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SHORT COMMUNICATION

Colour descriptors for plant-based milk alternatives discrimination

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Abstract Colour characteristics of plant-based milk alternatives (PBMAs: almond, coconut, cashew, oat, soy) were monitored during long-term storage to select suitable descriptors for PBMAs differentiation. All colour descriptors evaluated varied depending on the raw material used in the plant-based milk alternative production. Long-term storage of plant-based beverages resulted in slightly noticeable (0.5–1.5) and noticeable (1.5–3.0) colour changes. Based on all colour descriptors, an absolute differentiation of PBMAs according to the type of raw material and storage time was achieved using canonical discriminant analysis. The results also indicate the possibility of using colour descriptors to detect the addition of honey to these products. Statistical analysis identified yellowness, browning index and lightness as the most discriminating parameters.

Keywords Plant-based milk alternatives · Storage · Colour · Statistical analysis

Abbreviations

*a**	Redness/greenness
ANOVA–Tukey HSD	Analysis of variance Tukey's honestly significant difference test
*b**	Yellowness/blueness
BI	Browning index
CDA	Canonical discriminant analysis
CIE *L*a*b**	Colour system defined by Commission Internationale de L'Éclairage
*L**	Lightness
PBMA	Plant-based milk alternative
PC	Principal component
PCA	Principal component analysis
PCF	Principal component factoring
TCD	Total colour difference
YI	Yellowness index
WI	Whiteness index

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Introduction

Plant-based milk alternatives (PBMAs) resemble cow's milk in appearance and consistency. The main reasons for consuming these dairy alternatives are lactose intolerance, cow's milk protein allergy, calorie concerns and the prevalence of hypercholesterolaemia.

They are generally water-soluble extracts of cereals (oats, rice, spelt), nuts (almond, cashew, hazelnut, coconut), seeds (sesame, sunflower, flax, hemp, poppy), pulses (chickpea, soybean, lupin) or pseudo-cereals (teff, quinoa, amaranth) (Alcorta et al. 2021; Sethi et al. 2016). They are produced by breaking down (size reduction) plant material extracted in water and further homogenising these fluids to imitate the properties of cow's milk. However, the different types of materials used for their production require different technical processing methods. The addition of other components (fruit or flavour components), thermal/non-thermal treatments and/or homogenisation can be used to produce the final product with desired properties (Sethi et al. 2016).

Several studies have focused on the evaluation of physicochemical parameters (e.g., fat content, ash content, viscosity, pH, carbohydrate content, emulsion stability) or volatile profile of PBMAs (Pointke et al. 2022; Reyes-Jurado et al. 2021; Sarangapany et al. 2022; Tangyu et al. 2019). However, little attention has been paid to the colour stability of these beverages. Colour is an important driver of product appeal and product associations. Therefore, colour plays a significant role in dairy alternatives. This study aimed to evaluate the colour of different PBMAs (cashew, almond natural, almond sweet, coconut, oat, soy) and to select appropriate colour descriptors for their differentiation.

Material and methods

Samples

Samples of plant-based milk alternatives (PBMAs) were produced in collaboration with a beverage manufacturer. PBMAs were produced from coconut, cashew, almond, oat and soya without the addition of preservatives under aseptic conditions according to a proprietary process. Almond 'milk' was produced in two forms—natural and sweetened with honey added. Samples were stored in the dark at 6 ± 1 °C for 4 months (recommended shelf life).

Reflectance measurements and colour evaluation

The experiments with PBMAs were performed in attenuated reflectance mode using the Large Integrating Sphere Assembly LISR 3100 connected with UV/Vis/NIR spectrometer Shimadzu UV3600 (Shimadzu, Japan) following the procedure described by Tobolková et al. (2021). Reflectance spectra were utilized to evaluate colour descriptors in the CIE $L^*a^*b^*$ colour system—parameters of L^* (lightness-darkness), a^* (redness-greenness), b^* (yellowness-blueness), chroma and hue angle. The parameters L^*, a^* and b^* were used to calculate the browning index—*BI* and the total colour difference—*TCD*. The yellowness index (*YI*) and whiteness (*WI*) were also determined as potential descriptors for PBMAs discrimination (Tobolková et al. 2021).

Statistical analysis

Differences between control and stored PBMAs were assessed by ANOVA-Tukey-HSD (honestly significant difference) multiple comparisons ($P < 0.05$). Experimental characteristics were processed using multivariate statistical methods: principal component analysis (PCA) and factor analysis (PCF) with varimax rotation were used to graphically represent differences between PBMAs (regardless of storage time), and canonical discriminant analysis (CDA) to quantify these differences.

Table 1 Changes in selected colour characteristics of plant-based milk alternatives (PBMAs) at the beginning (C) and at the end (E) of storage (after 4 months)

	ID	L*	a*	b*	Chroma	Hue angle	Yellowness index	Whiteness	BI	TCD
Coconut	C	99.52 ± 0.21^{a}	−0.32 ± 0.08^{a}	0.10 ± 0.03^{a}	0.33 ± 0.08^{a}	163.04 ± 2.50^{b}	7.34 ± 0.02^{a}	94.14 ± 0.63^{a}	0.10 ± 0.01^{a}	–
	E	99.86 ± 0.03^{a}	−0.47 ± 0.11^{a}	0.37 ± 0.05^{b}	0.60 ± 0.10^{a}	141.52 ± 1.06^{a}	7.50 ± 0.09^{a}	93.79 ± 0.50^{a}	0.30 ± 0.01^{b}	0.47 ± 0.09
Cashew	C	94.57 ± 0.33^{a}	1.32 ± 0.08	2.62 ± 0.09^{a}	2.89 ± 0.10^{a}	63.66 ± 0.18^{a}	12.94 ± 0.20^{a}	71.21 ± 4.95^{a}	3.67 ± 0.14^{a}	–
	E	95.61 ± 0.81^{a}	1.27 ± 0.06^{a}	2.68 ± 0.19^{a}	2.94 ± 0.26^{a}	64.73 ± 0.20^{a}	13.29 ± 0.31^{a}	67.20 ± 3.54^{a}	3.82 ± 0.23^{a}	1.05 ± 0.21
Almond natural	C	96.91 ± 0.52^{a}	0.30 ± 0.03^{b}	3.80 ± 0.14^{a}	3.80 ± 0.14^{a}	87.38 ± 0.44^{a}	14.09 ± 0.20^{a}	71.68 ± 1.16^{a}	4.02 ± 0.16^{a}	–
	E	97.32 ± 0.32^{a}	0.19 ± 0.02^{a}	4.15 ± 0.25^{a}	4.13 ± 0.23^{a}	85.81 ± 0.44^{a}	15.04 ± 0.91^{a}	70.01 ± 1.28^{a}	4.49 ± 0.28^{a}	0.69 ± 0.31
Almond sweet	C	95.82 ± 0.10^{a}	0.33 ± 0.06^{a}	4.28 ± 0.61^{a}	4.30 ± 0.46^{a}	85.48 ± 0.33^{a}	14.93 ± 1.35^{a}	72.25 ± 0.79^{b}	4.65 ± 0.83^{a}	–
	E	97.02 ± 0.47^{b}	0.48 ± 0.05^{b}	6.38 ± 0.76^{b}	6.40 ± 0.76^{b}	85.65 ± 0.13^{a}	18.73 ± 1.02^{b}	70.75 ± 1.33^{a}	7.10 ± 0.87^{b}	1.37 ± 0.52
Oat	C	98.71 ± 0.07^{a}	−0.28 ± 0.03^{a}	3.46 ± 0.12^{a}	3.40 ± 0.16^{a}	94.27 ± 0.12^{a}	13.21 ± 0.23^{a}	75.68 ± 1.79^{b}	3.27 ± 0.12^{a}	–
	E	98.10 ± 0.02^{a}	−0.14 ± 0.00^{b}	4.99 ± 0.10^{b}	4.87 ± 0.23^{b}	93.08 ± 0.25^{a}	14.04 ± 0.47^{b}	70.62 ± 1.72^{a}	4.99 ± 0.10^{b}	1.35 ± 0.09
Soya	C	98.66 ± 0.55^{a}	−0.50 ± 0.03^{a}	5.30 ± 0.64^{a}	5.37 ± 0.35^{a}	95.32 ± 0.52^{b}	15.52 ± 1.27^{a}	70.14 ± 4.24^{a}	5.03 ± 0.69^{a}	–
	E	98.21 ± 0.46^{a}	−0.05 ± 0.00^{b}	6.74 ± 0.23^{b}	6.74 ± 0.23^{b}	90.36 ± 0.58^{a}	17.47 ± 1.29^{b}	69.70 ± 1.64^{a}	6.90 ± 0.24^{b}	1.62 ± 0.24

L^* lightness, a^* redness/greenness, b^* yellowness, *BI* browning index, *TCD* total colour difference

^{a,b}Mean values with different superscript letters in the same column indicates significant difference between control (C) and expired (E) PBMAs ($p < 0.05$)

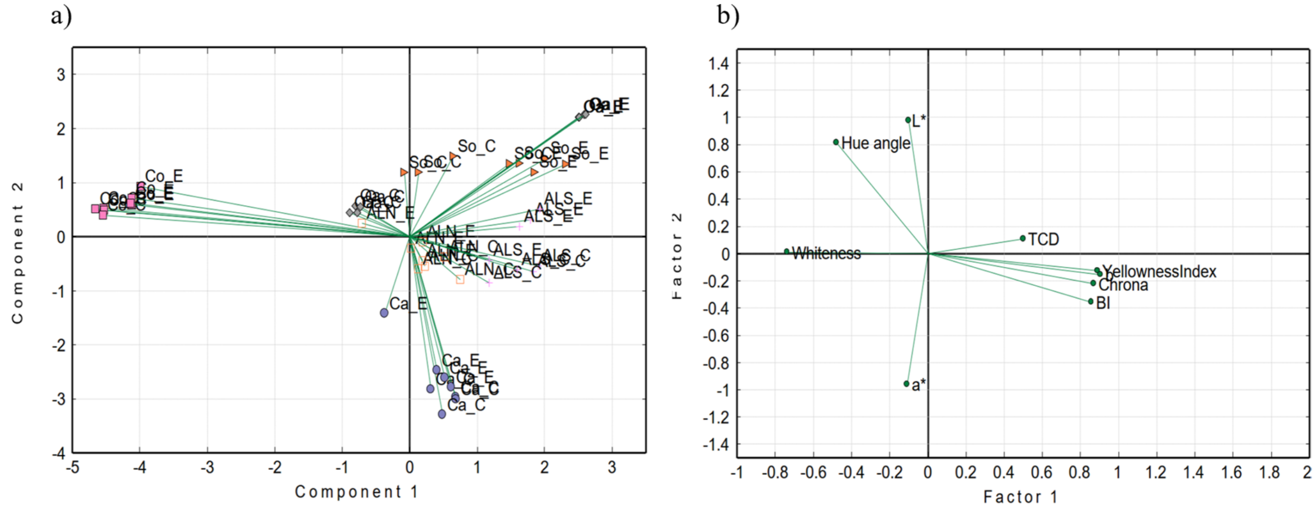
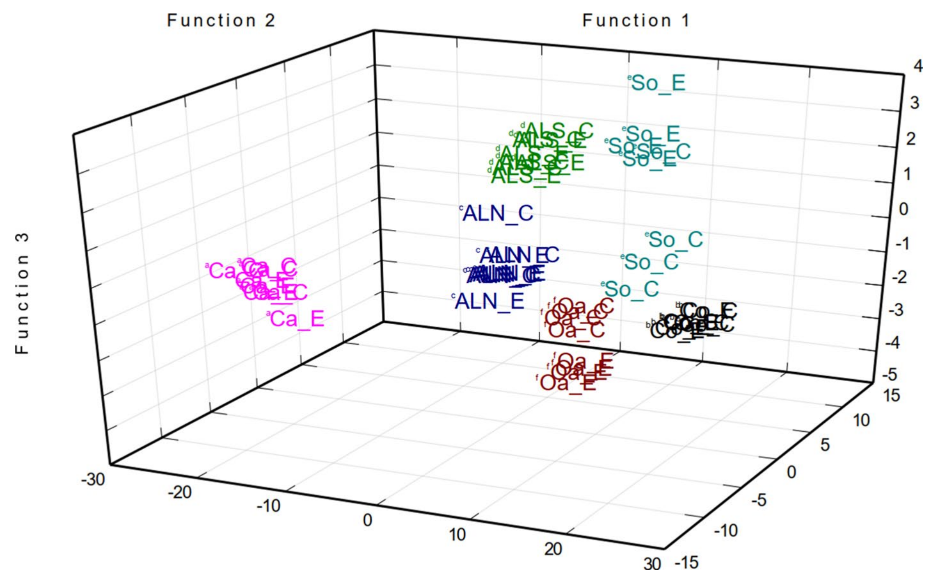


Fig. 1 Differentiation of plant-based milk alternatives (PBMAs) using a principal component analysis and b principal component factoring with varimax rotation (plot of factors). All experimental data were used as variables for principal components construction. Co_C/E—coconut PBMA control/expired, Ca_C/E—cashew PBMA control/expired, ALN_C/E—almond PBMA natural control/expired, ALS_C/E—almond PBMA sweet control/expired, Oa_C/E—oat PBMA control/expired, So_C/E—soy PBMA control/expired, *L**—lightness, *a**—redness/greenness, *b**—yellowness/blueness, *BI*—browning index, *TCD*—total colour difference

Fig. 2 Canonical discriminant analysis of studied plant-based milk alternatives (PBMAs) according to the type of raw material used for their production. Co_C/E—coconut PBMA control/expired, Ca_C/E—cashew PBMA control/expired, ALN_C/E—almond PBMA natural control/expired, ALS_C/E—almond PBMA sweet control/expired, Oa_C/E—oat PBMA control/expired, So_C/E—soy PBMA control/expired



Results and discussion

PBMAs are creamy fluids with similar properties to those of cow milk. In terms of consumer acceptance, whiteness and lightness can be considered the most important parameters characterising the quality of these beverages, since their alterations indicate quality changes in the food products due to processing. These parameters are mainly affected by the dispersion of the oil particles and their size, the type and concentration of chromophores or the processing methods (Reyes-Jurado et al. 2021).

Table 1 summarises the changes in selected colour descriptors of different PBMAs at the beginning (C) and at the end of the storage period (E, after 4 months). In general, the differences in colour between PMBAs were mainly related to the raw material used for their production (Reyes-Jurado et al. 2021). The highest *L** and *WI* values were found for coconut 'milk' and the lowest for cashew 'milk'. These results are similar to those reported by Jeske et al. (2017). Yao et al. (2022) described lower values of *L** and *a**, and higher values of *b** for oat and soy 'milks' compared to our results, however, authors expressed colour in Hunter *L*a*b** colour system. The higher *b** and *YI* of soy and oat PBMAs may be due to pigments (carotenoids, anthocyanins) released from their seed coats during blending (Gebregziabher et al. 2022; Kazimierczak et al. 2020; Jeske et al. 2019). Differences between the natural and sweetened almond 'milk' are also apparent—significantly higher values of yellow (b^*), chroma, and *BI* were found in the sweetened variant (Table 1). On the other hand, the unsweetened almond 'milk' was characterised by significantly higher L^* and *WI* ($P < 0.05$).

Regarding the effect of storage, Table 1 shows increasing values of L^*, b^*, *YI* and *BI* and decreasing values of a^* and *WI*. The browning index, which indicates the intensity of the brown colour, increased significantly during storage ($P < 0.05$), with the highest increase observed in sweetened almond 'milk', probably due to the formation of Maillard products. The *TCD* values were calculated to assess the effect of storage on the colour of PBMAs. According to the scale proposed by Cserhalmi et al. (2006), colour changes can be considered as slightly noticeable (0.5–1.5), except for coconut and soy PBMAs. The higher *TCD* and *BI* values of sweetened almond milk may indicate a negative effect of honey addition on its colour stability during storage.

Although some differences in PBMA's colour were apparent, multivariate statistical methods were used to visualise and quantify these differences. Principal component analysis (PCA) transformed the original 9 experimental descriptors into new variables—principal components (PC). The first 3 PCs cumulatively explain more than 90% of the whole dataset variability. For the construction of the first PC, values of *BI*, b^* and *YI* had the most significant weight, whereas in the second PC, the values of L^* and a^*, and in the third PC, *WI* and *TCD* played the dominant role. The plot of the eigenvectors (Fig. 1a) shows that there are 5 groups of vectors corresponding to individual samples. Although the groups are not clearly separated, the grouping tendency indicates that colour descriptors can be used to discriminate PBMAs. Similarly, PCF confirmed the key role of L^*, b^* and *BI* values for discrimination. The plot of factors (varimax rotation, Fig. 1b) also shows mutual positive/inverse correlations of individual colour descriptors, e.g. strong positive correlations between *BI*, b^*, *YI* and chroma and inverse correlations between *WI* and *YI* and/or L^* and a^*.

As can be seen from the CDA results, an absolute classification of PBMAs was achieved. Although the groups of individual samples in Fig. 2 are not clearly separated, the discrimination of PBMAs according to the type and storage time (C vs. E) resulted in 100% accuracy. As in the case of PCA and PCF, values of *BI*, b^*, *YI* and L^* revealed the highest discrimination power.

Conclusion

The experiment has demonstrated the potential use of colour descriptors to discriminate plant-based milk alternatives according to the raw material used in their production and storage time, as well. Contrary to expectations, the importance of whiteness for PBMAs discrimination was not confirmed. The parameters of b^*, *BI*, *YI* and L^* seem to be more important. Further research should focus on increasing the number of PBMAs to test the suitability of selected colour parameters for their discrimination, as well as to confirm the theory of a possible negative effect of sweetening on colour stability.

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Data availability Not applicable.

Code availability Not applicable.

Declarations

Conflict of interest There are no conflicts of interest to declare.

Consent for publication Not applicable.

Ethical approval Not applicable.

Consent to participate Not applicable.

References

Alcorta A, Porta A, Tárrega A, Alvarez MD, Vaquero MP (2021) Foods for plant-based diets: challenges and innovations. Foods 10:293. https://doi.org/10.3390/foods10020293

Cserhalmi Z, Sass-Kiss Á, Tóth-Markus M, Lechner N (2006) Study of pulsed electric field-treated citrus juices. Innov Food Sci Emerg Technol 7:49–54. https://doi.org/10.1016/j.ifset.2005.07.001

Gebregziabher BS, Zhang S, Ghosh S, Shaibu AS, Azam M, Abdelghany AM, Qi J, Agyenim-Boateng KG, Htway HTP, Feng Y, Ma C, Li Y, Li J, Li B, Qiu L, Sun J (2022) Origin, maturity group and seed coat color influence carotenoid and chlorophyll concentrations in soybean seeds. Plants 11:848. https://doi.org/10.3390/plants11070848

Jeske S, Bez J, Arendt EK, Zannini E (2019) Formation, stability, and sensory characteristics of a lentil-based milk substitute as affected by homogenisation and pasteurisation. Eur Food Res Tech 245:1519–1531. https://doi.org/10.1007/s00217-019-03286-0

Jeske S, Zannini E, Arendt EK (2017) Evaluation of physicochemical and glycaemic properties of commercial plant-based milk substitutes. Plant Foods Hum Nutr 72:26–33. https://doi.org/10.1007/s11130-016-0583-0

Kazimierczak R, Średnicka-Tober D, Leszczyńska D, Nowacka A, Hallmann E, Baranski M, Kopczyńska K, Gnusowski B (2020) Evaluation of phenolic compounds and carotenoids content and mycotoxins occurrence in grains of seventeen barley and eight oat cultivars grown under organic management. Appl Sci 10:6369. https://doi.org/10.3390/app10186369

Pointke M, Albrecht EH, Geburt K, Gerken M, Traulsen I, Pawelzik E (2022) A comparative analysis of plant-based milk alternatives part 1: composition, sensory, and nutritional value. Sustainability 14:7996. https://doi.org/10.3390/su14137996

Reyes-Jurado F, Soto-Reyes N, Dávila-Rodríguez M, Lorenzo-Leal AC, Jiménez-Munguía MT, Mani-López E, López-Malo A (2021) Plant-based milk alternatives: types, processes, benefits, and characteristics. Food Rev Int. https://doi.org/10.1080/87559129.2021.1952421

Sarangapany AK, Murugesan A, Annamalai AS, Balasubramanian A, Shanmugam A (2022) An overview on ultrasonically treated plant-based milt and its properties—a review. Appl Food Res 2:100130. https://doi.org/10.1016/j.afres.2022.100130

Sethi S, Tyagi SK, Anurag RK (2016) Plant-based milk alternatives an emerging segment of functional beverages: a review. J Food Sci Technol 53:3408–3423. https://doi.org/10.1007/s13197-016-2328-3

Tangyu M, Muller J, Bolten CJ, Wittmann C (2019) Fermentation of plant-based milk alternatives for improvement flavour and nutritional value. Appl Microbiol Biotechnol 103:9263–9275. https://doi.org/10.1007/s00253-019-10175-9

Tobolková B, Takáč P, Mangová B, Kozánek M (2021) A comparative study of colour characteristics of thermally/non-thermally treated mealworm larvae (Tenebrio molitor) by means of UV/Vis spectroscopy and multivariate analysis. J Food Meas Charact 15:3791–3799. https://doi.org/10.1007/s11694-021-00957-z

Yao Y, He W, Cai X, Bekhit AEDA, Xu B (2022) Sensory, physicochemical and rheological properties of plant-based milk alternatives made from soybean, peanut, adlay, adzuki bean, oat and buckwheat. Int J Food Sci 57:4868–4878. https://doi.org/10.1111/ijfs.15814