the initial quality (Q_0) and the quality limit (Q_l). It depends on the mechanism of the process of quality decrease of the specific attribute (Table 1 from Tijskens and Polderdijk, 1996). For a number of products, measurement of the initial quality (Q_0) is sufficient to predict the keeping quality when values for k are available. These are products with the limiting quality attribute decreasing according to the linear/Michaelis-Menten and exponential mechanism (Table 1). Unfortunately, this is not the case for products decreasing according to the autocatalytical mechanism because no information can be obtained about Q_{max}, the maximally possible quality (Table 1). Therefore, an attempt to predict the keeping quality of a product with a limiting quality attribute decreasing according to this mechanism should start with a method of evaluating Q_{max}.

For cucumbers the limiting quality attribute is colour. Stored at 20°C this is the case for 85% of all cucumbers (data not published). An approach is described to define, describe and predict the keeping quality of batches of cucumbers.

Table 1 Overview of respective quality functions.

kinetic mechanism	f(Q)
Linear/Michaelis-Menten[a]	Q_0-Q_L
Exponential	$Ln(Q_0/Q_L)$
Autocatalytic	$Ln((Q_{max}{}^{b} - Q_L)/Q_L{*}Cba)$ $Cba = (Q_{max}{}^{b}-Q_0)/Q_0$

[a] If the amount of substrate is much larger than the specificity factor Km, which is probably the case in the initial region of decay then Michaelis-Menten reduces to a linear mechanism.

[b] Q_{max} represents the quality maximally possible at (minus) infinite time.

The definition of the batch keeping quality is derived from the practical classification routines used at auctions in the Netherlands. From a large batch, often comprising over 1000 cucumbers, four boxes of twelve cucumbers are randomly selected and judged on colour. When more than two cucumbers (~ 4.2%) have a colour considered too yellow, the whole batch is considered unacceptable. Because of this the batch keeping quality can be defined as the number of days for which 95% of a batch has an acceptable colour.

Description of the batch keeping quality is accomplished by fitting colour data to a model that assumes a colour change from green to yellow according to a logistic function. Logistic behaviour is the consequence of the autocatalytic mechanism of quality decrease. During the fitting procedure, some of the model parameters are allowed to vary for individual cucumbers while others are assumed to be specific for a given growing condition and cultivar. This system allows the individual cucumber, the growing condition and the cultivar to have their specific effects on the batch keeping quality.

For the prediction of the batch quality, a measure of Q_{max} of the batch is necessary.

While information about Q_{max} for individual cucumbers could not be obtained, it is assumed that information regarding the distribution of Q_{max} can be obtained from the skewness of the colour distribution for batches of cucumbers. The difference between the colour distribution and the distribution of Q_{max} is regarded as a measure of the stage of maturity of the batch. Hypothesis is that the colour distribution contains sufficient information, like the skewness, to predict the batch keeping quality. This would allow discrimination with regard to batch keeping quality on the basis of very simple measurements, namely the colour of each cucumber in the batch.

Material & Methods

Cucumbers

Cucumber (*Cucumis sativus* L.) plants of three cultivars ('Enigma', 'Flamingo', and 'Jessica') were planted at the end of July and at the end of August 1995 at the experimental research station in Naaldwijk (PBG). The plants were grown hydroponically at a density of 1 (= low plant density) or 3 plants m^{-2} (= high plant density). Two nutrient solutions of 1.5 (= low EC) and 7 dS m^{-1} (= high EC) were applied (Janse, 1995). Cucumbers of marketable size and colour were harvested once a week, transported to ATO-DLO within 2 h and stored in the dark at 20 °C and 100% RH. Date of harvest (= day -1) was recorded for each individual cucumber. More than 800 cucumbers, harvested in 9 weeks, were monitored during storage.

Colour measurements

Image analysis was used for the colour measurements. The system is developed at ATO-DLO and consists of a colour video camera (JVC KY-F30 3CCD) in a container with a controlled light environment, connected to a personal computer. During a measurement, the cucumber image is separated from the background and the light intensities for the red and blue colour are separately averaged over all the pixels that belong to the cucumber image. The ratio of the blue to red intensity has a very high correlation with a colour card, showing predefined colour stages of the cucumber (Central Bureau of Fruit and Vegetables in the Netherlands) and was used for cucumber colour assessment (Schouten et al., 1997). Colour was measured twice a week, starting on day 0. This was repeated until the process of yellowing finished, until bacterial spoilage was eminent or rubber necks (Janse, 1995) appeared.

Data analysis

Equations and mathematical description of the model were developed using MAPLE V (Waterloo Maple Software, Waterloo, Canada). Calculations of the batch keeping quality have been performed with MATLAB 4 (The Mathworks, Inc., Natick, USA). Distributions were fitted using Tablecurve 2.01 (Jandel Scientific, San Rafael, CA).

Results & Discussion

Colour distribution

Prediction of keeping quality for individual cucumbers on the basis of colour only is not possible because of the unknown Q_{max}. This also applies for cucumber batches, but now extra information is available. By not only measuring the colour but also noting the colour distribution additional information is available to characterise the batch keeping quality.
It is assumed that the maturity of a batch can, indirectly, be measured by examining the colour distribution. The maximal green colour distribution (f_{max}) is assumed to be normally distributed. This can be regarded as the variation in chlorophyll content mainly due to growing conditions (Schouten et al., 1997). At harvest a batch of cucumbers with distribution f_0 will be available. This batch does not consist of cucumbers with a colour greener than is allowed by f_{max}, but can have cucumbers with a colour more yellow than is available in f_{max}. This can result in skewness of f_0 but only when f_0 and f_{max} are partly overlapping, thereby changing f_0 from normal to skewed (Fig. 1a). This happens when a batch is in an early stage of maturity. However, when a batch is in a later maturity stage then f_0 will not be limited by f_{max} and no skewness in f_0 will be encountered (Fig 1b). This behaviour of f_0 can be described by the binomial distribution and is a consequence of the autocatalytic mechanism. The binomial distribution, however, can not be used for practical applications because f_0 is a mathematically continuous and not a discrete function. For practical applications a continuous function is needed, like the Gamma distribution.
In Fig. 2 the f_0 colour distributions are shown for different treatments. The considerable skewness of f_0 for the high EC treatments indicates an early stage and the absence of the skewness for the low EC + low plant density indicates a later stage of maturity. This is consistent with the view of Lin and Ehret (1991) that factors inducing rapid fruit growth (low plant density, high EC) result in younger fruit at harvest.

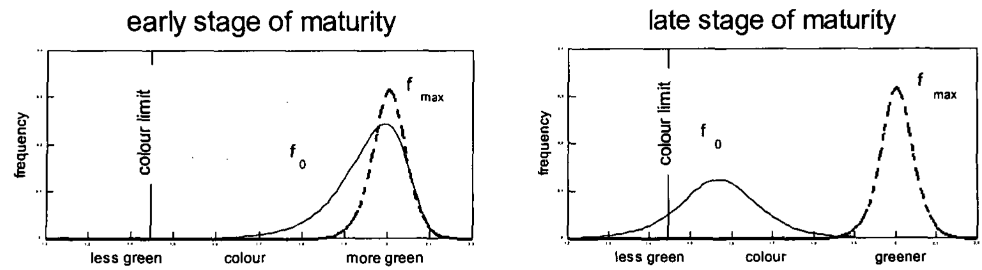

Figure 1 Schematic effect on the shape of the colour distribution f_0, with a given constant *maximally green distribution* f_{max}, *in case of an early (Fig. 1a) or an late stage of maturity (Fig. 1b)* of a batch.

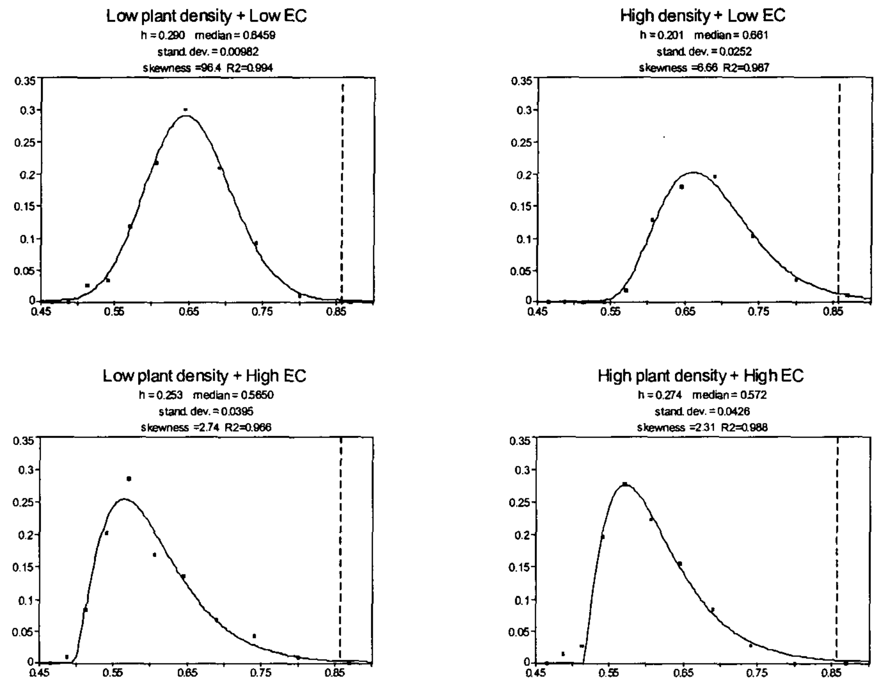

Figure 2 *Colour distributions for four different treatments.* Values on the X-axis represent the inverse colour (expressed as colour card value) and values on the Y-axis represent the relative distribution. The colour limit (dashed line) is indicated. The distribution is fitted to the Gamma function. The Gamma function is characterised by values for the maximum height (h), the median, a measure of the standard deviation (stand. dev.) and a measure of the skewness. These values are indicted for each of the four treatments. Colour distributions for four different treatments. Values on the X-axis represent the inverse colour (expressed as colour card value) and values on the Y-axis represent the relative distribution. The colour limit (dashed line) is indicated. The distribution is fitted to the Gamma function. The Gamma function is characterised by values for the maximum height (h), the median, a measure of the standard deviation (stand. dev.) and a measure of the skewness. These values are indicted for each of the four treatments.

Model description

For the development of the model an approach is used in which both the random effects of biological variation between individual units and the fixed effects of treatment and cultivar are incorporated in one non-linear model (Wilkinson et al., 1997).

The change of colour in time of cucumbers can be modelled adequately using a logistic function. The model is based on a simple degreening process where the green colour (Gr) is broken down by an enzyme system (Enz) which increases in time. The increase in enzyme activity is considered to be a crude description of the process of senescence. This results in the following kinetics, with reaction rate k, which can be solved for individual cucumbers (Eq. 1,2).

$$Gr + Enz \rightarrow 2\,Enz \tag{1}$$

$$Gr = Gr_{min,c} \frac{Gr_{max,c,gr,i} - Gr_{min,c}}{1 + \frac{Gr_{max,c,gr,i} - Gr_{0,c,gr,i}}{Gr_{0,c,gr,i} - Gr_{min,c}} e^{(tk_{c,gr}(Gr_{max,c,gr,i} - Gr_{min,c}))}} \tag{2}$$

Gr_{max} mathematically represents the maximum (dark) green colour possible at minus infinite time and practically represents the maximally possible chlorophyll concentration at the specific growing condition. Gr_{min} mathematically represents the maximum (light) yellow colour at infinite time and practically represents the colour when no chlorophyll is left. Gr_0 is the colour of the cucumber at t=0.

From Fig. 3a, where the actual degreening process for several cucumbers from a batch of the cultivar 'Enigma' is shown, it is clear that the variation in colour decreases towards a common asymptotic value. The variation in colour is described in the model (Fig. 3b, Eq. 2) by building in three sources of variation. First source of variation is the cultivar depending variation (index c) (Schouten et al., 1997). Second source of variation is caused by the growing condition (index gr). The rate constant k depends both on treatment and cultivar but does not vary with individual cucumbers. Third source of variation is the random individual variation (index i) for each cucumber due to the genetic variation and variation in preharvest conditions for cucumbers of the same treatment and cultivar.

The keeping quality of a batch can be defined as the number of days for which 95% of a batch still has an acceptable colour (Fig.3). To estimate the batch keeping quality for a batch all colour data are fitted to the model using non-linear regression. Data for all cucumbers of the same cultivar are fitted simultaneously as these cucumbers have at least one parameter in common, namely Gr_{min}.

Only 40 cucumbers per treatment were used in the fit procedure because of computational limitations. Cucumbers were randomly selected when they reached the colour limit without bacterial spoilage to have sufficient data for the last part of the degreening process. Estimations of model parameters are presented for cucumbers differing only in treatment, not in cultivar. The cultivar effect turned out to be small from earlier model calculations (Schouten et al., 1997). The blue/red ratio was used, without transformation, for Gr in equation 2. For Gr_0 the first colour measurement (day 0) was used.

The statistics of parameter estimation is presented in Table 2. The reaction rate, k, is clearly correlated with EC, the concentration of nutrient solution for the cucumber plant, indicating that a preharvest condition has a clear effect on the degreening process. Interestingly, a batch grown with a high value of EC results in a slow reaction rate of the degreening process (Table 2). A high value of EC also corresponds to a batch in an early stage of maturity having a colour distribution with considerable skewness (Fig. 2). Probably, the reaction rate is an indication of the rate at which the colour distribution f_0 evolves from f_{max}. Therefore, younger fruit has probably a lower rate of yellowing.

According to table 2 the most favourable growing condition (high EC, low plant density) has the highest and the least favourable growing condition (low EC, high plant density) has the lowest batch keeping quality. It is, however, not clear why the batch in the latter stage of maturity (Fig. 2) and the less favourable growing conditions (low EC, low plant density) has a batch keeping quality comparable to the batch in the early stage of maturity (Fig. 2) with the more favourable growing condition (high EC, low plant density), respectively 14,3 and 15,9 days (Table 2). Therefore, skewness of the colour distribution is not sufficient to describe the batch keeping quality.

Hypothesis is that a colour distribution contains sufficient information to specify the batch keeping quality. It is assumed that

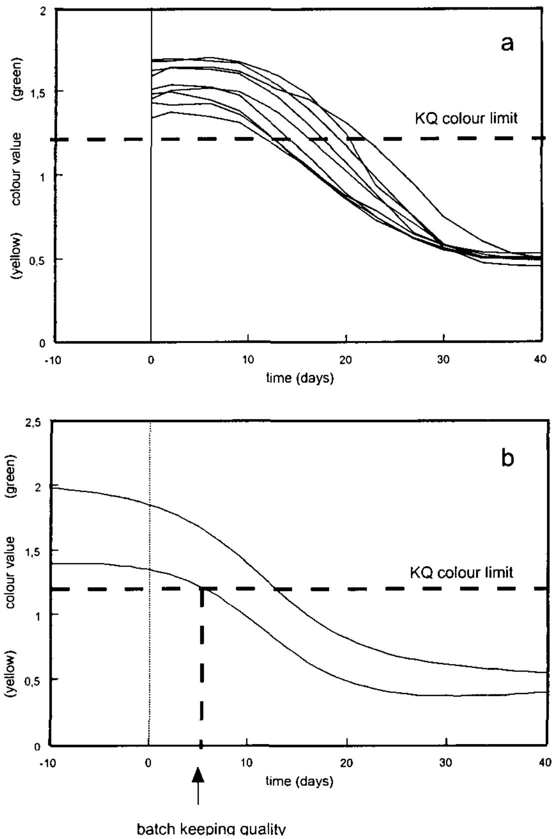

Figure 3 The degreening process for a part of a real batch with indicated colour limit. In Figure 3b the 90% confidence interval is showed. The batch keeping quality, the number of days for which 95% of the cucumbers of the batch still has an acceptable colour,

Table 2 Overview of the parameter estimates. Results are shown for cucumbers batches at different growing conditions. k depicts the reaction rate of the degreening process, Gr_{min} is the maximum yellow colour, expressed as colour card value and batch KQ is the batch keeping quality expressed in days. All estimates differ significantly from each other.

Treatment	Low plant density/Low EC	High plant density/Low EC	Low plant density/High EC	High plant density/ High EC
k	0.158	0.161	0.119	0.122
Gr_{min}	0.458	0.468	0.434	0.449
Batch KQ	14.3	8.4	18.3	15.9

the colour distribution can be described according to the Gamma distribution (Fig. 2). Parameterisation of the Gamma distribution enables the quantification of the colour distribution. It is likely that a suitable combination of parameters, such as a measure of skewness, median and a measure of standard deviation (Fig. 2) has a high correlation with the batch keeping quality. This is under investigation.

This approach of predicting the batch keeping quality on the basis of colour measurements is not possible without the accuracy in colour measurement obtained with the image analysis system. Products with a limiting quality attribute according to the autocatalytic mechanism will benefit from this approach. Particularly, products with colour as quality limiting attribute, like tomatoes, (Tijskens and Evelo, 1994) should be suitable.

References

Janse J., (1995): Effect of growing methods on the incidence of rubber necks in cucumber fruits. *Acta Horticulturae* **379**: 281-288.

Lin W.C. and Jollife P.A. (1995): Canopy light effects shelf-life of long English cucumber. *HortScience* **26**, 1299-1300.

Schouten R.E. Otma E.C. van Kooten O. Tijskens L.M.M. (1997): Keeping quality of cucumber fruits predicted by biological age. *Postharvest Biol. Technol. 12*, 175-181.

Tijskens L.M.M. and Polderdijk A.A. (1996): A generic model for keeping quality of vegetable produce during storage and distribution. *Agric. Sys.* **51**:431-452.

Tijskens L.M.M. and Evelo R.G. (1994): Modeling colour of tomatoes during postharvest storage. *Postharvest Biol. and Techn.* **4**, 85-98.

Wilkinson C., Schouten R.E., Jongbloed G. (1997): Copernicus workshop. June 4-6 Leuven.