How to Choose Criteria to Harvest Apples. The Dynamics of Maturity

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Keywords: colour, firmness, state description models

Abstract

The storage behaviour of apples is simulated with a model based on the changes in green ground colour of three apple cultivars ('Elstar', 'Topaz' and 'Pinova') during ripening on the tree in the same orchard in three consecutive seasons, and also the effects of at-harvest maturity criteria. Taking the variation over the seasons into account (mainly found in the potential greenness), using a fixed fraction of ground colour at the moment of harvest as a harvest criterion was found to exhibit a better performance than using a harvest criterion of a fixed colour. The second part of the paper deals with theoretical relations between the product properties at the moment of harvest. These relations constitute the calibration curve per season for harvest indices like the Streif index. Variations in properties due to different seasonal conditions can affect the range of colour, as indicated in previous examples, and the synchronisation in the biological shift factor for different properties (here colour and firmness). The first effect (colour range) generates a change in slope between the two variables (colour and firmness), the second one a parallel shift. These findings can be used to improve the general performance of harvest indices over the seasons and orchards.

INTRODUCTION

Achieving an optimal harvest date has, for a very long time, been an important issue in fruit research and practice. For apples the well known Streif index (Streif, 1976, 1996) is frequently used to determine the picking date by means of destructive methods, and normally with an amazing success. But sometimes it fails badly. Maturity indices have been developed completely based on empirical relations between quality attributes. The underlying principles and mechanisms of maturity indices are hardly known. What we are basically dealing with in determining an optimal harvest date, is the variation between seasons in the mutual relationships between maturity stage, quality related properties (e.g. firmness, ground colour, starch and sugar or soluble solids content) and the kinetics of these properties during growth and subsequent fruit storage (and vegetables). Although the optimal picking date has been studied for many years, these relations are hardly studied and analysed consistently over several seasons, let alone fully understood.

The content of this contribution will be twofold. In the first place, determining the picking date of apples based on fruit ground colour (mainly chlorophyll pigments) in absolute magnitude or relative to the range of change. The second part will deal with harvesting indices in general, to understand the mostly hidden relations more clearly. Both parts are mainly based on theoretical considerations complementary to some information on fruit ground colour during growth (Tijskens et al., 2006).

PICKING DATE BASED ON GROUND COLOUR

Assume one can determine the optimal picking date based on fruit ground colour, mainly chlorophyll content (see Zude and Herold, 2002). Fruit ground colour is here expressed as red-edge (nm) (Tijskens et al., 2006). The dynamic changes (logistic model see Eq. 1 top) in red-edge was shown to be remarkably stable (same rate constant) during growth and ripening at the tree over 4 seasons and for 3 cultivars (Tijskens et al., 2006).

The range of red-edge change however, did exhibit seasonal effects (see as an example Fig. 1). In determining the optimal harvest date, one can use a fixed value in colour (here completely arbitrary chosen as 710.5 nm) or a fixed fraction of the red-edge range (here completely arbitrary chosen as 90%) that is hence different for every the season (Fig. 1). So, the effect of either choice (fixed or relative) will only show up when comparing seasons (or cultivars). Due to the larger range in red-edge in that season, that is the apple flesh was considerably greener at the start, the harvest of 2006 at an absolute value of red-edge (Fig. 1 left) will decay the first, while at a relative value (Fig. 1 right) it will decay last. Taking into consideration that the apple flesh was greener at the start in season 2006, the latter choice seems to be more appropriate. That means that the harvest criterion used to determined optimal harvest date, has to be adapted every season to the then prevailing circumstances.

STATE DESCRIPTION MODELS

When using maturity indices, complex properties that can hardly be measured (e.g. maturity, firmness at the tree) are expressed in terms of other, easier to measure properties or attributes (e.g. ground colour). What is done mathematically is to remove time from the dynamic models of both properties. Which property is chosen in the long run is for these deductions not important. That choice will depend on other more practical issues, like availability and ease of measurement, relations with maturity etc.

Assume we are dealing with expressing firmness by chlorophyll content that determines the green ground colour. And also assume both variables change according to a sigmoidal behaviour, frequently modelled with the logistic model (Eq. 1), here expressed in the notation for biological shift factor Δt (Tijskens et al., 2005).

$$C = C_{min} + \frac{C_{max} - C_{min}}{1 + e^{k_C \cdot (C_{max} - C_{min}) \cdot (t + \Delta t_C)}}$$

$$F = F_{min} + \frac{F_{max} - F_{min}}{1 + e^{k_F \cdot (F_{max} - F_{min}) \cdot (t + \Delta t_F)}} \qquad \text{Eq. 1}$$

where F represent firmness, C colour, t time, Δt the biological shift factor and k the rate constants. Indices min and max represent the maximum and minimum value possible. The only variable that is exactly the same for firmness and colour in these equations is the time. So, when searching for an expression for firmness as function of colour, we can extract the time from the colour equation, and substitute that in the firmness equation. After some (cumbersome) algebraic rearrangements, the following relation emerges:

$$F = \frac{F_{max} - F_{min}}{1 + e^{\left(\Delta t_F - \Delta t_C + \frac{\log\left(\frac{C_{max} - C_{min}}{C - C_{min}}\right)}{(C_{max} - C_{min}) \cdot k_C}\right) \cdot k_F \cdot (F_{max} - F_{min})}} + F_{min} \qquad \text{Eq. 2}$$

This equation hence, expressed the behaviour of firmness as function of the chlorophyll content, taking into consideration all differences in parameter values that can possibly occur during different seasons and for different cultivars as a result of physiological plant responses to different environmental (stress) conditions. Taking into consideration that only a part of the complete range of colour change (C_{max}-C_{min}) will occur during ripening at the tree, simulation will be restricted to ¼ to ¾ of the range.

Every season the relation between firmness and ground colour can be different due to differences in e.g. rainfall, temperature, sunshine etc. In Figure 3 an example is shown for the effect of different maturity stages in chlorophyll content (Δt_C) on firmness assuming the firmness shift factor (Δt_F) remains unchanged. Roughly, the behaviour is linear with the same slope, but with different offsets. In fact Figure 3 can be considered a calibration curve for the maturity index over the seasons assuming that firmness is a good parameter for the harvest date. All kinds of 'what-if' experiments can be conducted using these types of models. Of course when colour maturity is different for a season, the firmness maturity will change more or less in the same way. That will decrease the effect: with exactly the same shift in time for colour and firmness (when all other parameters remain unchanged) the behaviour in Figure 3 will be a single line for all seasons. And that is actually the basic assumption but mostly uncertain assumption underlying harvest indices.

In the previous section, it was shown that the range of colour change depends on seasonal influences. Now, suppose that this is the only model parameter different per season. The relation between firmness and colour changes all of a sudden quite drastically (Fig. 2). The behaviour is still roughly linear, but now each time (season) with a different slope.

Differences in rate constants (k_C and k_F) are not very likely between the seasons, in view of the results found on colour change (previous section, Tijskens et al., 2006). When there would be difference (e.g. in a very extraordinary season), the effects on the behaviour as shown in the examples Figures 3 and 2 will be tremendous, and much more pronounced than the variation in limiting values of biological shift factors.

CONCLUSIONS

Setting up harvest limits can be chosen to reflect a fixed value or a fixed percentage of the range of change. To ascertain a predefined maturity stage, the simple desk top experiment of section one, indicates that the choice of harvest limit can have a major effect on storage behaviour, and hence quality behaviour and that a relative fraction is the most logical to use. However, the range of change is rarely taken into consideration when using harvest maturity indices.

Digging into (possible) underlying rules for the different relations sometimes found between one quality attribute (hard to measure: firmness) and another one (easy to measure: colour), it has been shown that these rules can be found, based on a very simple principle of removing time from the mechanistic models for the separate quality attributes. Of course, the exact mechanism will have a considerable effect, and for every quality attribute to be used, that mechanism has to be determined and modelled. The line of reasoning however, remains the same for every mechanism.

Calibration curves can be drawn up when the mechanisms are known, and effects of weather and growing conditions can be included in that relation once they are known. In short, when harvest maturity is an important commercial issue (and it is), it is time to study the effects of seasonal and regional differences on the behaviour of important quality attributes of fruit.

ACKNOWLEDGEMENTS

The financial support of the EU by means of a grant for a short term scientific mission of COST 924 action is gratefully acknowledged.

Literature Cited

Streif, J. 1976. Einfluss der Temperatur auf verschiedene Reifemerkmale von Äpfeln. Erwerbsobstbau 18:168-171.

Streif, J. 1996. Optimum harvest date for different apple cultivars in the 'Bodensee' area. p.15-20. In: A. de Jager, D. Johnson and E. Höhn (eds.), Determination and Prediction of Optimum Harvest Date of Apples and Pears. Proc. COST 94, The Postharvest Treatment of Fruit and Vegetables. ECSC-EC-EAEC, Brussels-Luxembourg.

Tijskens, L.M.M., Heuvelink, E., Schouten, R.E., Lana, M.M. and van Kooten, O. 2005. The biological shift factor. Biological age as a tool for modelling in pre- and postharvest horticulture. Acta Hort. 687:39-46.

Tijskens, L.M.M., Herold, B., Zude, M., Schlüter, O. and Geyer, M. 2006. Biological variation in the apple orchard. p.27-34. In: J. Ovesná, V. Pouchová, K. Mitrová (eds.), Proceedings COST 924 workshop. From plant to Human genes, November 2006, Prague, CZ. ISBN 80-86555-99-2.

Zude, M. and Herold, B. 2002. Optimum harvest date determination for apples using spectral analysis. Europ. J. Hort. Sci. 67:199-204.

Figures

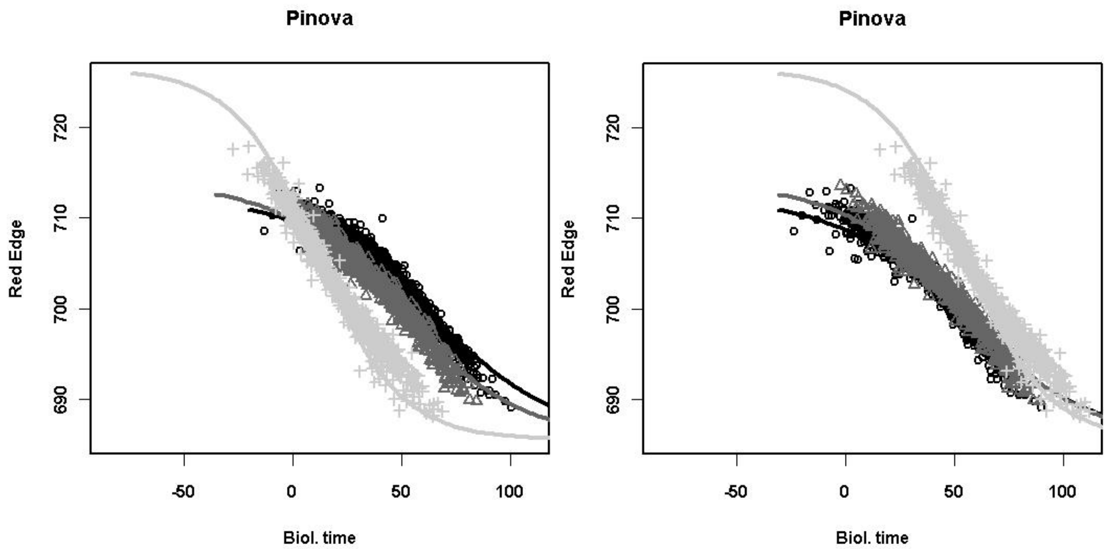

Fig. 1. Change in chlorophyll content, expressed as red-edge (nm) in apples (cv. 'Pinova') in 2004 (black), 2005 (gray) and 2006 (light gray). Left: when harvesting at an absolute value of red-edge (here 710.5 nm), Right: when harvesting at a relative value (here 90%). These limiting values are chosen completely arbitrary. Time is expressed as biological time, relative to the moment of harvest harvest.

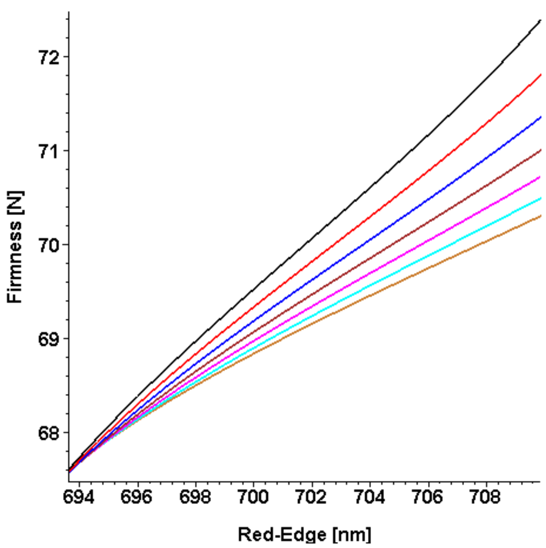

Fig. 2. The effect of different values for C_{max} on the relation between ground colour and firmness. Top: lower values, bottom: higher values.

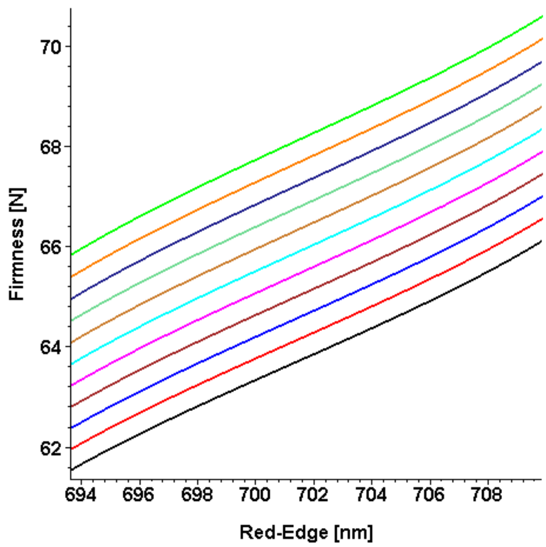

Fig. 3. Firmness versus red-edge at different levels of (red-edge) maturity. Top: more mature, bottom: more immature.