Scaling Transparency, Opacity, Apparent Flavour Strength and Preference of Orange Juice

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ABSTRACT

Twenty-three orange juice samples were carefully prepared with different concentrations. A sphere-based spectrophotometer was used to measure the samples in terms of spectral trans-reflectance function. The data were analysed using the Kubelka-Munk theory. Psychophysical experiments were conducted. Subjects judged attributes of 'transparency', 'opacity', 'apparent flavour strength' and 'preference' on juice samples contained in highball glass. The accuracy and repeatability of the visual results were shown to be consistent. Different models based upon the measured spectral data were successfully developed to fit the visual results.

1. INTRODUCTION

Hutchings[1] suggested that six attributes are closely associated with the total appearance of an object: visual structure, surface texture, colour, gloss, translucency and temporal features. This paper describes methods for scaling important appearance attributes associated with the translucency properties of orange juice including transparency, opacity, apparent flavour strength and preference[2] .

Twenty-three orange juice samples were prepared using SUNNY DELIGHT® ORIGINAL. The juice as bought was defined as 100% concentration and this was diluted using de-ionised water[3] to form samples with different concentration from 0% to 100%. All the samples were placed in an air-conditioned laboratory with a temperature of 21°C±1°C, in which all experiments were conducted.

A sphere-based spectrophotometer (GretagMacbeth® CE7000A) was used to measure the trans-reflectance of the juice samples. The instrument was calibrated using a white ceramic reflectance standard and a black trap. The liquid samples were placed into a cuvette having a path length of 5mm. Spectral measurements of trans-reflectance were obtained. For the trans-reflectance measurements white and black backings were attached to the cuvettes; while strong diffuse light transmitted through the liquid samples and reflected back through the sample then to the photodetectors[1]. These backings were made from card and had luminance factors ***Y*** of 90.3 and 4.3 respectively. The same backings were also used in psychophysical experiments and digital imaging experiments. The spectral data were analysed using the absorption coefficient (K) and scattering coefficient (S) calculated according to the Kubelka-Munk theory [4, 5]. Internal transmittance (T_i) measurements were also used[6, 7] to correlate with psychophysical results.

$$K_x = S_x(a-1) \tag{1}$$

$$S_x = \frac{\operatorname{arcoth}\left[(1-aR_b)/bR_b\right]}{b} \tag{2}$$

$$Ti = \left[(a - R_b)^2 - b^2\right]^{1/2} \tag{3}$$

$$a = \left[R_w + \left(\frac{R_b - R_w + R_g}{R_b R_g}\right)\right] \Big/ 2 \tag{4}$$

$$b = \left(a^2 - 1\right)^{1/2} \tag{5}$$

where: S_x is scattering at depth x; K_x is absorption at depth x; R_b is reflectance of the sample when placed on a black backing; R_w is reflectance of the sample when placed on a white backing; R_g is reflectance of the white backing. Note that reflectance, scattering and absorption are functions across the whole visual spectrum. At a later stage, Little[8] found that by replacing the reflectance values in Equations. (2), (3) and (4) by the tristimulus values could also account for observers' perception of appearance quality. This is called "Little" method in the following discussion.

A set of psychophysical experiments was conducted. The samples were put into highball glasses for observers to judge the attributes of transparency, opacity and apparent flavour strength and preference in a VeriVide viewing cabinet as illustrated in Figure 1. The walls of the VeriVide viewing cabinet were painted in white with a *CIELAB L** of 90.

For transparency and opacity, category judgements were made by each observer on each individual sample using a scale from 1 to 10. The references for opacity and transparency were an opaque sample (a piece of black cardboard) and a clean glass containing de-ionised water respectively. These two references were presented to each observer before each experimental session. For apparent flavour strength and preference, category judgements were made using a seven point scale. A scale value of 1 represented a low strength and highly disliked, while 7 represented a high strength and highly liked, respectively.

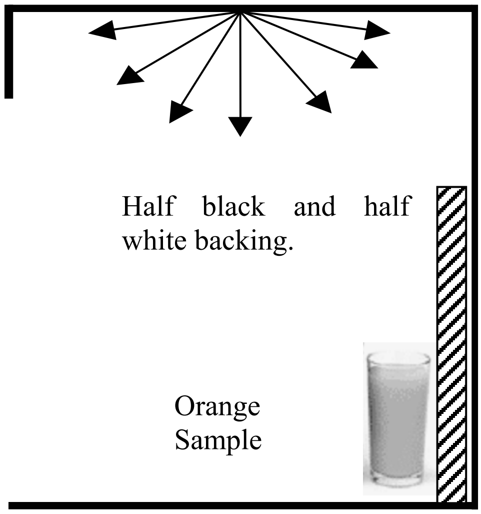


Figure 1: Experimental set-ups for psychophysical experiment using highball glasses in VeriVide viewing cabinet.

The samples were presented to observers in a random order. Ten observers, who passed the Ishihara vision test, participated in the experiments including 5 British, 1 French, 3 Chinese and 1 Pakistani. The experiment was divided into 4 sessions according to the attributes scaled: transparency, opacity, apparent flavour strength and preference. The whole experiment was conducted within 4 days. One day one session was conducted for one attribute to ensure minimal change in colour of the specimens and to allow observers consistency of thought on the day. Each sample was assessed twice in each session. In total, there were 1840 observations; i.e., 23 samples x 2 times x 10 observers x 4 attributes.

Coefficient of Variation (*CV*) was used as a statistical measure to indicate the agreement between two sets of data. This involves calculation of the root-mean-square deviation of the distances of the points from the 45° line as a percentage of the mean value of the y set, which gives results independent of the size of the set y. It can be considered as relative percentage error.

$$CV = \frac{100}{\bar{y}}\sqrt{\frac{(x_i - y_i)^2}{n}} \qquad (6)$$

Since a categorical judgement method was used, the observers' data were treated as interval scale data and arithmetic mean was used to represent the panel results [9].

2. RESULTS

The first set of experiment results were compared with the repeated results for each observer. The mean of these comparisons was used to indicate the repeatability of observers as shown in Table 1. The repeatability for opacity was slightly higher than that for transparency. However, this degree of repeatability is highly satisfactory.

Table 1: The summary of observer performance for Psychophysical experiment.

	CV	Experiment with highball glass
Observer repeatability	Transparency	6
	Opacity	3
Observer accuracy	Transparency	14
	Opacity	17

The averages of all observers' results give mean data for all experiments. These averaged results can be used as standard observer results. Comparing each individual observer results with standard results gives observer accuracy as shown in Table 1. Opacity data were slightly worse than transparency data. However, the mean *CV* range from 14 to 17 indicates acceptable results.

It is believed that the relationship between transparency and opacity are equal and opposite. Figure 2 shows the results from the experiment in terms of transparency and opacity against concentration of juice samples. The 95% confidence error bar was also plotted at each data point representing the spread of visual data between observers. Considering the size of the deviations, the transparency scale and opacity scale crossed within the range from 26.7% to 40.0% concentration. When the two sets of data are added together, the sum is consistently between 9 and 10. These results are not significantly different from 10 when compared with the observer errors. Hence, the formula of "Transparency = 10 – Opacity" seems to fit this data.

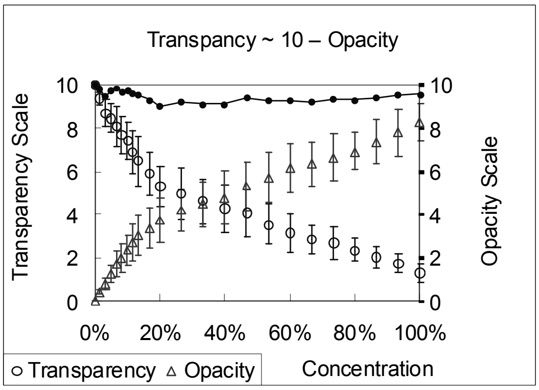
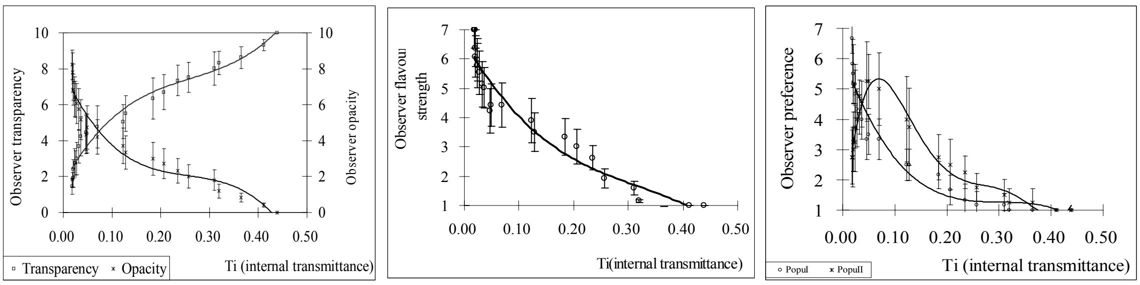


Figure 2: The relationship of transparency and opacity vs. concentration with 95% confidence error bar fitted on each panellist point.



(a) (b) (c)

Figure 3: ***T_i*** coefficient based on digital imaging method fitted with observer transparency and opacity scales (a), and apparent flavour strength (b) and observer preference scales (c), with 95% confident level error bar plotted.

Different models based upon the measured spectral data were developed to fit the four sets of psychophysical results. In addition, a digital camera based imaging system developed to measure colour accurately[10] was extended to provide values of *K, S,* and T_i using the Little method. It was found that the results from the spectrophotometer and the imaging system agreed well with each other. The T_i calculated from the luminance factors "*Y*", which was proposed by Little[8], was used to reveal the relationship with the visual transparency, opacity, apparent flavour strength, and preference as shown in Figure 3. Figure 3(a) is a plot of visual transparency and opacity results against the T_i. The trend is very close to that in Figure 2, i.e. with an increase of *Ti*, a sharp fall of Opacity (or an increase of transparency) and followed by a gradual fall (or rise) observed. Also, as expected, the results show that T_i and concentration have a reverse relationship, i.e. a low T_i corresponds to a high concentration. Figure 3(b) shows that initially flavour strength sharply reduces when T_i increases. This is followed by a more gradual reduction of strength towards high T_i (low concentration). Figure 3(c) indicates that the preference results were divided into two populations: one group preferred high concentrations; the other group preferred a mid-range concentration. People have previously been shown to have different food colour preferences [1]. The results here demonstrate that physical measures such as T_i can be used to model these psychophysical measures.

These results provide an understanding of the product science of orange juice product and give the industry the ability to engineer their drinks in scientific and consumer terms. However, we would expect that such expectations arise from the perceived colour appearance of the juice. Figures 4(a) and 4(b) show the experimental samples plotted on a^*b^* and L^*h_{ab} diagrams. It can be seen that the colours are all located in yellow region. With a concentration increase there is a slight hue shift towards red and a gradual increase of chroma. These results are the same with samples measured against a black backing and a white backing. However, the lightness changes in opposite direction with two different backings. Taking into account the above finding in the experiment, it can be concluded that colour appearance of the juice plays a key role in the sensation of flavour strength and preference.

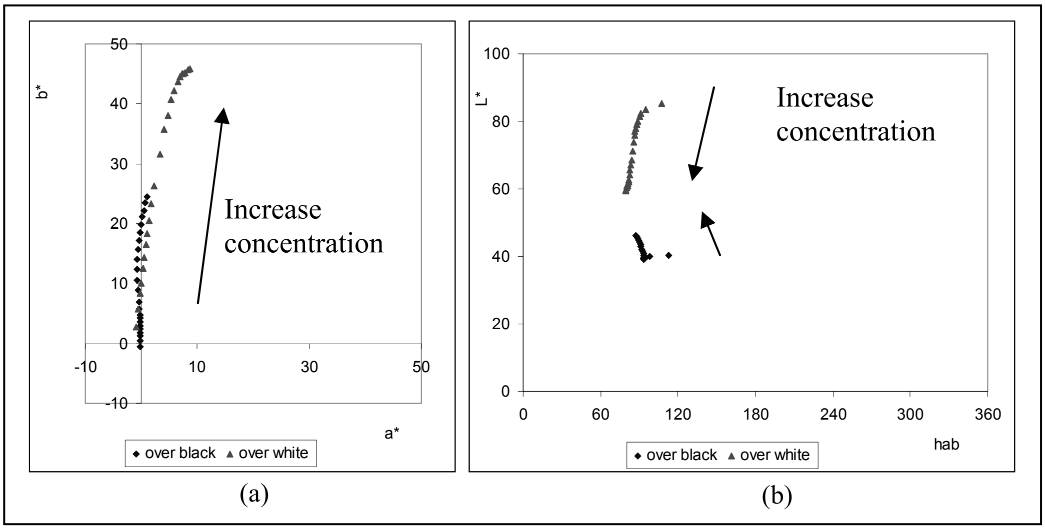


Figure 4: The colours of twenty-three samples plotted on CIE a*b* and L*h colour plates to show the colour changes when concentration changes.

3. CONCLUSIONS

A study was carried out to develop methodology for scaling important appearance attributes associated with orange juice including transparency, opacity, apparent flavour strength and preference. Observer performance is consistent in terms of repeatability and accuracy. It was found that T_i coefficients based on the Little method had good correlations with 4 sets of visual results. Finally the conclusion can be drawn that colour appearance of the juice plays a key role in expectations of flavour quality.

References

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