Effects of LED Light Environment and Viewing Background on the Attractiveness of Blueberries and Strawberries

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Abstract. This study aimed to assess how human perception of strawberries and blueberries is influenced by different lighting conditions, including variations in illumination levels and correlated color temperature (CCT), as well as different viewing backgrounds, using light-emitting diode (LED) color-changing features. Fifty participants, comprising 25 males and 25 females, were tasked with evaluating the visual appearance of strawberries and blueberries against two distinct backgrounds under three illuminance levels (400lx, 800lx, 1200lx) and five CCT values (2700K, 3300K, 3900K, 4500K, and 5100K), resulting in a total of fifteen light sources with varying illuminations and CCTs. The findings of the experiment revealed that both illuminance level and CCT significantly influenced the perceived color appearance of strawberries and blueberries. It was observed that strawberries appeared more visually appealing under light sources with higher illuminance levels and lower CCT, whereas blueberries were found to be more attractive under light sources with lower illuminance levels and relatively lower CCT. Additionally, concerning the background color, strawberries exhibited enhanced attractiveness specifically under conditions of 1000lx illuminance and 2700K CCT, particularly against a black background.

Keywords: Fruit; Correlated color temperature;Attractiveness; Illumination level; Viewing Background

1 Introduction

Fruit is an indispensable food for everyone in their daily life. Fruit is rich in micronutrients and vitamins, which are beneficial to the body, and it is obvious that fruit sellers prefer their fruits to look more appealing. Among the environmental factors that influence food consumption, visual cues such as color and texture are considered to be the most critical determinants of food perception and choice[1][2].Some evidence suggests that light sources alter the appearance of food color, thereby altering human visual evaluations.Jost-Boissard (2009) found that fruits and vegetables tend to be more appealing when their colors are highly saturated[3].In addition, The study examined how the appearance of red, green, and yellow bell peppers is influenced by different light sources, namely incandescent (INC), fluorescent (FL), and metal halide (MH).The results showed that the color of green peppers was more acceptable under incandescent light than under halogen lamps[4].Wansink (2012) Lighting affects consumer eating behavior[5].Lighting conditions also affect human subjective

ADDT 2024, May 24-26, Luoyang, People's Republic of China

DOI 10.4108/eai.24-5-2024.2350065

perception and physiological rhythms[6][7][8][9].Illumination level is one of the most critical parameters of lighting and some evidence suggests that it has an impact on the sensory aspects of food.Gregson (1967) Illumination has an effect on perceived sour flavor intensity[10].Rebollar (2017) Illumination levels can influence consumers' tasting experience as well as their willingness to buy[11].In addition to illuminance, CCT is also an important attribute of lighting.Huang (2018) found that the CCT of the light source affected the color preference of fruits and vegetables[12].Yang (2016) documented that the hue of light has the capacity to influence not only consumers' sensory perception and acceptability of foods but also their willingness to consume those foods[13].Hasenbeck (2014) investigated the impact of color and illumination levels of lighting on the willingness to consume bell peppers. The findings indicated that participants exhibited the highest willingness to consume bell peppers under yellow lighting, while their willingness was lowest under blue lighting[14].In addition to illumination level and color temperature, background color may also affect visual perception. Besides illumination levels and color temperature, it's important to consider the phenomena of color assimilation and simultaneous color contrast when evaluating the interaction between background and foreground colors. Color assimilation refers to the perception of a color being influenced by its surrounding colors, making it appear closer to the colors of its surroundings. Conversely, simultaneous color contrast occurs when the perceived color of an object is influenced by the colors adjacent to it, causing it to appear more different from its surroundings. These effects play a crucial role in how we perceive colors in different contexts and lighting conditions. Schiffersetein (2016) discovered that an additional significant factor impacting the appearance of food is the viewing background. They demonstrated this by presenting five different vegetables against four distinct background colors; the background affects the attractiveness of the vegetables, and the best backgrounds are very different for different vegetables.In addition, research has revealed that the visual perception of orange juice dilutions can be influenced by the background against which they are presented[15].The above studies have shown that people make different visual evaluations of food under different lighting conditions and viewing contexts.The purpose of this study was to examine the visual evaluation of strawberries and blueberries at different illumination levels and CCT and viewing contexts. In order to make the experimental design as how practical as possible, preliminary market research was conducted prior to this study. It is hoped to provide some references for fruit farmers, fruit store owners and others who wish to have seemingly more appealing views of strawberries and blueberries.

2 Method

2.1 Experimental participants

Fifty volunteers, consisting of 25 females and 25 males, took part in the study. The age range of the participants, both male and female, was between 18 and 25 years. No specific details regarding the purpose of the study were disclosed during the recruitment phase. All respondents were Chinese students enrolled at Dalian Polytechnic University and had successfully completed the Ishihara Colour Vision Test.

2.2 Visual evaluation questionnaire design

The current study employed the semantic differential method。A total of five evaluation indicators (willingness to buy, attractiveness, freshness, appetite, and sweetness) were selected for the experimental questionnaire, each of which was categorized from "not at all" to "very much" on a nine-point scale (1-9).

2.3Experimental setup

The experiments were conducted in a dark room equipped with a DALI dimming system.The CCT and illuminance levels were controlled by a cell phone to produce 15 different light environments. These light environments had 5 CCT values (2700K, 3300K, 3900K, 4500K and 5100K) and 3 illuminance levels (400lx, 800lx and 1200lx). The light settings were selected based on a study of fruit stores in Dalian, China. The colors of the CCTs used ranged from warm yellow to cool white, and the illuminances covered the range of typical illuminance levels used in Chinese fruit stores. The relative spectral power distribution of the experimental light sources was measured using a SFIM-300 spectral scintillation illuminometer (Fig. 1)

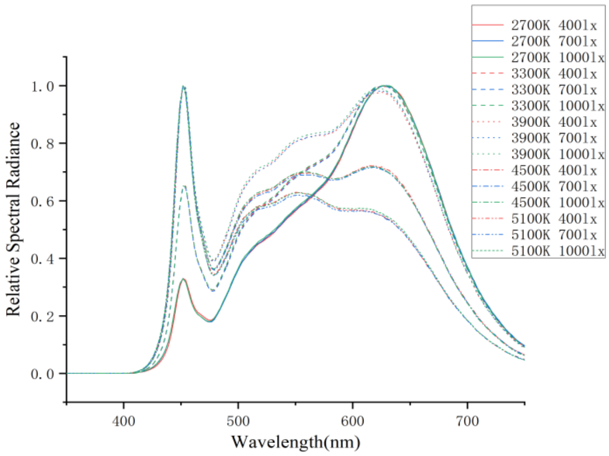

Fig. 1 Relative spectral power distribution of experimental light sources

The temperature of the experimental environment was kept constant at 23°C during the experiment. The experiment was conducted for a total of 25 days and a total of 50 participants were evaluated. Their positions were kept consistent across experiments. Blueberries and strawberries were displayed on plates, and observers assessed the appearance of blueberries and strawberries in different light environments and viewing Background.The experiment required that participants needed to observe without touching the experimental sample and rate five evaluation metrics. In the experiment, the light sources were randomly grouped in each testing session. Each observer conducted a total of 360 evaluations, encompassing 16 lighting CCT combinations (3 lighting levels * 5 CCTs + 1 repeated trial), 2 background conditions, 2 food samples, and 5 response scales.

2.4 Experimental setup

Participants were screened with the Ishihara Colour Vision Test.Participants were screened with the Ishihara color vision test. Participants who passed were required to sign a consent form for the experiment and fill in the questionnaire with basic information such as name, gender, and age before the experiment began. After that a black jacket will be put on the participant so that no colored light will be reflected on the experimental sample. All lights will be turned off only the light needed for the experiment will be turned on so that it is the only lighting in the room.Before the start of the experiment, observers will have about 5 minutes to adapt to the dark environment with only the experimental light turned on. At the same time, we will inform participants of the experimental procedure and precautions. At the beginning of the experiment, 15 light environments were randomly selected. Observers were asked to close their eyes for 30 seconds while the lights were changed. The purpose of this is to eliminate the short-term memory of the previous light, and this step needs to be repeated each time the light environment is changed. After opening the eyes again to adjust to the light, we placed the fruit and background plates on the table. Subjects were asked to observe the samples and to record the relevant experimental results from the questionnaire. After the observer had finished recording all the light environments for a background and a sample, the sample and background were changed and the experiment was repeated. The experiment is shown in Figure 2.

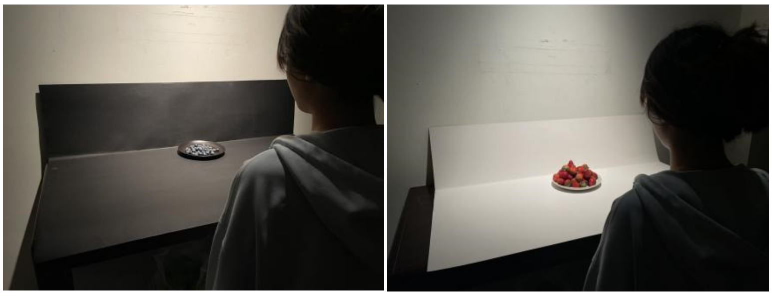

Fig 2 Experimental Diagram

3 Discussion

For the calculation of repeated measures ANOVA, the overall covariance value F needs to be calculated first, and then the variance factor is calculated from the individual error value and data error value in the data. The specific formula is as follow:

$$F = \frac{MS_{\text{treatment}}}{MS_{\text{error}}} = \frac{\frac{SS_{\text{treatment}}}{\text{df}_{\text{treatment}}}}{\frac{\text{SS}_{\text{error}}}{\text{df}_{\text{error}}}} \tag{1}$$

$$SS_{total} = SS_{treatment(excluding-individual-difference)} + SS_{subject} + SS_{error} \tag{2}$$

$$df_{total} = df_{treatment(within-subject)} + df_{between-subjects} + df_{error} \tag{3}$$

3.1 Reliability Test of Visual Perception Questionnaire

We assessed the reliability of the questionnaire by using Cronbach's alpha to measure the internal consistency and uniformity of variances in the visual perception questionnaire as shown in Table 1. The formula utilized is as follows:

$$r_{tt} = \frac{n}{n-1}\left[1 - \frac{\sum_{i=1}^{n} SD_i^2}{SD_t^2}\right] \tag{4}$$

In formula (4), r_{tt} is the reliability coefficient of the evaluation scale.n is the number of subjects. SD_i^2 is the score variance of item i. SD_t^2 is the variance of the total score of the scale.

The higher the value of Cronbach's alpha, the higher the internal consistency of the questionnaire The results are shown in the table and the Cronbach's coefficient is greater than 0.7, which indicates that the questionnaire is reliable and can be used.

Table 1 Reliability Statistics

Evaluation indicators	willingness to purchase	attractiveness	freshness	appetite	sweetness
Cronbach's Alpha	.739	.725	.727	.724	.736

3.2 Factor analysis

In order to investigate whether the subjects have an effect on the results of the experiment. This study was designed with five variables: willingness to buy, attractiveness, freshness, appetite, and sweetness. The experimental data of the subjects were collected with a scale.The data obtained was first subjected to KMO sampling appropriateness factor analysis and Bartlett's Test, KMO = 0.886,Bartlett's Test significance = 0.000 （Table 2） . indicates that there is a correlation between the variables analyzed and a correlation is suitable for factor analysis.

Table 2 KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.886
Cronbach's Alpha	Sig.	.000

After passing the factor analysis, after extracting the common factors with the principal component analysis in factor analysis, the number of common factors was selected based on the principle that the eigenvalue is greater than 1. Attractiveness (0.921) was selected to explain 80.349% of the total variance.Before determining whether there is an interaction of factors within the three subjects, it is necessary to determine whether the interaction is consistent with Mauchly's Test of Sphericity. If $P<0.05$, the assumption is not satisfied; if $P>0.05$, the assumption is satisfied. When the Mauchly's Test of Sphericity assumption condition was violated, correction using the Greenhouse-Geisser method was required.

3.3 Impact of strawberry attractiveness

$\chi^2 = 54.905$ for background * color temperature * illuminance, $p = 0.018$, so for the interaction term, the dependent variable did not satisfy Mauchly's Test of Sphericity. corrected with using the Greenhouse-Geisser approach.The background*color temperature*illumination interaction was not statistically significant, $F(6.211, 304.339) = 0.951$, $p = 0.461$.

Using the same method background*color temperature $F (2.731, 133.813) = 1.312$, $p = 0.274$ is not statistically significant. However, the background*illumination interaction $F(1.763, 86.399) = 4.098$, $p=0.024$ and color temperature*illumination, $F(5.346, 261.972) = 3.920$, $p=0.001$ had a significant effect on the results.Because there was an interaction between background* illuminance and color temperature* illuminance on attractiveness, a simple effects test for within-subjects factors was required.It was found that there was a significant simple effect of illumination level at each CCT and that attractiveness ratings were higher at higher illumination levels (mean ratings: 5.874 at 400lx, 6.406 at 700lx, and 6.572 at 1000lx).

For background* illuminance, it was found that 400lx (6.028) was significantly different from 700lx ($P=0.005$, 6.4) and 1000lx ($P=0.019$, 6.464) on white background. But 700lx was not significantly different from 1000lx.There was a difference between 400lx (5.720) and 700lx ($P<0.001$, 6.412) and 1000lx ($P=0.017$, 6.680) against each other on a black background.

For color temperature * illuminance, it was found that there is a significant difference between 5100k and 2700k ($P=0.01$), 3300k ($P=0.01$), 3900k ($P<0.01$), 4500k ($P<0.01$) at 400lx illuminance. But there was no significant difference between 3300k-5100k.There are significant differences between 2700k and 3300k ($P=0.044$), 4500k ($P=0.009$), and 5100k ($P=0.042$) under 700lx illumination. There is also a significant difference between 3300K and 4500K ($P=0.029$).At 1000lx illumination 2700k was significantly different from 3300k ($P<0.01$), 3900k ($P<0.01$), 4500k ($P=0.01$) and 5100k ($P=0.02$). In conclusion the optimal illumination for strawberries was 1000lx, 2700k, black background.

3.4 Blueberry Attractiveness Impact

$\chi^2 = 83.628$ for background*color temperature*illumination, $p<0.001$. so for the interaction term, the dependent variable did not satisfy Mauchly's Test of Sphericity. corrected with using the Greenhouse-Geisser method, the background*color temperature*illumination interaction was not statistically significant, $F(5.143, 251.983) = 0.901$, $p = 0.483$.Using the same method background*color temperature $F (2.737, 134.089) = 0.338$, $p = 0.78$. background*illumination interaction $F (2, 98) = 1.878$, $p = 0.158$. color temperature*illumination, $F (5.675, 278.082) = 2.136$, $p = 0.053$ not statistically significant.Post hoc tests of significant main effects of blueberry illumination levels showed significant differences in attractiveness ratings across illumination levels:400lx (5.184) was significantly different from 700lx and 1000lx. But there is no significant difference between 700lx and 1000lx.A post hoc test for a significant main effect of CCT for blueberries provided a significant difference ($p<0.001$) between 2700K (4.857) and 3300K, 3900K, 4500K, and 5100K. The results indicate that people are more attracted to blueberries at low illumination levels and low color temperatures. The optimal illumination was probably 400lx, 2700K. viewing background had no effect on blueberries.

3.5 Impact of viewing background on attractiveness

In this study, we used A0 paper and trays as backgrounds for both fruits because they have accurate colors that can be reproduced over time.For strawberries, a simple effects analysis based on the interaction of background * illumination showed that a black background only made sense at 1000lx and 2700K.However, there was no significant effect for the blueberry background factor.

4 Conclusions

In this study, the influence of illuminance levels, correlated color temperature (CCT), and viewing environment on the visual appearance and attractiveness of blueberries and strawberries was explored..The experiments utilized 15 types of LED lights to create different light environments, along with two background colors (black and white).

The results of the experiment revealed significant effects of illuminance level and CCT on attractiveness. The study found that strawberries appear more visually appealing when displayed under high illuminance and low correlated color temperature light sources, while blueberries exhibit greater attractiveness under low illuminance and relatively low correlated color temperature light sources. The influence of the viewing background on attractiveness was relatively small, although statistically significant differences were observed under specific conditions (e.g., black backgrounds being more suitable for displaying strawberries than white backgrounds).Overall, the study underscored the importance of lighting conditions for the visually attractive presentation of fruits.

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