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COLOUR DEVELOPMENT IN THE APPLE ORCHARD

L.M.M. Tijskens[1], Tatjana Unuk[2], Stanislav Tojnko[2],
Janez Hribar[3], Marjan Simčič[3]

[1]Horticultural Supply Chains, Wageningen University, NETHERLANDS
[2]University of Maribor, Faculty of Agriculture and Life Science
Maribor, SLOVENIA
[3]University of Ljubljana, Biotechnical Faculty, SLOVENIA
e-mail: Pol.Tijskens@wur.nl

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ABSTRACT

Colour is traditionally one of the important appearance features of all fruit for consumers in deciding to buy them. Colour is therefore important in the postharvest supply chain. But where does that colour of fruit come from? Clearly the period of growing and the circumstances during growth are important for developing this important feature.

During several seasons (2007-2009), the skin colour of individual apples of different cultivars (‘Braeburn’, ‘Fuji’, ‘Gala’, ‘Golden Delicious’) were measured using a Minolta CR-400 chromameter during the last 40-60 days before (commercial) harvest. By including the biological variation between individual apples in the analyses and applying non linear indexed regression analysis based on process oriented models, explained parts were obtained for the a*-value, all exceeding 90%.

The estimated rate constants for the colouration process were remarkably similar for all cultivars (except ‘Fuji’) and growing conditions. That would indicate that the process of colouration is really reflecting the degradation of chlorophyll and not the production of red or yellow coloured blush (anthocyanins). The expected effect of growing conditions (fertilization and crop level, hail net or not, sunny side or shady side of the tree) did change the mechanism nor the kinetic parameter values but could all be attributed to the minimal obtainable skin colour (asymptotic values of the logistic model).

This type of information from the production period may constitute an important link to postharvest supply chain management.

Key words: colour, state of development, biological variation, maturity, hail net

MATERIAL AND METHODS

Apples of 4 cultivars (‘Braeburn’, ‘Fuji’, ‘Gala’, ‘Golden Delicious’) were grown during different seasons in the same orchard near Maribor (Slovenia). About 60 days before expected commercial harvest about 40 apples per treatment were selected and labelled (Fig. 1). The skin colour of the same individual apples was measured repeatedly over time using a Minolta CR-400 chromameter.

The treatments existed of two levels of N-fertilisation and three crop loads (‘Golden Delicious’, 2001, 2002), the presence or absence of a hail net, and the side of the tree that the apples were growing on (sunny side and shady side, ‘Gala’, ‘Fuji’, ‘Braeburn’).

Details in the ‘Golden Delicious’ experiments can be taken from Tijskens et al. (2009).

The colour model and analysis

The different treatments in the orchard during growth (fertiliser, crop load, hail net) and of different locations at the tree (sunny side of shady side) may have a marked effect on the colouration of apples. The more important question, however, is where the variation between the individual fruit belonging to the same treatment will be found. In this paper, the subject will be limited to the a* aspect of colour measured, since for product changing from green to yellow or red, that aspect contains the majority of information. The model applied is the (nowadays standard) logistic model expressed in the biological shift factor system (Tijskens et al., 2005), as described many times for all kinds of fruit types (Schouten et al., 2007; Tijskens et al., 2007, 2008ab, 2009; Unuk et al., 2008):

$$\mathrm{col} = \frac{\mathrm{col}_{\max} - \mathrm{col}_{\min}}{1 + e^{-(\mathrm{col}_{\max} - \mathrm{col}_{\min}) \cdot k_c \cdot (t + \Delta t)}} + \mathrm{col}_{\min}$$

Eq. 1

with *col* the measured colour (here a* value), *col$_{max}$* the maximum and *col$_{min}$* the minimum colour the apples can possibly reach, t is the time (days), Δt is the biological shift factor (days) and k_c the reaction rate constant (1/colour unit/day). The model is primarily based on a massive simplification of the occurring physiological process (Schouten et al., 2002).

The biological shift factor Δt contains all the information on biological variance between the individual fruit in a batch. It expresses the maturity stage of an individual fruit relative to the midpoint of the logistic function. For representing the results in an appealing fashion, the colour is standardised using an algebraic transformation of Eq. 1 to separate the effect of asymptote values from the effect of the biological shift factor (Δt):

$$\mathrm{col}_{\mathrm{stan}} = \frac{\mathrm{col} - \mathrm{col}_{\min}}{\mathrm{col}_{\max} - \mathrm{col}_{\min}} = \frac{1}{1 + e^{-(\mathrm{col}_{\max} - \mathrm{col}_{\min}) \cdot k_c \cdot (t + \Delta t)}}$$

Eq. 2

The data of season 2001 and 2002 of ‘Golden Delicious’ apples, did not cover the whole range of colour development but only the first half of the logistic curve. These data were therefore analysed using a simple exponential behaviour as an approximation of that region.

$$\mathrm{col} = \left(\mathrm{col}_{ref} - \mathrm{col}_{min}\right) \cdot e^{-k_c \cdot (t + \Delta t)} + \mathrm{col}_{min}$$
Eq. 3

The parameters in this equation reflect the same properties as in Eq. 1. Col_{ref} is a value chosen as a reference for Δt, chosen to be -10, about halfway the development range.

The data were analysed for each treatment separately, based on Eq. 1 using indexed non linear regression (nls) and based on Eq. 3 using mixed effects non-linear regression (nlme) procedures of the (freeware) statistical package R (www.R-project.org). Since the model is based on (simplified) mechanisms, the variation present in the data should not be sought in the rate constants but more in biological shift factor (Δt). The rate constant k_c was therefore estimated in common for all fruit, while the biological shift factor was estimated per individual fruit.

Figure 1. ‘Gala’ apple with identification label and measuring spot

RESULTS AND DISCUSSION

To get a feeling of the behaviour of the data, some examples are shown in Figure 2. Although the shown simulated lines already put some order in the data, the overall picture is however, more of a chaotic nature. Clearly the general drift is a sigmoidal process. The results of the statistical analyses are shown in Table 1 and Table 2.

Most striking in Table 1 is the difference in col_{min} (the most green state the apples ever can have had) among the different treatments, while the maximal obtainable colour (col_{max}) is hardly affected. Nevertheless, the behaviour of colour for both sides (sunny and shady) shows exactly the same pattern as can be taken from the standardised colour versus biological time (Fig. 3). Besides the small but nevertheless important variation in the col_{min} value in all seasons around its value determined by the cultivar studied, all variation between individual apples can be attributed to the state of maturity as expressed by the biological shift factor Δt. Very clearly the biological shift factor Δt indicates the effects of tree side, delivering more mature fruit at the sunny side mounting from 4 up to 12 days for ‘Fuji’ and ‘Gala’, while ‘Braeburn’ seems to be more affected by light (8 to 13 days). Also the hail net affects the maturity stage, from 0 up to 6 days. N-fertilisation level and crop load (‘Golden Delicious’ – Table 2) is somewhat more obscure.

In all these analyses, the rate constant could indeed be applied in common for all the individuals in a batch with remarkably high explained parts (R^2_{adj}), mostly well over 90%. Only some series of ‘Golden Delicious’ (Tab. 2) were somewhat lower due to the limited development towards the end value (shorter period of measurement). Although the rate constants seem to be somewhat different for different cultivars, they don’t seem to depend on the treatment. Moreover, the rate constants are highly similar over the different seasons. Of course the level of enzymes acting on this colouration process may vary over the different cultivars, affecting the actual observed rate constant. The similarity however is so striking that the conclusion can be drawn that the colouration process observed in the orchard is basically the breakdown of chlorophyll, not the formation of red or yellow colouring compounds.

CONCLUSIONS

The process of colouration of apples in the orchard occurs for all cultivars along the same mechanism. The differences in visual colour for differently coloured cultivars are completely covered by difference in the asymptotic values and range of colour change (col_{max} and col_{min}). The different treatments do not change the mechanism, but rather the stage of maturity of the apples and the range over which colour can change. The similarity in rate constant for the 4 different cultivars, grown in different seasons, indicated that the most important process in

Table 1. Result of the nls indexed regression analysis on ‘Gala’, ‘Fuji’ and ‘Braeburn’, based on Eq. 1

CV	Year	Loc	net	Parameters				Standard error				R^2_{adj}	N_{obs}	N_{gr}	sd.dt	p.dt
				col_{min}	col_{max}	k_c	Δt	col_{min}	col_{max}	k_c	Δt					
Braeburn	2008	sh	+	-20.61	37.12	0.0015	-41.68	0.43	1.06	0.0001	1.27	0.98	397	40	7.35	0.49
Braeburn	2008	sh	-	-20.61	34.76	0.0015	-36.30	0.73	1.18	0.0001	1.88	0.97	401	42	6.14	0.65
Braeburn	2008	su	+	-18.21	34.38	0.0014	-28.43	1.06	0.88	0.0001	1.67	0.96	400	40	9.03	0.99
Braeburn	2008	su	-	-9.72	36.48	0.0016	-28.86	1.06	1.00	0.0002	1.91	0.95	353	36	9.64	0.75
Fuji	2008	sh	+	-21.72	34.32	0.0009	-46.32	0.83		0.0000	2.08	0.92	478	41	8.33	0.27
Fuji	2008	sh	-	-20.87	35.23	0.0009	-41.78	0.94		0.0000	2.39	0.93	441	39	10.14	0.60
Fuji	2008	su	+	-12.71	38.61	0.0007	-35.07	1.29		0.0000	2.45	0.93	432	38	12.92	0.78
Fuji	2008	su	-	-8.81	36.20	0.0008	-29.38	1.39		0.0001	3.10	0.92	448	40	16.82	0.81
Gala	2007	sh	+	-12.43	38.21	0.0037	-20.79	0.71	0.72	0.0003	0.98	0.93	468	43	5.04	0.24
Gala	2007	sh	-	-11.49	39.82	0.0036	-22.12	0.73	0.87	0.0003	1.03	0.93	443	41	4.53	0.00
Gala	2007	su	+	-4.80	37.91	0.0045	-16.47	0.97	0.58	0.0004	0.98	0.92	397	37	3.03	0.20
Gala	2007	su	-	-4.75	38.56	0.0042	-16.81	0.97	0.62	0.0004	1.09	0.91	424	39	4.76	0.76
Gala	2008	sh	+	-10.82	41.22	0.0033	-20.01	0.84	1.15	0.0003	1.61	0.94	292	39	6.03	0.10
Gala	2008	sh	-	-6.86	39.95	0.0034	-18.18	0.88	1.06	0.0003	1.34	0.94	279	40	5.31	0.01
Gala	2008	su	+	7.06	39.53	0.0042	-11.98	1.36	0.63	0.0006	1.49	0.90	308	41	5.58	0.15
Gala	2008	su	-	9.87	39.46	0.0042	-8.83	1.766	0.68	0.0007	2.36	0.86	297	41	9.04	0.00

Table 2. Result of the mixed effects regression analysis on ‘Golden Delicious’, based on Eq. 3. NL is N-fertilisation level, CL is crop load

CV	Year	NL	CL	Parameter				Nobs	R^2_{adj}	Standard error of estimates		
				col_{min}	Δt	k_c	stdev Δt			col_{min}	Δt	k_c
Golden D	2001	60	low	-16.79	-32.87	0.0099	8.66	158	0.84	0.19	1.78	0.0009
Golden D	2001	60	medium	-17.75	-34.68	0.0054	13.82	163	0.89	0.26	2.69	0.0004
Golden D	2001	60	high	-18.70	-32.68	0.0054	11.41	155	0.92	0.24	2.20	0.0004
Golden D	2001	105	low	-19.22	-36.72	0.0041	13.55	145	0.91	0.33	2.78	0.0004
Golden D	2001	105	medium	-17.85	-39.76	0.0063	9.45	160	0.86	0.18	2.02	0.0006
Golden D	2001	105	high	-17.88	-38.18	0.0061	8.67	164	0.88	0.18	1.76	0.0005
Golden D	2002	60	low	-24.00	-33.89	0.0031	13.50	291	0.91	fixed	2.28	0.0002
Golden D	2002	60	medium	-24.00	-33.14	0.0034	13.26	303	0.95	fixed	2.05	0.0001
Golden D	2002	60	high	-24.00	-27.18	0.0050	6.45	295	0.88	fixed	1.09	0.0002
Golden D	2002	105	low	-24.00	-36.33	0.0032	10.79	293	0.94	fixed	1.79	0.0001
Golden D	2002	105	medium	-24.00	-33.69	0.0034	10.97	298	0.91	fixed	1.85	0.0001
Golden D	2002	105	high	-24.00	-34.62	0.0036	9.55	294	0.95	fixed	1.57	0.0001

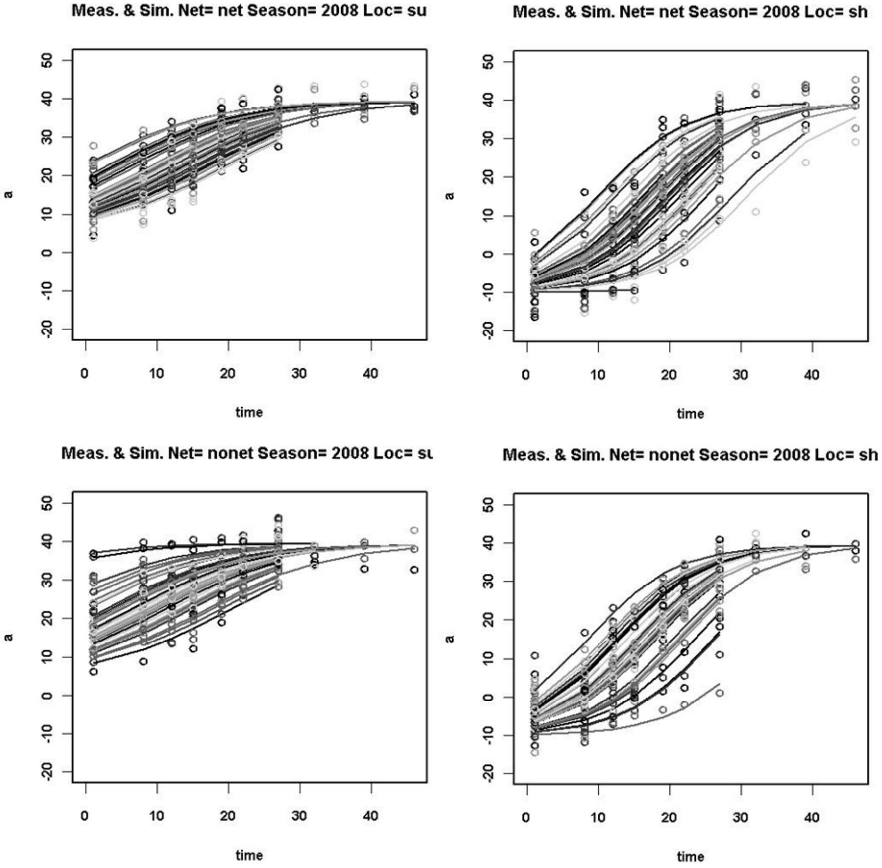

Figure 2. Colour behaviour of ‘Gala’ apple (season 2008) as function of time counting from first measurement. Top: without hail net, bottom: with hail net. Left sunny side, right: shady side. Lines represent the estimate individual behaviour

colour formation is related to chlorophyll decay, rather than formation of red coloured compounds. How this information can be used in growing apples, or the subsequent postharvest storage, is currently not yet clear. The most important practical consequence is that the technology to assess the stage of maturity and hence optimal harvest date, is available. Using this technology, all effects of biological variance between individuals can be taken into account.

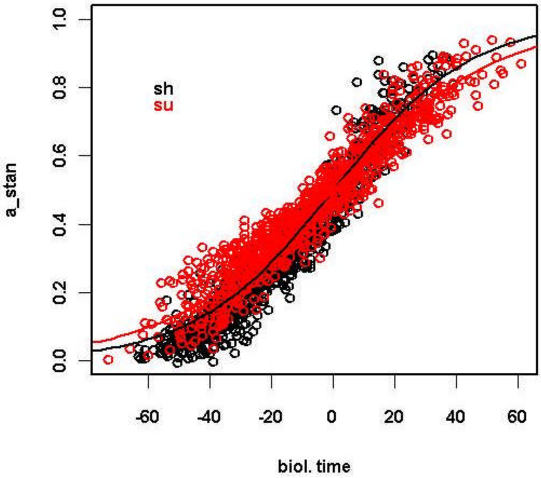

Figure 3. Standardised colour *vs* biological time (t + Δt) for 'Fuji' apples on both sides of the tree

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CZYNNIKI WPŁYWAJĄCE NA WYBARWIENIE JABŁEK

L.M.M. Tijskens, Tatjana Unuk, Stanislav Tojnko,
Janez Hribar i Marjan Simčič

STRESZCZENIE

Klienci wybierając owoce w sklepie zwracają głównie uwagę na ich kolor. Kolor musi być zatem brany pod uwagę przez dostawców. Lecz jak powstaje kolor owoców? Bez wątpienia okres wzrostu oraz warunki podczas wzrostu mają duży wpływ na wykształcenie tej ważnej cechy.

W latach 2007-2009 badano zmiany koloru skórki indywidualnych jabłek różnych odmian (‘Braeburn’, ‘Fuji’, ‘Gala’ i ‘Golden Delicious’), przy użyciu kolorymetru Minolta CR-400, w ostatnich 40-60 dniach przed przewidywanym zbiorem. W analizie uwzględniono biologiczne zróżnicowanie pomiędzy indywidualnymi jabłkami i zastosowano nieliniową regresję do stworzenia modelu rozwoju, który był zgodny w ponad 90% z rzeczywistymi wartościami a*.

Tempo zmian zabarwienia było podobne dla wszystkich odmian (z wyjątkiem ‘Fuji’) oraz dla warunków wzrostu. Wskazuje to, że proces wybarwiania owoców w rzeczywistości odzwierciedla rozkład chlorofilu, a nie produkcję czerwonych lub żółtych barwników (antocyjanów). Warunki wzrostu (nawożenie i plonowanie, zastosowanie lub nie siatek chroniących przed gradem, poziom nasłonecznienia i położenie owocu w koronie drzewa) nie zmieniły mechanizmu ani kinetyki procesu, ale mogły się przyczynić do uzyskania minimalnego koloru skórki (zbliżanie się do asymptoty w modelu logistycznym).

Powyższe informacje z okresu produkcyjnego mogą dostarczyć ważnych danych przydatnych w łańcuchu dostaw jabłek po zbiorze.

Słowa kluczowe: kolor, stadium rozwoju, różnorodność biologiczna, dojrzałość, siatka przeciwgradowa