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Analysis of Reflected Metamer Light Effect on Cheese Palatability

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Abstract

Functional lighting can control a specific wavelength in order to emphasize a desired color signal of an object. In this study, for the purpose of designing functional lighting for cheese, the effect of lighting on the palatability of cheese was analyzed from reflected light. To investigate the palatability difference caused by different illuminants, a psychophysical experiment was conducted using five types of cheese under metameric lighting with fixed color temperature and illuminance. A total of eight observers participated in this experiment: four of them who loved eating cheese were classified as group A, and the remaining four who disliked eating it were classified as group B. The experiment revealed that observers in group A agreed that illumination sources made the cheese look most palatable, whereas observers in group B showed variability in their preferred light sources. Based on these results, guidelines for designing an illumination source that can improve cheese palatability by controlling the wavelength band were determined, under the constraint that the reflected light exists within a specific chrominance region.

Introduction

Recent years have witnessed the development of various types of light-emitting diode (LED) lamps, enabling us to control the spectral distribution of light sources. By taking advantage of this development, studies have been conducted on identifying light sources that can detect foreign matter in a physical body or that can improve the visual freshness of foods. These are referred to as functional lighting.

Nakauchi et al. [1] developed a method for designing an illuminant to support color discrimination while maintaining an arbitrary illuminant color as demonstrated and applied to foreign substance detection in blueberry jam. Ito et al. [2] proposed a functional illuminant to help people in distinguishing blood vessels from skin using three types of LEDs. Kondo et al. [3] proposed functional lighting that helps detect plaque on teeth. The functional illuminant was optimized to enhance the color difference between the plaque and the teeth in a CIELAB color space. Tsuchida et al. [4] introduced color enhancement factors to control the spectral power distribution of illumination, which could enhance one or more colors at once while retaining the appearance of white color. Higashi et al. [5] proposed a practical system composed of commercial LEDs and Red Green Blue (RGB) cameras for extracting optical features and predicting the pearl quality from RGB images. Despite its wide utilization in different fields, there are only a few studies on functional lighting in the field of food, and its relationship with palatability has not been sufficiently analyzed.

This study focused on cheese, which is consumed around the globe and comes in many varieties, with the aim of designing functional light sources that can improve its palatability. Previous studies have investigated factors related to cheese palatability, such as shelf life [6], the storage temperature and duration [7], the proportion of vegetable fat [8], etc. However, little has been investigated about the visual factors. Barbut evaluated cheddar cheese preference under three light sources [9]. Santagiuliana et al. showed that both visual and oral cues influence the palatability of heterogeneous cheeses [10]. These studies have been analyzed under limited conditions for specific cheeses. In this paper, the influence of reflected light using metamer lighting on the palatability of cheese is analyzed.

Measurement

There are various types of cheese that differ in color, the number of components, and surface spectral reflectance. The reflectance of 10 types of commercially available cheeses, Gruyere, Gouda, Colby Jack, Conte, Smoked Black Pepper, Smoked Plain, Parmigiano Reggiano, Parmesan, Mimolette, and Red Cheddar, was measured. Cheeses were kept in square shapes, with sides measuring 3 cm and a thickness of 1 cm. A monochromator was used as the light source to emit a monochromatic light beam at 1 nm intervals (SPG-120S, Shimadzu Corporation) on the cheeses. Spectral reflectance was measured using a spectroradiometer (CS-2000, Konica Minolta). The half width of the wavelength was 1.0 nm. The wave-length band from 400 nm to 700 nm was yielded in 10 nm steps. Figure 1 shows the measurement environment.

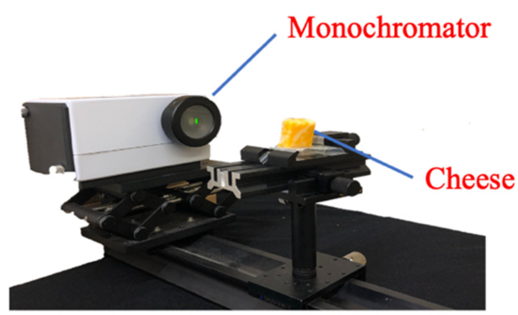


Figure 1. Measurement Environment. Measurement was conducted in a dark room.

The study hypothesized that similar spectral reflectance would have the same preference. Therefore, extraction and analyzation of cheeses with different spectral characteristics were performed. Cheeses could be sorted into four clusters based on the shape of the spectral reflectance using the K-means method. Parmesan, Gouda, Red Cheddar, and Smoked Cheese with Black Pepper were selected to represent each cluster and were analyzed together with Colby-Jack, which has multiple colors. Figure 2 shows the selected cheeses and their spectral reflectance.

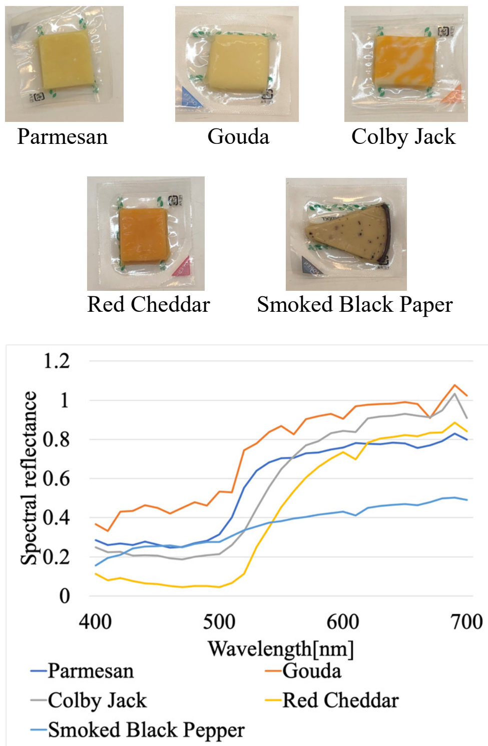


Figure 2. 5 Types and Spectral reflectance of Cheeses to be Analyzed.

Metameric Lighting Design

THOUSLITE LEDCube, which consists of 14 patterns of LED output, was used as the illuminating device. The peak wavelengths of the LED were 370 nm, 385 nm, 420 nm, 450 nm, 480 nm, 505 nm, 525 nm, 540 nm, 555 nm, 590 nm, 595 nm, 610 nm, 635 nm, and 660 nm. As shown in Fig. 3, the device was mounted on an viewing cabinet (45 cm in width and 55 cm in height), and the cheese was placed on the white paper tray to be illuminated. To solely control the colors reflected from the cheese without the color reflected from the tray, metameric spectral distributions were designed for 3,000 K and 4,500 K. Metameric illuminant was designed by controlling the wavelength around 450 nm, 500 nm, 560 nm, and 610 nm at about 50 nm intervals. Finally, three types of metameric illuminants at 3,000 K, and five types of metameric illuminants at 4,500 K were designed.

Figures 4(a) and 4(b), respectively, show the normalized spectral distributions of the three types of metamers (a1 – a3) designed for 3,000 K and five types of metamers (b1 – b5) designed for 4,500 K. An illuminance of 500 lx was used across the board to reproduce the lighting conditions of the food floor and those during a meal.

Experiments

To investigate the palatability difference due to difference in illumination sources, an evaluation experiment was conducted. Figure 5 illustrates the experimental conditions. The viewing cabinet was placed on the table, and the experiment was conducted in a simplified dark room. The visual distance was set to 40 cm.

Experimental Method

A total of eight Japanese university students in their twenties participated in this experiment. Four of them who loved eating cheese were classified as group A, and the remaining four who disliked eating it were classified as group B. One illuminant (a1 or b1) was set as a reference for each color temperature, and cheese palatability viewed under other metamers was rated. To verify the reproducibility of the experiment, every observer underwent two sessions of all illumination patterns in two separate days.

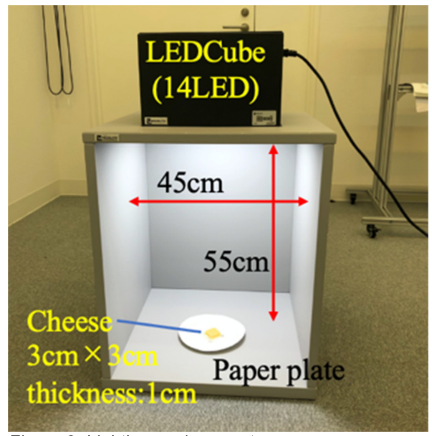
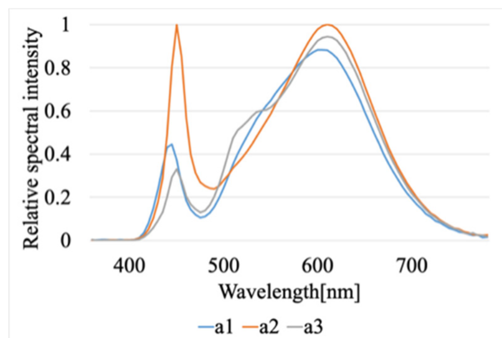
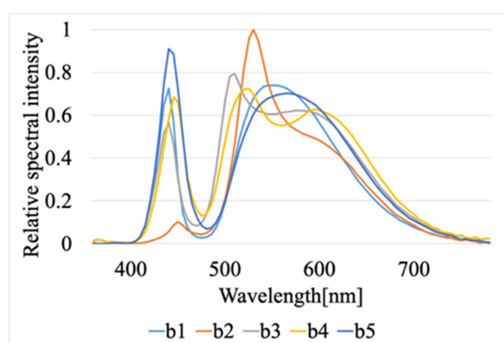


Figure 3. Lighting environment.



(a) 3,000K



(b) 4,500K

Figure 4. Spectral distribution of the designed metameric illuminant.

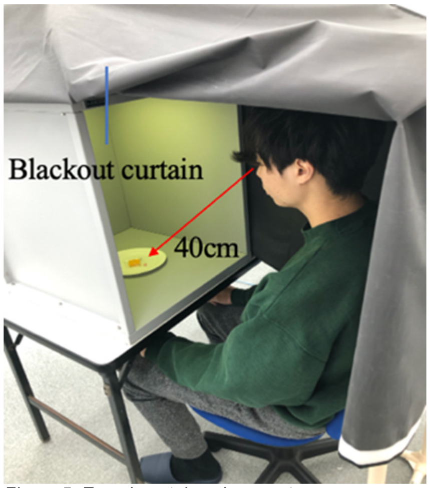


Figure 5. Experimental environment.

In the experiment, the observer sat on a chair in a dark room and acclimatized for 10 minutes. Thereafter, one of the five cheeses was randomly placed on a white paper plate and set at the center of the viewing cabinet. The evaluation experiment was conducted in accordance with the procedure shown in Figure 6. The evaluation experiments were performed separately at 3,000 K and 4,500 K using the metameric lighting designed in the previous section.

First, the reference illuminant (a1 or b1) was irradiated for 5 s followed by the test illuminant (3,000 K: a2–a3, 4,500 K: b2–b5) also irradiated for 5 s. The observer then evaluated the palatability of cheese under the test illuminant. One illuminant (a1 or b1) was set as the reference for each color temperature, and the cheese palatability was rated as 3 under a 5-point Likert scale. As for the remaining metamers, cheese palatability was rated in relative terms, wherein if the cheese under the test illuminant looked more palatable than the reference, it was rated as 4 or 5. Subsequently, reference illuminant was evaluated for palatability prior to illumination of every other metamer.

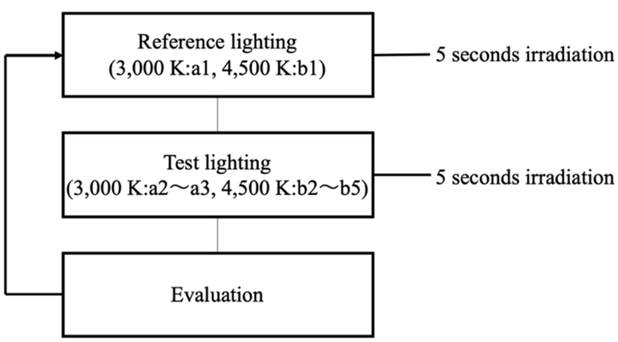


Figure 6. Experimental procedure

Results

The average palatability obtained under 4,500 K metamers for the five types of cheese are shown in Table 1. As shown in the table, the experiments revealed that observers in group A agreed consistently in terms of illuminant b4 that made the cheese look most palatable, whereas observers in group B showed variability in their preferred illuminants.

Inter-variance and intra-variance were calculated. The total inter-variance was 0.33 with 0.18 and 0.37 for group A and B, respectively. Figure 7 shows the intra-variance for each observer. These results indicate reproducibility of each observer; the variance was smaller and more stable in group A than in group B. These findings confirm that palatability was consistent in group A, a group of cheese lovers, whereas it was variable and unstable in group B, a group of non-cheese lovers.

Introspective reports revealed that group B was more focused on lower-level features associated with primitive visual perception, such as color and contrast of the cheese, whereas group A was focused on higher-level features, such as the softness and freshness of the cheese. Furthermore, in order to analyze the effect of each wavelength of illuminant on the observers in group A, the spectral reflectance of cheeses at 4,500 K, where there was a difference in evaluation among the illuminants, was analyzed. As shown in Table 2, it was found that 450–500 nm and 600–675 nm had positive correlations, while 525–600 nm had a negative correlation.

Table 1. Average palatability values for each group at 4,500 K. (X: Parmesan, Y: Gouda, Z: Colby Jack, S: Red Cheddar, T: Smoked black Pepper).

(a) Group A

	b1	b2	b3	b4	b5
X	3.00	1.50	4.25	4.50	4.00
Y	3.00	1.50	3.88	4.13	3.88
Z	3.00	1.38	3.63	4.13	3.50
S	3.00	1.88	3.63	4.38	3.50
T	3.00	1.13	3.88	4.13	3.50
Ave.	3.00	1.48	3.85	4.25	3.68

(b) Group B

	b1	b2	b3	b4	b5
X	3.00	1.63	3.25	3.75	3.63
Y	3.00	2.38	3.50	3.88	3.63
Z	3.00	2.38	4.13	3.88	3.50
S	3.00	2.13	4.00	3.38	3.25
T	3.00	2.00	3.25	3.63	3.63
Ave.	3.00	2.10	3.63	3.70	3.53

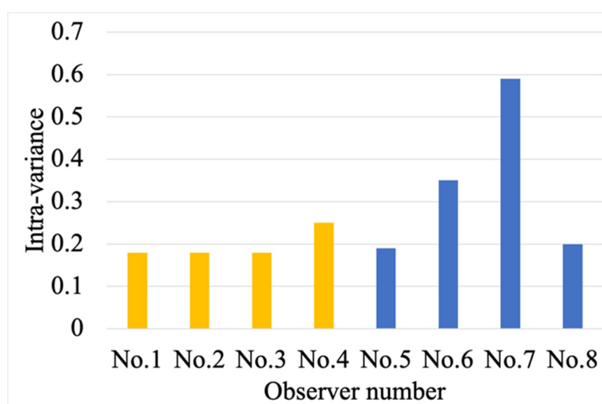


Figure .7 Intra-variance of evaluation values.
(No.1〜4: Group A observers; No.5〜8: Group B observers）

Table 2. Correlation between evaluation value and spectral reflectance.

Wavelength [nm]	Correlation coefficient
400–450	-0.43
425–475	0.13
450–500	0.93
475–525	0.61
500–550	0.36
525–575	-0.89
550–600	-0.78
575–625	0.57
600–650	0.95
625–675	0.97

Lighting Design for Improved Palatability

As described in the previous section, in terms of reflected light from the cheese, there was a correlation between spectral light intensities in a specific band of wavelength and in assessment values. Thus, three types of 4,500 K metamers (b6 to b8) were newly designed in consideration of the mentioned correlation, and a verification experiment using the same experimental procedure in Sec. 4 was conducted on the four members of group A.

Figure 8 shows the normalized spectral distribution. In the verification experiment, in addition to the three newly designed metamer lightings, five types of metamer lighting, including b4 lighting with the highest palatability evaluation in Group A and the reference illuminant b1, were used. Figure 9 shows a graph in which the intensity of the reflected light by Parmesan is normalized when four lightings, except the reference illumination, are applied. Compared to b4, b6 and b7 have greater intensities of 450–500 nm, 600 nm, 650 nm, and 625–675 nm, which is a positive correlation wavelength band. The 525–575 nm and 550–600 nm intensities, which is a wavelength band of negative correlation, were smaller. These two lightings are cases where all the correlated wavelength bands are improved. Additionally, they were designed in order to verify stepwise the intensity at which the palatability was improved. Lighting b8 improved only in the wavelength band of negative correlation compared to b4. Because we assumed that the palatability might be improved even if only the negative correlation improved.

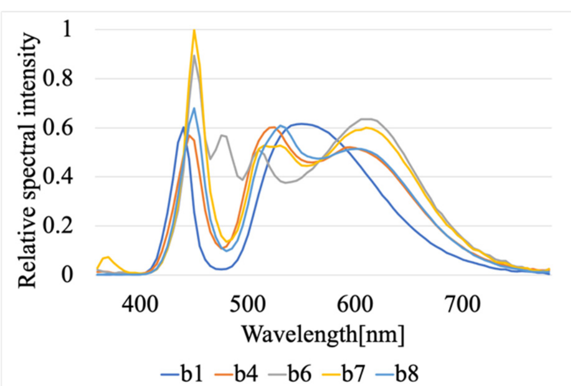


Figure 8. Spectral distribution of metamers used in verification experiments.

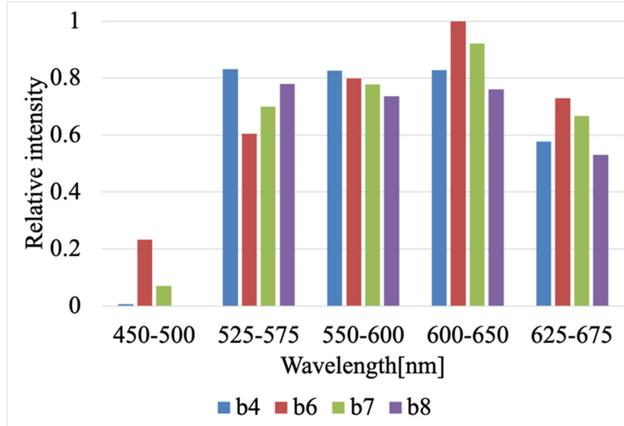


Figure 9. Relative intensity of reflected signals of Parmesan.

The results revealed that palatability was enhanced under the newly designed illuminants, especially for metamer b8. Moreover, as indicated by the red square in Fig. 10, palatability in group A was enhanced when reflected light from the cheese reached a specific range of chromaticity (highly palatable chromaticity range). Based on these results, the study was able to determine the following guidelines for designing an illumination source that can improve cheese palatability for cheese lovers: 1) determination of the color temperature of the light source, 2) identification of metamers with a feature wherein reflected lights from all cheeses reach a highly palatable chromaticity range, and 3) among all the metamers identified, selection of the wavelength range that is highly correlated with the assessment results as the optimal illuminant.

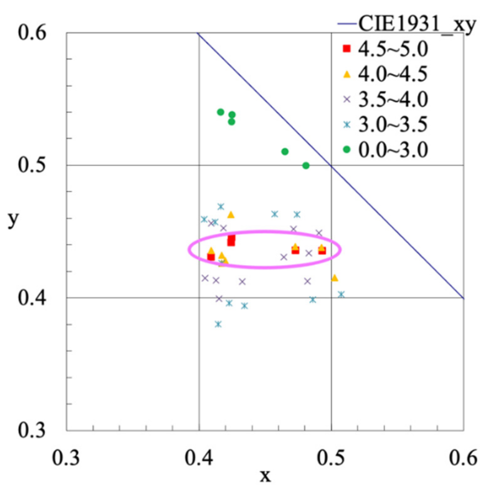


Figure 10. Relationship between the chromaticity coordinates of reflected light and evaluation values in group A.

Conclusions

In this study, the effect of reflected metamer lighting on the palatability of cheese was analyzed. Evaluation experiments were conducted using multiple metamers for the analysis of five commercially available cheeses selected based on the spectral reflectance characteristics. As a result, observers in Group A, who loved eating cheese, agreed in terms of illumination sources that made the cheese look most palatable, whereas observers who dislike eating it showed variability in their preferred light sources.

Moreover, the former observers were focused on higher-level features, such as the softness and freshness of the cheese, while the latter observers were more focused on lower-level features associated with primitive visual perception, such as color and contrast of the cheese.

Furthermore, by controlling the color area of the reflected light of the cheese and the spectral energy of a specific wavelength band, this study was able to determine the guidelines for designing an illumination source that can improve cheese palatability.
For future studies, verification of the proposed design method, not only on various cheeses but also on other foods, is recommended.

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Author Biography

Gaku Yamashita received the B.E. degree from Chiba University in 2020. He is currently a master course student in Chiba University. He is interested in perceptual control of real objects.