Biological Variance in Agricultural Products Experimental Examples

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Abstract

Based on the colour development of tomatoes (theoretical) and apples (measured) as an example the approach to biological variance from a new perspective is made more clear and more explicit. The origin of biological variance is traced back to the stage of maturity at the moment of harvest. By modelling the colour development of individual units in a batch in a generic fashion, and using this model in a non-linear regression analysis on all data from different stages of maturity at harvest, orchards and storage temperatures combined, the effects of biological variance present and its changes in time can be described and predicted. From the analysis it is clear that the most important variable to explain and described variance in colour is the difference between the actual colour and the minimally possible colour for that cultivar. The explained part obtained (well over 95%) is a major indication of the usefulness and applicability of this approach

INTRODUCTION

In every batch of agricultural produce, a variance is present in all properties. The occurrence of this biological variance is an intrinsic part of the production process. It can originate from a variety of sources like climatic and weather conditions, growing area and soil structure, soil management like fertilisation and ploughing etc. More specific, it is a consequence of variation in the producing sequence as affected by the non-constant external factors like temperature, rainfall and solar radiation. Internal factors, like the level or concentration of compounds and enzymes, will also have an effect on the occurrence and magnitude of biological variance.

Up to now, the effects of biological variance have been minimised by sorting and grading on external quality attributes, and by ensuring the external conditions applied are as constant as possible. Only crudely was understood what really happens. For quite some decades, this approach was sufficiently successful. With internal quality attributes (e.g. taste, flavour and aroma) becoming increasingly important to consumers and to trade, time has come to devote our attention to the understanding of the processes that govern the occurrence and behaviour of biological variance in general.

Theoretical considerations are presented in Tijskens et al. (2000, 2001). In this paper an example is shown for the decay of the green colour of apples from different growing conditions and picked at different stages of maturity during storage

MODELLING BIOLOGICAL VARIANCE

Obtaining scientific knowledge is completely based on repeatability of experiments. This means that, except for the temperature dependency, rate constants are independent of the experimental conditions. So, assuming condition-independent rate constants, the variability, observed in our fruits and vegetables, has to be found in the initial conditions of the reactants.

For the colour of produce, this is no different. When we follow the development of the colour of individuals in a batch, instead of following the mean colour of a complete batch, we can already detect considerable differences.

Generally colour behaves according to a logistic function.

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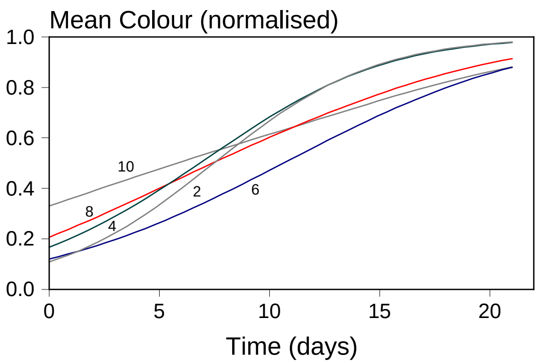
$$c = c_{-\infty} + \frac{c_{+\infty} - c_{-\infty}}{1 + \frac{c_{+\infty} - c_0}{c_0 - c_{-\infty}} \cdot e^{-k \cdot (c_{+\infty} - c_{-\infty}) \cdot t}} \qquad \text{eq. 1}$$

Normalising colour on a scale of 0 to 1 (eq. 2) and expression the maturity (or colour) at harvest time contained in C_0 as a time of biological development (t_m) results in (eq. 3):

$$c = \frac{1}{1 + \left(\frac{1}{c_0} - 1\right) \cdot e^{-k \cdot t}} \qquad \text{eq. 2}$$



bserved colour, k for the rate constant of the
and tm for the maturity stage expressed as
ons, +∞ and -∞ to the colour obtainable at +∞

harvest of 5 batches of 50 tomatoes each is
nal distribution with mean 0 days and stand.
relatively small sample of individuals already
of the mean colour of a batch as a whole (see

Fig. 1), which is different for each repetition of this theoretical experiment.

So, by working with mean data, the estimated rate constant of a process can be wrong by at least 100% as can be taken for the maximal slope of the shown curves (Tijskens et al. 1996, 1999, Allen 1988).

COLOUR IN APPLES

The colour of more than 500 apples, cv. Granny Smith, from 3 orchards and picked at two different stages of maturity, was measured during storage at 3 different temperatures (1, 4 and 10 °C) using the CIE L*,a*,b* system. The same apples were measured repeatedly in time up to 142 days using a non-destructive measuring technique (Minolta). Analysing all data using the logistic equation (eq. 1) revealed indeed one reaction rate constant common for all conditions in the experiment with an explained part of 95.5% over 3190 observations (see Table 1). The estimated energy of activation was extremely small for each orchard and picking maturity, and close to zero. The biological variance was found to reside solely in the initial colour (C_0) and $C_{-\infty}$ (eq. 1).

A clear pattern was observed for the variables C_0 and $C_{-\infty}$ (see Fig. 2), most probably related in a yet unknown way to growing and climatic conditions, the most interesting variable was the difference between both (dCol), which is directly related to the maturity at harvest. Taking the difference between C_0 and $C_{-\infty}$ constitutes some kind of correction to get rid of all yet unexplained effects of growing.

In Fig. 3 an example is shown for the distribution of the colour difference (dCol) at the start of the experiment, using the Weibull distribution as an empirical way of describing the behaviour mathematically. During storage at various temperatures, the distribution of dCol changed, showing of the small but skew distribution at harvest time, gradually changing in a broader but more standard distribution pattern. Based on the theoretical deduced distribution function (see Tijskens and Konopacki 2001) the dynamic parameters of the distribution could be estimated by trial and error. In Figure 4 fundamentally the same behaviour can be observed as for the empirical Weibull distribution.

CONCLUSIONS

The natural variation in agricultural produce can indeed be described by the theoretically deduced relationships.

The accuracy and predicting power seems to be sufficient to warrant success of further research in the area.

Good and fundamental modelling has to be combined with non-destructive and individual monitoring and integral non-linear regression analysis to obtain reliable results, capable of increasing our knowledge on biological variance.

The observed distribution of quality attributes over the individuals of a population, is strongly connected with the number of individuals in a batch and the specific rate constant of the process that changes that particular attribute.

Literature Cited

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Tables

Table 1. Results of Statistical non-linear regression.Kinetic parameters

Location	Harvest	N_{obs}	R^2_{adj}	k_{ref} *1/day*	*Ea* *kJ/mol*
Arnovo Selo	Early	535	95.7	0.02515	-0.6
Arnovo Selo	CM	536	96.5	0.02529	-0.4
Blanca	Early	538	96.3	0.02490	-1.1
Blanca	CM	507	96.4	0.02478	-1.4
Krško	Early	536	93.7	0.02464	-1.2
Krško	CM	538	94.5	0.02473	-1.1
All	All	3190	95.5	0.02537	0 (fixed)
		CM = commercial maturity Early = picked 1 week before CM			
T_{ref}	20 °C				

Figures

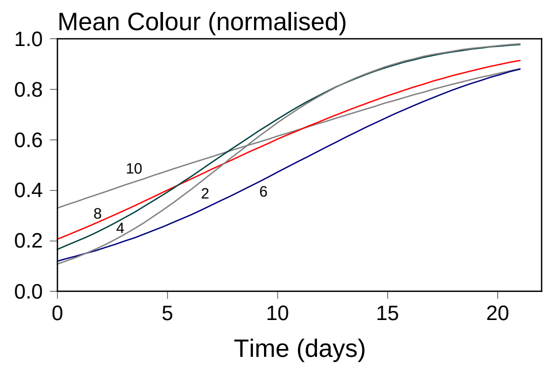

Fig. 1 The dynamic behaviour of mean colour in batches of tomatoes with different initial standard deviations based on eq. 3.

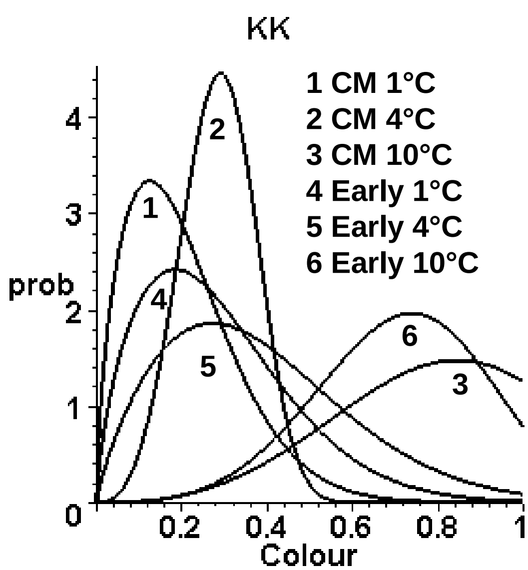

Fig. 2 Distribution pattern for the estimated values for $Col_{-\infty}$, orchard Krško, two maturity stages at harvest, prepared for three storage temperatures.

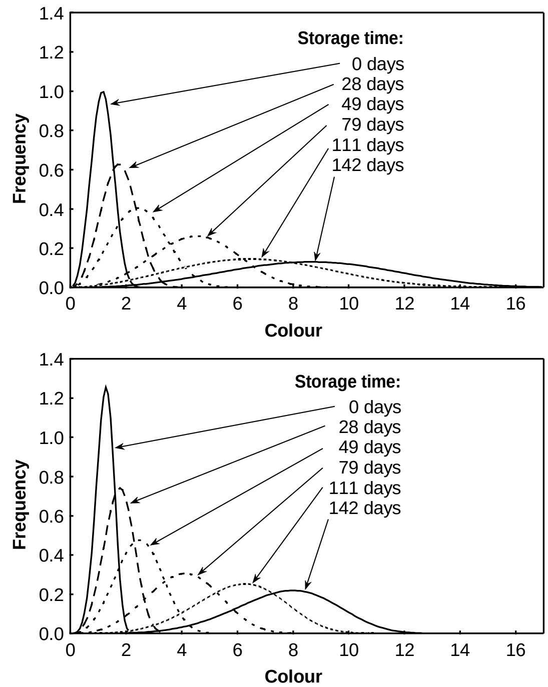

Fig. 3 Distribution in colour difference (dCol) from orchard at Krško at early (top) and mature (bottom) stage of maturity and stored up to 142 days at 4 °C.

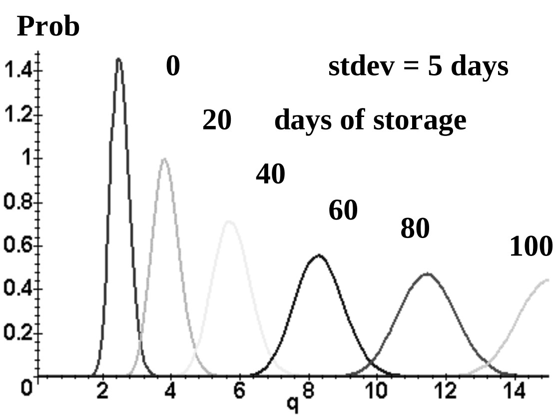

Fig. 4 The changing appearance of distribution in colour during storage. Theoretical distribution function. Orchard Krško, mature harvest, stored at 4 °C.