Modelling the Colour of Strawberry Spread During Storage, Including Effects of Technical Variations

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Key words: strawberry spread, colour, modelling, technical variation

The colour of freshly processed strawberry spread changes relatively rapidly from a bright red to a dull red, which then makes its appearance generally less acceptable for consumers. The colours of strawberry spreads following several processing conditions were measured under different storage conditions. Additional sugar and colorant had only slight effects on the colour decay, while exclusion of oxygen and daylight did not affect this process. The only condition that clearly maintained the freshly processed appearance was storage at 4°C. Hexagonal bottles were filled with the strawberry spreads and their colour was repeatedly measured at the six sides of the bottles, using a Minolta chroma meter. Data were analysed using non-linear indexed regression analysis based on a logistic function for the three colour aspect of a*, b* and L*. This technology allowed the determination of the variation in these data in terms of improved reliability (R², adj >90%). It also allowed better interpretation of the processes involved. All variations in the data could be attributed to technical variation.

INTRODUCTION

Visual perception of the colour of fresh and processed fruit is the first factor that affects quality perception, as this supersedes both flavour and textual perceptions [Ford et al., 1997]. The colouring compounds in strawberries are mostly anthocyanins, which are widely distributed water-soluble plant pigments [Mazza & Miniati, 1993]. In strawberries, pelargonidin 3-glycoside is the predominant anthocyanin [Wang et al., 2002; Aaby et al., 2005] and it is largely responsible for the red colour of the fruit [Aaby et al., 2005].

The main factors that affect the final anthocyanin concentrations and the colour of a spread are the processing conditions [Garcia-Viguera & Zafirlla, 2001], fruit variety, freezing period of the fruit prior to processing, and method of preparation [Gimenez et al., 2001; Talcott, 2007]. Additives to extend the shelf life of spreads can have an impact on their anthocyanin stability [Kopjar et al., 2003]. Ascorbic acid can accelerate anthocyanin degradation, and pH can have an impact on colour and pigment stability. Addition of pectin in viscous products increases the anthocyanin stability [Buchweitz et al., 2013], while the sugar concentration affects the colour stability due to a lower water activity [Hubbermann et al., 2006].

The temperature during storage of spreads has a major impact on colour and pigment stability. Spreads stored at 37°C show 98% pigment degradation after 3 months of storage, while those stored at 20°C show similar degradation after 6 months [Giusti & Jing, 2007]. Furthermore, compared to low-temperature storage (4°C) [Haffner et al., 2003], anthocyanin degradation is greater when spreads are stored at 20°C [Wicklund et al., 2005] or 15°C [Patras et al., 2011]. Fortunately, colour degradation is not as drastic as pigment degradation, which suggests that polymerised pigments and co-pigmentation reactions are important for the colour of these products during storage [Giusti & Jing, 2007].

Through monitoring the effects of processing conditions and additives on the changes in colour of strawberry spreads, the main aim of this study was to determine the effects of the measuring techniques (i.e., of strawberry spread colour measurements using closed hexagonal jars) and the inevitable measuring errors induced by these techniques, through the application of novel approaches to data analysis.

MATERIAL AND METHODS

Plant material

Frozen strawberries (Fragaria × ananassa cv. ‘Senga Senega’) were purchased from a local store in Kamnik (Slovenia) and stored at -20°C until further use.

Processing and storage conditions

Frozen strawberries (800 g) were thawed in a microwave (Gorenje MNO 20) at 800 W for 2 min. Thawed fruit mate-
Table 1. The strawberry spread components and storage conditions.

<table>
<thead>
<tr>
<th>Series</th>
<th>Production</th>
<th>Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Soluble solids (%)</td>
<td>Pectin (%)</td>
</tr>
<tr>
<td>A</td>
<td>38</td>
<td>0.6</td>
</tr>
<tr>
<td>B</td>
<td>38</td>
<td>1.2</td>
</tr>
<tr>
<td>C</td>
<td>43</td>
<td>0.6</td>
</tr>
<tr>
<td>D</td>
<td>38</td>
<td>0.6</td>
</tr>
<tr>
<td>E</td>
<td>38</td>
<td>0.6</td>
</tr>
<tr>
<td>F</td>
<td>38</td>
<td>0.6</td>
</tr>
<tr>
<td>G</td>
<td>38</td>
<td>0.6</td>
</tr>
</tbody>
</table>

where col is the measured colour (i.e., the a*, b* or L* value), col_max is the maximum and col_min is the minimum colour that the samples can possibly reach at + or – infinite time, Δt is the shift factor (in days), t is the time (in days), and k is the reaction rate constant (in L/mol/day). Here, Δt is a stochastic parameter that is different for each individual sample, and it expresses the colour development in terms of the time of the colour change relative to the midpoint of the sigmoid curve. Preliminary analyses showed that the ranges of the changes in the colour values (i.e., col_max – col_min) were approximately constant per combination of processing condition and jar side. The reordering of Equation (1) provides Equation (2), which is the final equation that was used in the analyses of all of the colour values.

\[
\text{col} = \frac{\text{col}}{1 + e^{-k_c A t}} + \text{col}_{min} 
\]

where col is the measured colour (i.e., the a*, b* or L* value), and col is the range of the change.

Statistical analysis

The model development and the mathematical deductions were conducted in Maple 14 (MapleSoft, Waterloo Maple Inc, Waterloo, Canada), which is a computer programme that is used to handle and solve algebraic and differential equations. The data were analysed using the indexed non-linear regression procedure ‘nls’ of package R (R Development Core Team R, 2005), based on Equation (2). The concept of ‘indexed’ indicates that some parameters (k, Δt, col) were estimated in common for all of the individual samples (i.e., fixed effects), while the minimum asymptote col_max was estimated as a stochastic parameter for each side of each jar (i.e., random effects), to determine the variation in the samples. The normality of the distributions was tested using Shapiro-Wilk tests in package R.

RESULTS

Raw data

The range over which the colour aspects changed during storage was the largest for a*, while b* and L* showed consid-
erably smaller ranges than expected for a red-coloured product. The variation over the different processing conditions and jar sides, however, was smallest for a* relative to the range of changes. Indeed, for the colour aspects b* and L*, the variation was larger than the ranges of the changes. Figure 1 shows some examples for all three of the colour aspects under the same processing conditions. For the other processing conditions, the results were similar. The range of the changes and the existing variation can be seen in the cloud of points around the mean behaviour (i.e., the simulated line).

**Analysis per production series**

Apparently, the magnitudes of the variation did not change with time. This would signify that there was a shift in the lower limits for the different series of production procedures and jar sides. Biological variation of the plant material was not very likely after the intense blending and mixing applied during the processing. This implies that the variation was caused by technical variation between the different jars and the jar sides, since no other type of variation exists. Purely technical variation induced by aberrations in the thickness and structure of the jar sides makes it also plausible that the ranges of the changes were relatively constant per processing condition. The data were therefore analysed per processing condition using indexed non-linear regression based on Equation (2), with variation of the lower asymptote (colmin) per jar side, while at the same time estimating the other parameters (colr, k, Δt) in common for all of the combinations. These data are shown in Table 2.

The explained parts (R^2adj) were all high (>90%), except for series D (see Table 2). The full ranges of the colour changes were not reached in this series, due to storage at a much lower temperature (4°C). The standard errors of the estimates obtained were all low (≤10%). For each colour aspect, the ranges of the changes (colr) and the shift factor (Δt) were similar under all of the experimental conditions, except again for the series with storage at 4°C. This probably signifies that the existing variation in asymptote values is indeed technical one, which was caused by the constant differences in the aberrations in the different jar surfaces. In other words, the variations were technical variations induced by the structure and thickness of the sides of the glass jars.

![Figure 1](image1.png)

**FIGURE 1.** Raw data of the colour aspect for processing condition A, showing the range of the changes and the existing variation. The lines represent the simulated mean behaviour based on the estimated parameter values, as shown in Table 2.

![Figure 2](image2.png)

**FIGURE 2.** Corrected data of the colour aspects (col-colmin) for processing condition A. Some of the variation remains unexplained (i.e., the width of the cloud of points around the simulated lines). The lines represent the simulated mean behaviours based on the estimated parameter values, as shown in Table 2.
TABLE 2. Result of the combined analysis of the three colour aspects for each processing procedure.

<table>
<thead>
<tr>
<th>Col</th>
<th>Series</th>
<th>Parameter</th>
<th>Standard error of estimate</th>
<th>Admin</th>
<th>Stochastic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>col</td>
<td>∆t</td>
<td>k</td>
<td>col&lt;sub&gt;min&lt;/sub&gt;</td>
</tr>
<tr>
<td>a</td>
<td>A</td>
<td>9.01</td>
<td>-49.63</td>
<td>-0.0041</td>
<td>5.09</td>
</tr>
<tr>
<td>a</td>
<td>B</td>
<td>8.54</td>
<td>-51.23</td>
<td>-0.0041</td>
<td>5.25</td>
</tr>
<tr>
<td>a</td>
<td>C</td>
<td>7.17</td>
<td>-64.30</td>
<td>-0.0043</td>
<td>4.44</td>
</tr>
<tr>
<td>a</td>
<td>D</td>
<td>11.20</td>
<td>-156.55</td>
<td>-0.0055</td>
<td>1.75</td>
</tr>
<tr>
<td>a</td>
<td>E</td>
<td>9.31</td>
<td>-50.90</td>
<td>-0.0036</td>
<td>5.07</td>
</tr>
<tr>
<td>a</td>
<td>F</td>
<td>8.16</td>
<td>-54.51</td>
<td>-0.0034</td>
<td>5.47</td>
</tr>
<tr>
<td>a</td>
<td>G</td>
<td>9.57</td>
<td>-36.16</td>
<td>-0.0036</td>
<td>5.32</td>
</tr>
<tr>
<td>b</td>
<td>A</td>
<td>2.64</td>
<td>-77.81</td>
<td>0.0108</td>
<td>5.67</td>
</tr>
<tr>
<td>b</td>
<td>B</td>
<td>2.72</td>
<td>-73.97</td>
<td>0.0107</td>
<td>5.41</td>
</tr>
<tr>
<td>b</td>
<td>C</td>
<td>1.80</td>
<td>-91.04</td>
<td>0.0225</td>
<td>4.71</td>
</tr>
<tr>
<td>b</td>
<td>D</td>
<td>2.24</td>
<td>-135.87</td>
<td>0.0099</td>
<td>5.90</td>
</tr>
<tr>
<td>b</td>
<td>E</td>
<td>2.19</td>
<td>-73.08</td>
<td>0.0157</td>
<td>5.72</td>
</tr>
<tr>
<td>b</td>
<td>F</td>
<td>1.35</td>
<td>-81.06</td>
<td>0.0300</td>
<td>5.01</td>
</tr>
<tr>
<td>b</td>
<td>G</td>
<td>1.67</td>
<td>-49.80</td>
<td>0.0335</td>
<td>5.81</td>
</tr>
<tr>
<td>L</td>
<td>A</td>
<td>3.52</td>
<td>-32.79</td>
<td>0.0185</td>
<td>24.28</td>
</tr>
<tr>
<td>L</td>
<td>B</td>
<td>3.60</td>
<td>-31.34</td>
<td>0.0162</td>
<td>24.09</td>
</tr>
<tr>
<td>L</td>
<td>C</td>
<td>2.89</td>
<td>-38.59</td>
<td>0.0177</td>
<td>23.24</td>
</tr>
<tr>
<td>L</td>
<td>D</td>
<td>3.94</td>
<td>-149.00</td>
<td>0.0197</td>
<td>24.38</td>
</tr>
<tr>
<td>L</td>
<td>E</td>
<td>3.59</td>
<td>-30.96</td>
<td>0.0164</td>
<td>24.02</td>
</tr>
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<td>L</td>
<td>F</td>
<td>3.15</td>
<td>-28.02</td>
<td>0.0175</td>
<td>23.33</td>
</tr>
<tr>
<td>L</td>
<td>G</td>
<td>3.69</td>
<td>-25.79</td>
<td>0.0199</td>
<td>24.13</td>
</tr>
</tbody>
</table>

The standard deviation of the lower asymptote (sd.col<sub>min</sub>) was about the same for all of the processing conditions. This is also an indication that the variation was technical variation. The majority of the distributions of col<sub>min</sub> can be considered normal, as indicated by the probability of the Shapiro-Wilk tests (p.col<sub>min</sub>) being above 0.05.

The individually measured colour data were corrected for the lower asymptote (col - col<sub>min</sub>) as estimated for this series, which effectively removed the variation in the data. Figure 2 shows these corrected data for the same processing conditions as used in Figure 1. There is still some variation left that is not taken into account by the model and the analysis. It is however likely that also this unexplained variation is a technical variation, which might have been induced by different light conditions (i.e., stray light) during the measurements.

**Effects of the processing and storage conditions**

To determine the effects of the different processing conditions, the simulated behaviour for the mean value of the lower asymptote is shown in Figure 3. For the a* value, there were almost no effects of the processing conditions, except for the slightly darker initial colour at the high soluble solids content (series C). Only the lower storage temperature (series D) clearly had beneficial effects. For b* and L*, the additional soluble solids (series C) and the additional colorant (series F) appeared to cause darker initial colour, as can be seen from the lower asymptote, as well as darker final colour (upper asymptote), although these conditions did not affect the mechanism at work. In view of the small range of the change for these aspects, the effects on perception by the human eye will be negligible. The effects of storage temperature on the behaviour of L* showed the same effects as for a*, while the effects on b* appeared to be less pronounced. Apparently the yellowing is less sensitive to temperature.

**DISCUSSION**

The lower storage temperature had a beneficial effect on colour retention and anthocyanins content in strawberry jams [Mazur et al., 2014]. Storing the products at 4°C in the dark was indispensable for colour and pigmet retention, while illumination resulted in rapid discoulouration [Holzwarth et al., 2013]. The colour of anthocyanins is preserved much better when kept in the dark [Cavalcanti et al., 2011]. The presence of oxygen can amplify the anthocyanins degradation through different mechanisms [Patras et al., 2010]. However, gas con-
dictions (air vs. nitrogen) had no effect on anthocyanin loss during storage of strawberry juice [Bakker et al., 1992]. Exclusion of daylight during the storage, or of oxygen at the time of jar filling, did not affect the change in colour, neither kinetics nor level. The addition of pectin markedly enhanced anthocyanin stability [Buchweitz et al., 2013]. In our study, however, the addition of pectin did not have any protective effect on colour stability of the strawberry spreads.

Sugar at concentrations higher than 20%, did not to prevent significantly the decay of anthocyanins and colour in berries [Nikkhah et al., 2007]. On the other hand, a positive effect of sugar on colour retention was reported [Hubbermann et al., 2006], presumably due to lower water activity. Colour stability of strawberry syrup was greatly improved by increasing the concentration of anthocyanins [Cavalcanti et al., 2011]. We found that higher sugar content or higher anthocyanins concentration had only slight effects on colour deterioration rate during storage.

In short, except low temperature storage, all methods tested to achieve the greater colour stability (i.e., storing in the darkness, use of nitrogen for oxygen elimination, addition of pectin, addition of sugar, addition of colorant) were ineffective.

**CONCLUSIONS**

The range of the changes in colour of stored strawberry spread was, as expected, the largest for a*, while for b* and L* they were relatively small. Thus, the visual perception of colour will be determined for the most part by the a* value. The processing conditions had only minor effects on colour changes. Daylight and exclusion of oxygen also had little effect on the changes in colour for all three of these colour aspects. The addition of soluble solids and colorant had slight darkening effects. Temperature during storage was the only factor that affected the kinetics of colour changes (rate of change). The remaining processing conditions only affected the value of the model parameters col and colmin (range of change).

Colour changes of strawberry spreads during storage can be described by logistic functions in terms of all three of the colour aspects, a*, b* and L*. Indexed non-linear regression analysis on the data from the same samples in time was very powerful for the determination of the variation, and this considerably increased the reliability of the analysis. By including the variations in the analysis, the effects of the experimental conditions can be interpreted more clearly.

The system for measuring the colour of a semisolid produce such as marmalade, spread, jelly, dough during longer period (including the possibility of pasteurisation) in hexagonal or square jars seems quite applicable, especially when some modifications will be applied (e.g., shielding of direct and stray light), since the majority of variation in the data can be traced back to the glass structure by using the indexed non-linear regression technology.

The problem of discolouration of strawberry spreads can only be solved by investigating the real reasons and mechanisms behind the changes in anthocyanin degradation (i.e., the changes in reddishness) and polyphenols (i.e., browning). This analysis technology offers advantages for the unravelling of the mechanisms at work here. Further research on this topic will be undertaken.

**RESEARCH FUNDING**

This study was financed by statutory funds of the Department of Food Science and Technology, Biotechnical Faculty, University of Ljubljana.

**CONFLICT OF INTEREST**

None declared.

**REFERENCES**


