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Colour change of apple as a result of storage, shelf-life, and bruising

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A b s t r a c t. Two apple cultivars (Champion and Jonagold) were used to determine the colour of fruit skin in display conditions. The apples were stored for five months and then kept at shelf-life conditions for an additional 15 days. The colour of each apple was measured at six points around the fruit from blush to ground colour. The measurements were performed with the Braive 6016 colorimeter according to the L*a*b* system.

After storage, the colour of the apples was found to be stable, however, some changes in the colour components during display were observed. All the brightness and chromaticity parameters of blush were different to the ground colour, indicating red areas on this side of fruit. The blush did not change, while the slight increase in ground colour indicated the influence of shelf-conditions. All changes of colour at shelf-life could be described by linear regression, while the multiplicative model indicated the influences of time on the colour of fruit skin after bruising. The high blush colour consists of a more intensive component, which is frequently a reason why bruising is invisible in this area. The red component decreases after bruising, but increases under shelf-life conditions.

K e y w o r d s: apple, colour, storage, shelf-life, bruising

INTRODUCTION

The colour and size of apples are the most important quality parameters in the estimation of the consumer (Chen, 1996; Chen and Mohri, 1997; Dobrzański and Rybczyński, 2000a; Francis, 1995; Good, 2002; Kader, 1983; Paulus and Schrevens, 1997; Płocharski and Konopacka, 1999).

With the increasing diversity of pome fruit cultivars, fruit quality recognition is becoming more and more important. Along with quality estimation (quality is not a parameter, but determined by the values of the individual parameters, including colour), colour is one of the major factors in creating a fruit's image (Studman, 1994; Alchanatis and Searcy, 1995; Felföldi *et al.*, 1996; Kader, 1983; Kameoka *et al.*, 1994; Lancaster, 1992; Molto *et al.*, 1996; Motonaga *et al.*, 1997; Nielsen, 1996).

Studman (1994) observed that consumers of the 1990's are more conscious of quality than any previous generation. There is no doubt that the market has changed over the last decade, in most developing countries, including eastern-European countries. Therefore the appearance of the fruit and vegetables has a major influence on perceived quality. However, colour as one of the most important quality parameters is influenced by cultural and consumer preference.

Colour preferences depend on: Uniformity of external colour, repeatability of fruit colour in the crop, differences between high and ground colour, intensity of blush and ground colour (saturation of red), size of high colour area, brightness-darkness, whiteness, physical defects, dents, browning, bruising, and stage of maturity (ripeness).

After harvest, the cosmetic appearance of apples seems to be a most important quality factor. However, storage has a substantial influence on the final quality of fruit, as it affects the appearance and induces colour change (Dobrzański *et al.*, 2001; Kader, 1999; Kameoka *et al.*, 1994; Saks *et al.*, 1999). Firstly, some fruit is more influenced by storage conditions than other. Secondly, shelf-life is a period of storage, with unsuitable conditions, i.e., high temperature and low humidity, for keeping apples in good quality. During this period, the darkening of the skin observed by the consumers, decreases perceptions of colour, which influences the estimation of the fruit's quality. Impacts on fruit causes damage, and bruising leads to enzymatic changes expressed as browning of the tissue (Kuczyński *et al.*, 1994). Frequently, internal browning is visible externally.

Many researchers have concentrated on finding an automatic method for detecting bruise damage in apples (Bennedsen and Qu, 1996; Studman and Li, 1997; Blahovec, 1999; Brusewitz and Bartsh, 1989; Dedolph and Austin, 1961; Garcia *et al.*, 1994; Sinobas *et al.*, 1991). Some of the

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methods are based on visual light reflection (Ayuso *et al.*, 1996), light transmission (Kuczyński *et al.*, 1994), acoustic impedance (Chen *et al.*, 1992), vibration response (De Baerdemeaker *et al.*, 1982), CO_2 development etc. The most promising results have been reported using visual light and digital image processing (Bennedsen and Qu, 1996). The bruises are observed, while the oxidation process produces the brown colour (Kuczyński *et al.*, 1994). However, the visible volumetric increase after impact is related to the lapse of time and the properties of the skin (transparency and saturation of colour).

One of the basic conditions for an improvement of quality is the proper sorting and handling of the fruit for market (Bellon *et al.*, 1992; Bennedsen, 2002; Guyer *et al.*, 1993; Miller and Delviche, 1988; Studman, 1998). Hence, sorting apples according to the same level of high colour or having the same base colour should be the most important factor for improving quality and influencing price. Separating the ripe from the over ripe and the damaged would allow the 'good' food (having adequate shelf life) to be shipped fresh to market while the less desirable, the green, the over ripe and the bruised, could be sent to a processing plant where quality could be enhanced by appropriate bioprocessing (McClure, 1995).

Colour control has a great effect on sales, however, in many cases it is performed by visually, relying on the accuracy of an individual's eyes to determine colour. Unfortunately, every individual's colour perception is slightly different. Also, it is extremely difficult to accurately describe colour in words, since each person will interpret the colour described a little differently.

Therefore, the objectives of this research were to:

- describe and identify numerically the colour of apples, without relying on an individual's colour perception;
- apply this method in quality estimation of fruit colour after storage;
- detect the changes of skin colour during shelf-life and the results of impact and bruising.

THE PHYSICAL BASES OF HUMAN COLOUR PERCEPTION

An illuminated object reflects light, which is perceived and interpreted. In physics, visible light is said to be composed of electromagnetic rays. The electromagnetic rays of visible light are different only in their frequency from other rays such as: gamma rays, X-rays, ultraviolet, infrared, microwaves and rays carrying radio and television (Epson, 1995). The frequency range reflected is influenced by the physical and chemical properties of the object and by the frequency ranges which are absorbed. However, the colour of an object is unknown, because electromagnetic rays are colourless. The human eye converts electromagnetic rays into information which can be understood by the human brain. The brain then interprets this information as the sensation of colour. The eye is able to convert the various frequencies of electromagnetic rays into information which the brain perceives as different colours. The eye is also able to convert the intensity of rays into information which the brain interprets as a sensation of brightness. It is important to remember that all objects are colourless and the sensation of colour originates only in the human brain.

Embedded in the eye's retina are the staff cells and three different types of cone cells, which are responsible for daylight and colour vision. The retina contains approximately 120 million staff cells and 6.5 million cone cells. Three different types of cone cells convert various wavelengths of electromagnetic rays (Achenbach, 2001). The perception of red is allocated to cone cells with a maximum sensitivity of 620 nm. Green is allocated to cone cells with a maximum sensitivity of 520 nm and blue to cells with a maximum sensitivity of 450 nm.

Based on the fact that the retina of the human eye contains three different types of cone cells which are sensitive to the primary colours, red, green, and blue respectively, it is possible to formulate laws. These laws state that all colours can be derived from a mixture of three primary colours. The additive colour mixing process states that by mixing red, green, and blue, white is produced. This colour mixing process is used wherever light passed directly into the eye without being reflected from an object, e.g., monitors and televisions. In the case of the subtractive colour mixing process, colours are mixed from the primary colours cyan, magenta, and yellow using the process of subtracting or filtering. Subtractive colour mixing is used when the reflection of light from an object, e.g., coloured paper or peel, passes into the eye.

Because humans are able to distinguish between several hundred thousand shades of colour (approx. 350,000), it is necessary to introduce mathematical colour models which enable each shade to be described exactly in terms of a numbered value. Due to the number of colours, it is impossible to give each particular shade an individual name.

To enable colours to be described as geometrical interpretation, there are various 3-D models for colour description. Some of these, e.g., the RGB colour model are derived directly from the additive or CMY from the subtractive colour mixing system, which converts directly into numbers. The RGB colour system is often used by software as an internal colour model as it can easily be used for calculating and requires no conversion in order to display colours on a computer screen. The CMY colour model enables any colour to be created from the primary colours cyan, magenta, and yellow, which are converted into a system of numbers. Each of the primary colours in both models is allocated to one of the eight corners of the cube. Therefore, each colour in this cube is identified by its co-ordinates. Compared with the RGB and CMY colour models, the HSV (hue, saturation, and value) colour model, hexagon pyramid, has the advantage that the colours correspond closely to our perception of colour. Consequently, this colour space is often preferred for the practical implementation of colour measurement.

Most new colorimeters allow measurements of absolute colour to be displayed in any of five colour systems: Yxy, L*a*b*, L*C*Ho, Hunter Lab, or tristimulus values XYZ. Measurements of colour difference can be displayed in any of four systems: D(L*a*b*)/DE*ab, D(L*C*Ho)/DE*ab, D(Yxy), and Hunter D(Lab)/DE (Good, 2002). Two of these systems are frequently applied in any quality estimation of fruit colour.

The L*a*b* colour system is one of the uniform colour spaces recommended by CIE in 1976 as a way of more closely representing perceived colour and colour difference. In this system, L* is the lightness factor; a* and b* are the chromaticity co-ordinates (Good, 2002):

- L* (lightness) axis – 0 is black; 100 is white.
- a* (red-green) axis – positive values are red; negative values are green; 0 is neutral.
- b* (yellow-blue) axis – positive values are yellow; negative values are blue; 0 is neutral.

The lightness factor L* and chromaticity coordinates a* and b* are defined as follows:

$$L^* = 116\left(\frac{Y}{Y_0}\right)^{\frac{1}{3}} - 16, \quad (1)$$

$$a^* = 500\left[\left(\frac{X}{X_0}\right)^{\frac{1}{3}} - \left(\frac{Y}{Y_0}\right)^{\frac{1}{3}}\right], \quad (2)$$

$$b^* = 200\left[\left(\frac{Y}{Y_0}\right)^{\frac{1}{3}} - \left(\frac{Z}{Z_0}\right)^{\frac{1}{3}}\right], \quad (3)$$

where: X_0,Y_0, and Z_0 – are Tristimulus values of luminance, X_0=98.072, Y_0=100, Z_0=118.225 for standard illumination C and (2° observer), X_0=95.045, Y_0=100, Z_0=108.892 for standard illumination D_{65} and (2° observer).

The above formulas apply only when X/X_0, Y/Y_0, and Z/Z_0 are greater than 0.008856.

ΔE*ab is the Euclidean distance between two colours in the L*a*b* system and is defined as follows:

$$\Delta E^*_{ab}=[(\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2]^{1/2}. \quad (4)$$

MATERIALS AND METHODS

Two apple cultivars (Champion and Jonagold) were used to determine the colour of fruit skin after storage. The apples were divided in 5 quality classes. The colour of each apple was measured at six points around the stem-axis of the fruit from blush to ground colour. The colour of the fruit was studied after three and five months of storage. After five months the apples were kept at shelf conditions for 15 days. The colour was determined three times: on the day when the fruit was removed from storage, after 7 days, and 15 days of shelf-life. The fruits were bruised twice: on the blush area and on the opposite side representing ground colour. After impact the apples were tested each day during the first week, and then after 9, 13, and 17 days at shelf-life.

The measurements were performed with the Braive Instruments 6016 supercolor™ colorimeter (Braive, 1994) according to the L*a*b* system. The measuring system employed by Braive colorimeter is designed to provide accurate readings and a uniform response. The light received by the meter is divided three ways and passed through special filters whose light absorbing characteristics combine with the spectral response of the photo cells. Upon reaching the silicon photocells, light energy is converted into electrical signals and sent to the microprocessor, where it is adjusted to the illuminating condition desired and then converted into co-ordinates according to the chosen colour space. Readings are displayed on the LCD panel and can be transferred to a separate computer or processor through the data output terminal. For colour readings, these values are translated into Yxy coordinates or in colour L*a*b* standard. The device allows different settings for illumination and Observer.

The lightbooth screen displays the values of all standards, and following illuminations:

A – incandescent (tungsten) lamplight,
C – daylight (filtered tungsten),
D65 – daylight, colour temperature (6500°K),
F2/CWF – cool white fluorescent lamplight (4200°K),
F11 – narrow band fluorescent lamplight (4200°K),

and Observer:

CIE 2° – Standard Observer,
CIE 10° – Supplementary Observer.

All results were determined at daylight D65 of colour temperature 6500°K.

RESULTS

The brightness and chromaticity coordinates of the skin colour of Champion apples are presented in 3-d view on Fig. 1. The brightness indexes L* shows intensity of fruit colour; most of the Champion apples range from 40 to 72. Red, as the index of chromaticity a*, ranges for this cultivar from –10 to 53. Negative a* values of the ground colour were observed, and indicated partly, a slightly green colour of the skin.

The values of index b* for these apples were in the range from –5 to 43, indicating that the skin of Champion apples is more yellow as the red component of the colour is low. All indexes of colour (L*a*b* parameters) presented in this way show a large differentiation in skin colour for Champion apples, however, the L*a*b* indexes for several apples were

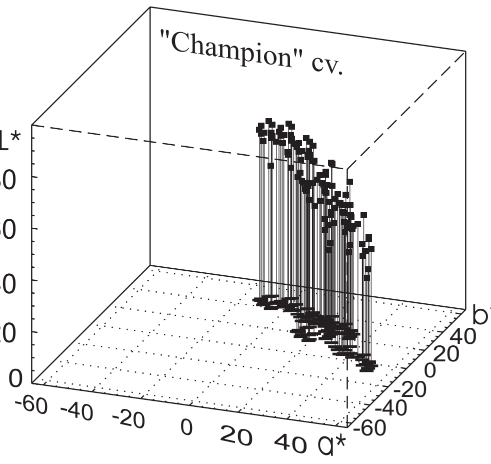

Fig. 1. The skin colour of Champion apples in 3-d view of brightness and chromaticity coordinates.

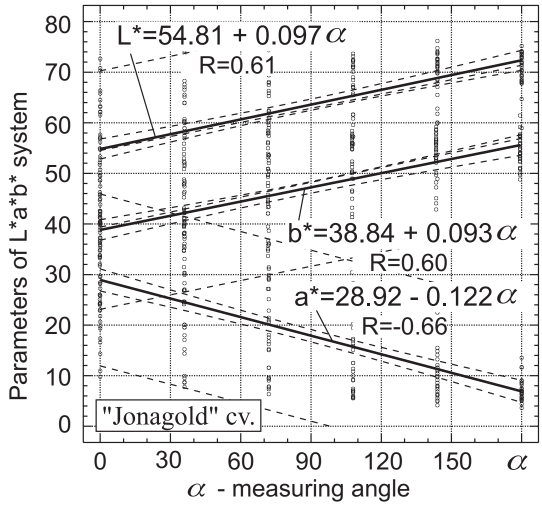

Fig. 2. The L*a*b* colour coordinates of best quality (5) Jonagold apples stored for three months.

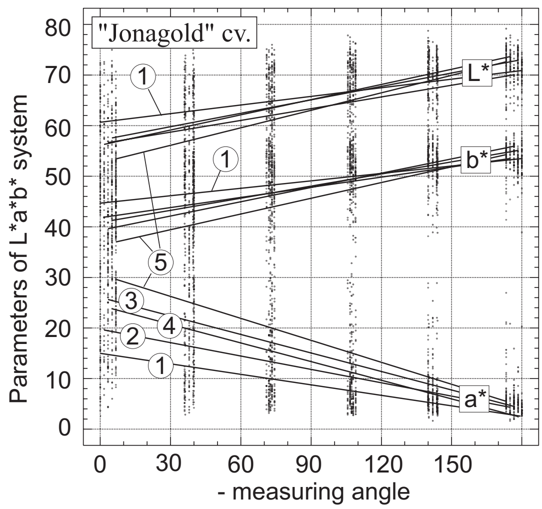

Fig. 3. The L*a*b* colour coordinates of five quality classes (1-5) of Jonagold apples stored for five months.

not significantly different. Some differences between cultivars were observed in a previous paper (Dobrzański and Rybczyński, 2001) on the cube of colour coordinates, where factors of brightness L* and chromaticity coordinates of a* and b* are represented in 3-d figures. Nonetheless, determination of fruit quality based on a 3-d view should be improved to clearly define the blush and ground colour of the apple skin.

Figure 2 presents the L*a*b* coordinates of the colour of best quality Jonagold apples stored for three months. The colour determined at six areas around the fruit shows the differentiation of each L*a*b* index from blush to ground. The most sensitive parameter is a*, which indicates a high red colour. In this case the correlation coefficient and slope parameter are higher than for both L* and b*.

Further, the storage of Jonagold apples for two additional months does not change the colour of the fruit, however, slight differences for all quality classes are observed (Fig. 3). The intensity of blush, indicates high values for red, ranging from 14.37 for low quality apples (1) to 29.62 for the best quality apples (5). The parameters of a linear regression prove the differentiation in the high values of index a*, where the slope range from –0.08 to –0.134, while the correlation coefficient range from –0.46 to –0.68 respectively (Table 1).

The lightness parameter L* of the ground colour and blush depend on the sun's rays during growing. On the other hand, the low value of L* parameter indicates the dark skin of the fruit observed. After five months of storage the colour of the apples was stable, however, some changes of colour components at shelf-life were observed. The brightness parameter L* of blush was completely different to the ground colour. The high colour of blush (Fig. 4) did not change, while the slight increase in ground colour is indicated by higher value of the slope (0.37) and correlation coefficient (0.55). The increases of the L* co-ordinate in this case tells us, that the apples seem to brighten during display.

The red component of colour on both sides, blush and ground colour, is steady at shelf-life. The low slope values (0.24 and 0.27) show that only slight increase in parameter a* is observed (Fig. 5).

The chromaticity coordinate b* is the parameter, which most significantly indicates the colour change of apple during display (Fig. 5). The ground colour of the fruit becomes especially more yellow after 7 days. The b* coordinate increases slightly after eight additional days of shelf-life. Linear regression (b*=41.89 + 0.65 d), a high value of the slope, and correlation coefficient (R=0.75) describe the influence of display on the coordinate b*. The increase of yellow in the apple skin during shelf-life, represented by the coordinate b* influences the perception of darkness and the increase of L* previously presented in Fig. 4.

T a b l e 1. Brightness parameter L* and chromaticity factors a* and b* of differ quality apple after 5 months of storage

Regression analysis – Linear model: Y = a + bX				
Q	Y	a	b	R
1	L*	60.67	0.056	0.52
2	L*	56.64	0.074	0.55
3	L*	56.28	0.096	0.65
4	L*	57.55	0.085	0.57
5	L*	53.40	0.107	0.64
1	a*	14.37	–0.080	–0.46
2	a*	19.65	–0.092	–0.57
3	a*	23.79	–0.118	–0.65
4	a*	25.63	–0.117	–0.64
5	a*	29.62	–0.134	–0.68
1	b*	44.66	0.049	0.56
2	b*	41.89	0.064	0.49
3	b*	39.62	0.091	0.62
4	b*	41.24	0.077	0.57
5	b*	36.99	0.096	0.61

Q – quality class, Y – dependent variable, a – intercept, b – slope, R – correlation coefficient.

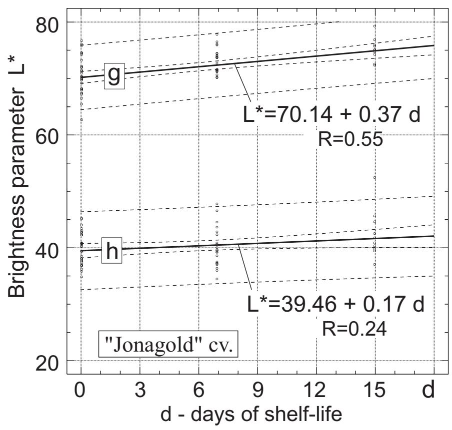

Fig. 4. The brightness coordinate L* of blush (h) and ground colour (g) of Jonagold apples during shelf-life.

The Figures from 6 to 9 present the L*a*b* colour coordinates of the best quality Champion apples during display and bruised apples kept up to seventeen days under the same conditions. The bruising inflicted caused the darkening of the fruit skin. All changes of colour during display are well described by linear regression, while the multiplicative model indicates more closely the influence of time after bruising on all colour coordinates. The high blush colour consists of more intensive components, which is frequently the reason why bruising is invisible on this area (Fig. 6–7). Only the red component presented by a* decreases after bruising, while it increases during shelf-life (Fig. 7).

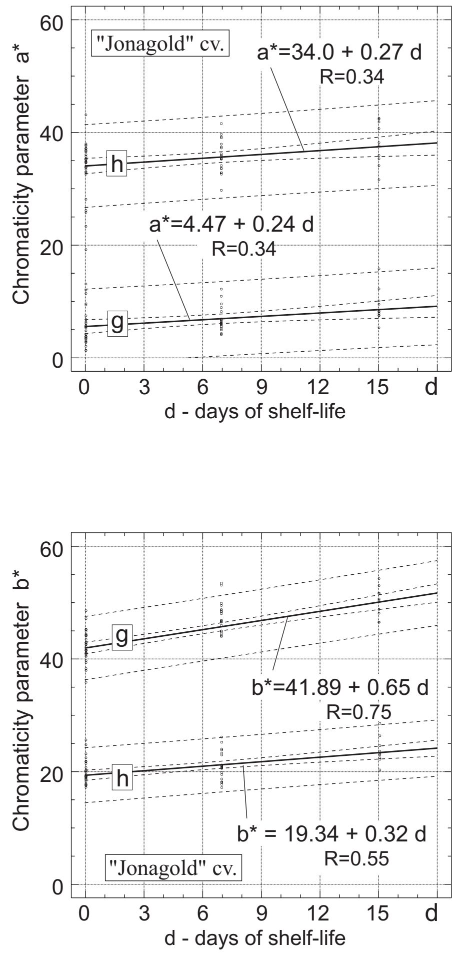

Fig. 5. The chromaticity coordinates a* and b* of blush (h) and ground colour (g) of Jonagold apples during shelf-life.

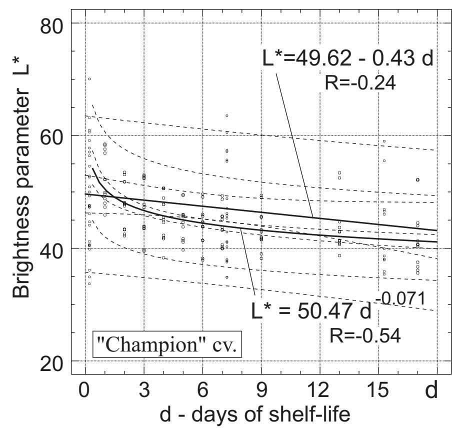

Fig. 6. The brightness coordinate L* of high colour of blush (h) during the shelf-life of Champion apples and the change of colour after bruising.

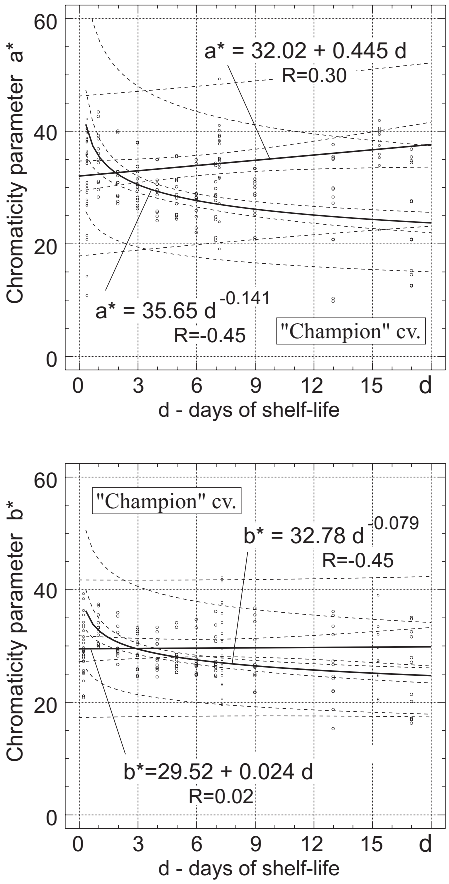

Fig. 7. The chromaticity coordinates a* and b* of high colour of blush during the shelf-life of Champion apples and the change of colour after bruising.

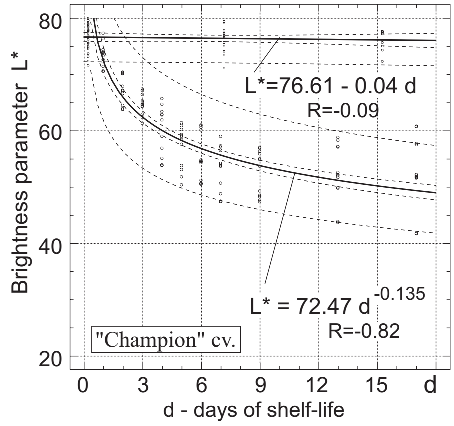

Fig. 8. The brightness coordinate L* of ground colour during the shelf-life of Champion apples and the change of colour after bruising.

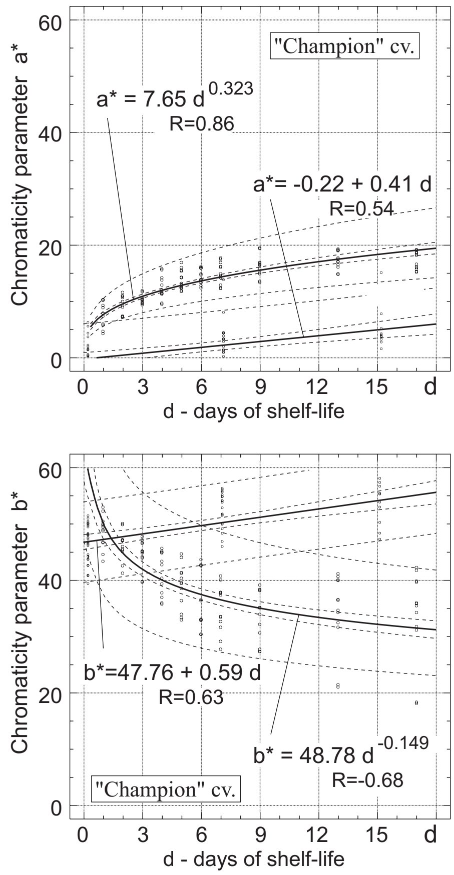

Fig. 9. The chromaticity coordinates a* and b* of ground colour during the shelf-life of Champion apples and the change of colour after bruising.

More distinct differences are visible on the ground area (Fig. 8–9). The brightness co-ordinate L* of the ground colour is stable during shelf-life. Darkening of the apple increases each day, especially during the first five days after bruising when L* rapidly decreases from 73.4 to 55.2 (Fig. 8). Keeping bruised apples for a long time under these conditions involves further darkening and a large differentiation in brightness (41.3 to 60.8).

After bruising, the red colour represented by chromaticity parameter a* increases for ground area from 3.27 to 18.3, while it increases from 0.39 to 4.78 during shelf-life. Champion apples, having no red in ground colour, gave a* values very near to zero (Fig. 9). However, the bruising caused browning of tissue, manifested as intensity of the red colour component on the skin and an increase of index a*. One day after bruising, the skin in this area becomes statistically different to the ground colour of Champion apples, being stable during a further display period of from 4 to 17 days (Fig. 9). It is easy to conclude, that only the bright side of the fruit changes its colour significantly (R=–0.82 and R=0.86) for L* and a*, respectively. The red component of bruising is similar to the high colour, being invisible on the blush area, while the bruising appears on the ground area, after only 2 days of display, affecting the unsatisfactory quality estimation.

The increase of yellow co-ordinates b* of Champion apples (Fig. 9), is similar to the results presented previously on Fig. 5 for Jonagold apples over the period of display. Positive linear regression (b*=47.76 + 0.59 d), slope, and correlation coefficient (R=0.63) indicates a similar influence of shelf-life on the coordinate b* for Champion apples. On the ground colour of Champion apples the bruising was statistically different after four days. At this time, the yellow colour of the fruit, represented by chromaticity parameter b*, decreases from 44.8 to 39.9. Display caused a further decrease of coordinate b*, however, the values covering larger differentiation in the range from 28.3 to 42.4.

CONCLUSIONS

1. The ground colour as well as blush depends on sunlight during ripening. Lightness parameter L* describing skin darkness represents freshness of product. Low value of L* indicates a dark fruit skin. The change of this parameter as a result of storage or shelf-life depends on storage conditions or bruising. More distinct differences are visible on the ground colour area. The brightness coordinate L* of ground colour is stable during the display of the apples. The darkness of the apple increases each day, especially during the five days after bruising when L* rapidly decreases. Keeping bruised apples for a long time under these conditions involves further darkening and a large differentiation of brightness.

2. Impact causes bruising, which results in a darkening of the apples. All changes of colour during shelf-life are well describe by linear regression, while the multiplicative model indicates more closely the influences of the period after bruising on all coordinate of colour. The high blush colour consists of a more intensive component, which is frequently the reason why bruising is invisible in this area.

3. The value of the chromaticity parameter a* indicates the high blush colour affecting cosmetic appearance. One day after bruising, the colour of bruised apples becomes statistically different from the ground colour, and remains uniform and stable during shelf-life. It can be concluded, that only the bright side of the fruit changes colour significantly. The red component of the colour is similar to the high blush area, however, after 2 days of display, the appearance of bruising on the area of ground colour seems to be unsatisfactory to the consumer.

4. The increase of yellow in Champion apples is similar to Jonagold during display. Positive linear regression indicates similar influence of shelf-life on the coordinate b*. On the ground area the bruising was statistically different after four days. At this time, the yellow in the fruit decreases. The shelf-life caused a further decrease in the yellow of the bruised apples, however, the values cover a larger differentiation of coordinate b*.

5. Estimation of fruit quality based on the L*a*b* system describing coordinates of colour could be useful in connection with marketing, for monitoring consumer preferences and assessing the products after storage and during shelf-life. This system, if properly integrated into a marketing plan, could improve the appearance of fruit, making consumers more aware of true quality factors.

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