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Computer vision as the golden tool: mathematical models for evaluating color and storage time of hamburgers with goji berry natural additive

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Abstract

A new approach to meat color and shelf-life assessment is reported here for hamburgers mixed with goji berry. Samples with powdered or aqueous extract of goji berry were monitored, compared with hamburgers without the additive for ten days and its L*, a* and b* properties were determined by computer vision using a homemade setup. Noteworthy results, in particular the luminosity, for all samples with goji berry – only or with salt and pepper – were perceived, and predictive mathematical models for these food mixtures are here presented. The addition of goji berry in hamburgers, pioneered in this study, present advantageous characteristics both in terms of storage time and a positive effect on human health owing to the polyphenols in the natural additive. This study also offers insights into a low-cost and reliable method for the quality control of meat with potential application in the food industry.

Keywords: CIE; color evaluation; meat color; computer vision system; RGB.

Practical Application: Computer vision can be replaced by the conventional colorimeter, already validated as a methodology for color, since it quickly an analyzes whole sample and does not allow human interference on the choice of points to be collected. Thus, for the industry, this method would be ideal, quick, low-cost and interference less.

1 Introduction

In 2019, beef cattle farming business in Brazil accounted for approximately 130 billion dollars, which represents a 3.5% increase compared with the previous year. Such amount includes all inputs for agriculture, investments in genetics, animal health improvement, food, nutrition, and sales within the country's domestic market (Associação Brasileira das Indústrias Exportadoras de Carnes, 2021). In 2021, Brazil exported 1.8 million tons of beef, which is equivalent to a free on board (FOB) value of US$9.2 million (Food and Agricultural Policy Research Institute, 2021). Due to this growing demand, meat industry seeks to offer higher quality products and meet safety criteria that encompass both human health and environmental issues (Teixeira & Rodrigues, 2019).

Efficient ways to ensure the quality of meat products are provided by retarding its oxidative processes through physical barriers, or by adding chemical additives directly (Al-Hijazeen, 2022; Lishianawati et al., 2022; Monteschio et al., 2020; Vital et al., 2016; Vital et al., 2018a; Vital et al., 2018b). Salt and pepper are meat preservatives and their addition dates back to many centuries. Besides these two substances, the food industry has incorporated nitrites – inorganic species that prevent bacterial growth and maintain the food color (Azeem et al., 2019) – and monosodium glutamate, a flavor enhancer responsible for the umami taste. However, in large amount intake, these additives are proven to be harmful for health (Bhat et al., 2020).

Natural antioxidants are highlighted as a good additive in foods since they are safe for food products and improve their nutritional, physical-chemical and visual characteristics during storage time (Al-Hijazeen, 2022; Alexandre et al., 2021; Guerrero et al., 2018; Huang et al., 2022; Monteschio et al., 2020; Ornaghi et al., 2020). Many authors have addressed the addition of these compounds to various types of food products such as beef burgers (Carvalho et al., 2020), packaging and edible coatings (Lourenço et al., 2019), beef steaks (Vital et al., 2018a), lamb meat (Lima et al., 2022), fish fillet (Vital et al., 2018b), among others.

The goji berry (*Lycium barbarum L.*) is a plant from Asia, whose fruits are rich in phenolic antioxidants, widely used in the East hemisphere for medical formulations, fresh consumption, preparation of teas, or even as a food supplement (Fratianni et al., 2018; Huang et al., 2022; Lu et al., 2019). Five classes of polyphenols are found in goji berry: benzoic acids, catechins, cinnamic acids, flavonoids and tannins, in addition to terpenes, organic acids and

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vitamin C (Donno et al., 2015; Huang et al., 2022; Wang et al., 2010) These phenols are responsible for ensuring the integrity of food and its natural appearance.

Color is the first sensory impact caused to human eyes and an essential feature to be considered by consumers during meat evaluation, since it indicates freshness, and plays a major role on shelf life (Eiras et al., 2017; Mancini & Hunt, 2005; Monteschio et al., 2020; Udomkun et al., 2018). Meat color is usually determined by colorimeters. However, only a small portion of the product can be assessed, often intuitively chosen by researchers, leading to inaccurate measurements and results (Tomasevic et al., 2019).

Computer vision has been exploited as a reliable, quick, low-cost, and non-invasive alternative for meat product analysis and requires only a single measurement to evaluate an entire sample. Digital images are able to capture the overall information and store data for transforming into a multivariate color measurement system (Lima et al., 2022; O'Sullivan et al., 2003; Passetti et al., 2017, 2019; Tarlak et al., 2016a, b).

In this study, we propose a mathematical model based on computer vision to investigate the performance of goji berry (powdered or in aqueous extract) as a natural preservative for maintaining the color of hamburger-type products. The color space parameters of these samples were determined using computer vision at different storage times.

2 Materials and methods

2.1 Ethic committee, local, animals, and diets

This experiment was approved by the Department of Animal Production and Research Ethic Committee at the State University of Maringá (UEM) in Maringá, Paraná, Brazil and it followed the guiding principles of biomedical research with animals (CAAE: 44460020.3.0000.0104 protocol number).

This study was conducted at the Rosa & Pedro Sector of the Experimental Farm Station at UEM. The sensorial evaluation was performed at the Meat Quality Laboratory at UEM. A total of 24 crossbred bulls (*Bos taurus taurus x Bos taurus indicus*) at 24 ± 3.2 months of age and weighting mean initial body weight of 385.5 ± 3.84 kg were used in a completely randomized design.

2.2 Samples and additives

The hamburgers were prepared by using the *Longissimus dorsi* of bulls, collected from the left half-carcass between from 6th to 13th ribs.

Goji berry (*Lycium barbarum L.*), black pepper (*Piper nigrum L.*) and commercial salt (Ajisal®) were purchased from local market in Maringá, Paraná, Brazil. The goji berry was dried in an oven at 55° C for 72 h and finely ground (Hamilton Beach®) for 2 min. The goji berry aqueous extract was prepared by dissolving the powder in distilled water and then added in different concentrations to the hamburgers.

2.3 Mass and sample proportion

Using a piece of meat, a set of 10 hamburgers was prepared in the following proportions (% mass/mass), which were analyzed in triplicate: Control sample (1): 80% meat and 20% fat; Sample 2: 98.9% control sample + 1% commercial salt + 0.1% pepper; Sample 3: 95.9% control sample + 1% commercial salt + 0.1% pepper + 3% goji berry powder; Sample 4: 92.9% control sample + 1% commercial salt + 0.1% pepper + 6% goji berry powder; Sample 5: 95.9% control sample + 1% commercial salt + 0.1% pepper + 3% goji berry aqueous extract; Sample 6: 92.9% control sample + 1% commercial salt + 0.1% pepper + 6% goji berry aqueous extract; Sample 7: 97% control sample + 3% goji berry powder; Sample 8: 94% control sample + 6% goji berry powder; Sample 9: 97% control sample + 3% goji berry aqueous extract; Sample 10: 94% control sample + 6% goji berry aqueous extract. All samples were placed on white Styrofoam trays, sealed with flexible polyvinyl chloride (PVC) film and random stored under refrigeration (2-4° C), free from contamination, under conditions comparable to commercial/home ones.

Ten hamburgers (~50 g, ~2 cm high) were prepared with a hamburger-maker in the following proportions (% w/w): Control sample (1): 80% meat and 20% fat; Sample 2: 98.9% control sample + 1% commercial salt + 0.1% pepper; Sample 3: 95.9% control sample + 1% commercial salt + 0.1% pepper + 3% goji berry powder; Sample 4: 92.9% control sample + 1% commercial salt + 0.1% pepper + 6% goji berry powder; Sample 5: 95.9% control sample + 1% commercial salt + 0.1% pepper + 3% goji berry aqueous extract; Sample 6: 92.9% control sample + 1% commercial salt + 0.1% pepper + 6% goji berry aqueous extract; Sample 7: 97% control sample + 3% goji berry powder; Sample 8: 94% control sample + 6% goji berry powder; Sample 9: 97% control sample + 3% goji berry aqueous extract; Sample 10: 94% control sample + 6% goji berry aqueous extract. All samples were placed on white Styrofoam trays, sealed with flexible polyvinyl chloride (PVC) film and random stored under refrigeration (2-4 °C), free from contamination, under conditions comparable to commercial/home ones.

2.4 Apparatus for the photographs

The homemade setup for photographs (Figure 1) was based on the reported by Girolami et al. (2013) with adaptations. A cardboard box (w = 60 cm, h = 30 cm, d = 32 cm) was fully covered of black paint and two drills were made on the upper part of the box: one of them to place a camera, and the other for a light source (T9 LED light bulb, 7000 lumens/12 V).

The photography images were obtained by using a cell phone camera (Xiaomi mi 8, 12MP, 4,000 x 3,000 pixels, sensor size 1/2.55" + 1/3.4" and stabilization) with focus stabilization. Zoom and flash resources were not used. Both the camera and the light source were placed orthogonally and ~30 cm (box height) from the samples for image acquisition with the LED placed 2 cm on the right side of the camera. The photographs were taken at intervals of 1, 3, 7 and 10 days (d).

Figure 1. Homemade setup for photographs: front (a) and upper (b) view.

2.5 Color instrumental measurement/mathematical modeling

Data were collected following the studies reported by (Tarlak et al., 2016a) and analysis was performed by using the IEC (International Electrotechnical Commission) Lab method by transforming components from RGB (red, green and blue) into the XYZ model. RGB images generally contain 8 bits of data per color channel and can be named as 24-bit RGB (8 bits x 3 channels) with values ranging from 0 to 255. The relationship between the RGB and XYZ models is defined in the Equations 1-3 below (International Electrotechnical Commission, 1999).

$$R'_{RGB} = \frac{R_{8bit}}{255} \quad (1)$$

$$G'_{RGB} = \frac{G_{8bit}}{255} \quad (2)$$

$$B'_{RGB} = \frac{B_{8bit}}{255} \quad (3)$$

If R'_{RGB}, G'_{RGB} and $B'_{RGB} \leq 0.04045$, then (Equations 4-6):

$$R_{RGB} = \frac{R'_{RGB}}{12.92} \quad (4)$$

$$G_{RGB} = \frac{G'_{RGB}}{12.92} \quad (5)$$

$$B_{RGB} = \frac{B'_{RGB}}{12.92} \quad (6)$$

yet, if R'_{RGB}, G'_{RGB} and $B'_{RGB} > 0.04045$, then (Equations 7-9):

$$R_{RGB} = \left(\frac{R'_{RGB}+0.055}{1.055}\right)^{2,4} \quad (7)$$

$$G_{RGB} = \left(\frac{G'_{RGB}+0.055}{1.055}\right)^{2,4} \quad (8)$$

$$B_{RGB} = \left(\frac{B'_{RGB}+0.055}{1.055}\right)^{2,4} \quad (9)$$

Thus (Equation 10),

$$\begin{cases} X = 0.4124R_{RGB} + 0.3576G_{RGB} + 0.1805B_{RGB} \\ Y = 0.2126R_{RGB} + 0.7152G_{RGB} + 0.0722B_{RGB} \\ Z = 0.0193R_{RGB} + 0.1192G_{RGB} + 0.9505B_{RGB} \end{cases} \quad (10)$$

From the XYZ model it is possible to obtain the L*, a* and b* components according to the following equations (Equations 11-12) (Azad & Hasan, 2017; Lima, 2020):

$$\begin{cases} L = \left[116 * f*\left(\frac{y}{y_0}\right)\right] - 16 \\ a* = 500*\left[f*\left(\frac{x}{x_0}\right) - f*\left(\frac{y}{y_0}\right)\right] \\ b* = 200*\left[f*\left(\frac{y}{y_0}\right) - f*\left(\frac{z}{z_0}\right)\right] \end{cases} \quad (11)$$

Where,

$$f(q) = \begin{cases} \sqrt[3]{q}, & q > 0.008856 \\ \left(\frac{841}{108}*q\right) + \frac{4}{29} & q \leq 0.008856 \end{cases} \quad (12)$$

In this case, $x_0 = 94.81$, $Y_0 = 100$ and z0 = 107.3 are the tristimulus values for the CIE illuminant D65.

The Adobe Photoshop CS3 software was used to collect forty color pixels from each photograph, ten points from each quadrant (quadrants are defined as four equal parts of an image already segmented). Parameters L*, a* and b* were, accordingly, determined through Equation 4 using the collected points.

3 Results

3.1 L, a* and b* values*

The L* values represent the luminosity perceived by an observer and can range from zero to one hundred, referring to black and white, respectively. The a* and b* values are vectors that represent the four colors perceived by the human eye, i.e., red, green, blue, and yellow; a* expresses the range of green to red (where green lies on a negative quadrant on a Cartesian coordinate axis, and red on a positive quadrant). The b* value, orthogonally to a*, represents the variation between blue (negative quadrant) and yellow (positive quadrant) (Hardeberg, 2001). In

Table 1 the L*, a* and b* parameters determined for hamburger samples with and without goji berry additives are shown.

On the first day of experiment (Table 1), sample 1 (control) clearly depicted a substantially higher luminosity than the other samples (L* > 35) whereas sample 4 presented the lowest value (L* < 25), while the luminosity parameters of the other trials remained on the 20 < L* < 30 range (Figure 2).

Parameter a*, which represents the red-green color variation, and parameter b*, related to the yellow-blue coloration. In both cases, sample 5 values outstand from the other tests, with color matching the red (a*) and yellow (b*) regions (Figure 3e and Figure 4e).

The scatter diagrams in Figure 3 show the correlation between a* and time (d) for all tests (refer to Table 1). The obtained data properly fit to a linear function, with a negative slope, which indicates that the color of the samples is changing from red to green. A coefficient of determination, R^2, is above 0.92 for the majority of the tests, except for samples 1 (control) and 3, with $R^2 \sim 0.774$ and 0.893, respectively. In this case it is possible to predict the value of a* for days not collected.

The correlation between variables b* and time (d) (refer to Table 1) is depicted in Figure 4. For the most essays, a coefficient of determination, R^2, is above 0.96, except for samples 3, 4, and 5, with R^2 ranging from 0.793 to 0.813. The obtained data

Table 1. Hamburger sample composition and its *L**, *a**, and *b** values.

	Sample composition	Time/d	*L**	*a**	*b**
Sample 1 Control	Meat (80%) + fat (20%)	1	36.7395	33.4875	15.1556
		3	24.2213	27.1952	14.2165
		7	24.9043	15.8341	6.5339
		10	26.9181	19.1876	3.4858
Sample 2	Control (98.9%) + commercial salt (1%) + pepper (0.1%)	1	27.2587	30.2940	15.4520
		3	26.6016	25.4270	12.3193
		7	29.6966	19.2123	6.2352
		10	29.6409	15.7982	1.9146
Sample 3	Control (95.9%) + commercial salt (1%) + pepper (0.1%) + ***goji berry* powder (3%)**	1	25.9158	19.9669	11.5624
		3	24.5696	20.2331	15.1192
		7	23.9979	11.9544	7.1578
		10	27.2371	11.1287	2.2293
Sample 4	Control (92.9%) + commercial salt (1%) + pepper (0.1%) + ***goji berry* powder (6%)**	1	21.5084	15.5809	10.3795
		3	22.9119	15.7700	13.6817
		7	23.3351	12.2468	6.2336
		10	25.7918	11.2936	-0.2875
Sample 5	Control (95.9%) + commercial salt (1%) + pepper (0.1%) + ***goji berry* aqueous extract (3%)**	1	29.1833	32.4025	15.9567
		3	29.8107	33.4108	19.9517
		7	28.1985	25.1634	10.3987
		10	28.4956	17.6180	3.7438
Sample 6	Control (92.9%) + commercial salt (1%) + pepper (0.1%) + ***goji berry* aqueous extract (6%)**	1	28.5228	30.0545	15.1932
		3	25.4791	27.5221	14.3142
		7	26.0462	19.7245	5.8566
		10	25.5686	15.4490	0.1994
Sample 7	Control (97%) + ***goji berry* powder (3%)**	1	27.6347	30.8648	14.8750
		3	25.4584	27.0803	14.4471
		7	26.6910	19.5457	5.4769
		10	27.7989	15.2978	0.8726
Sample 8	Control (94%) + ***goji berry* powder (6%)**	1	27.5359	31.1793	15.4848
		3	23.2544	26.6779	13.6280
		7	27.1658	19.3980	5.8213
		10	27.1469	15.3625	0.8307
Sample 9	Control (97%) + ***goji berry* aqueous extract (3%)**	1	27.5981	30.3229	15.5786
		3	25.2170	26.9568	14.5755
		7	26.8538	19.5201	5.5733
		10	26.6185	15.3038	0.3180
Sample 10	Control (94%) + ***goji berry* aqueous extract (6%)**	1	27.8646	31.0699	15.4290
		3	25.6173	26.9120	14.1944
		7	25.7669	19.3189	5.6258
		10	27.9565	15.8604	0.6773

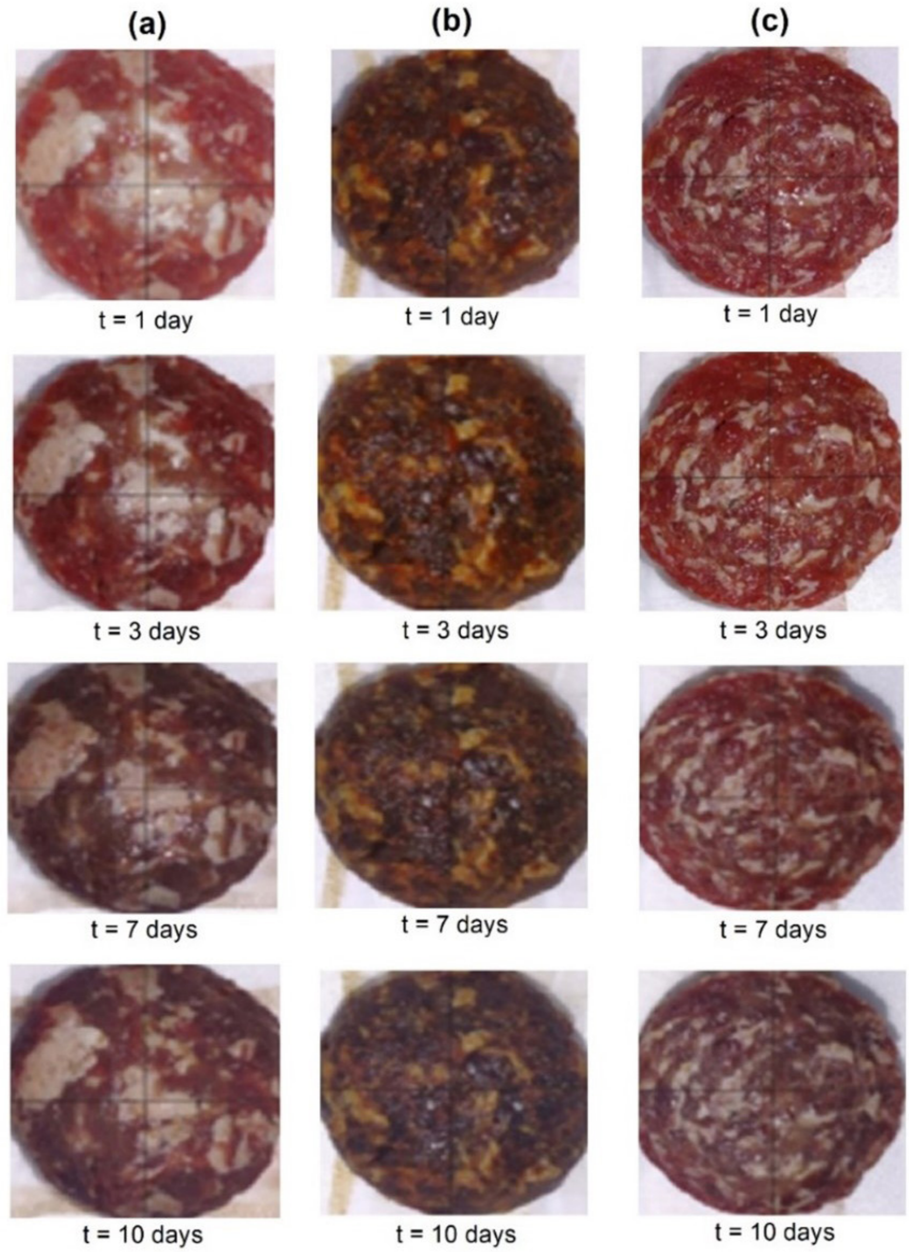

Figure 2. Hamburger color variation over time. (a) Sample 1: Meat only, (b) Sample 4: Meat + ajisal + pepper + 6% goji powder, (c) Sample 5: Meat + ajisal + pepper + 3% goji in extract.

properly fit to a linear function, with a negative slope, which indicates that the color of the samples is changing from yellow to blue. Choosing, for example, samples 1, 4 and 5, it is possible to estimate the parameters a* and b* when t = 5 and t = 9 days. (Table 2).

The meat color indicates salubriousness or freshness. The L*, a* and b* values for samples 7-10, comprising only those hamburgers containing goji berry powder or aqueous extract, exhibited a promising color preservation behavior. For all these samples the luminosity values tend to remain in the $25 < L^* < 30$ interval, in the same luminosity range as for control sample, or even with higher values in some cases.

4 Discussion

4.1 L, a*, and b* values*

A color space is both a specification of a coordinate system and a subspace in that same system where each color can be represented by a single point. In terms of digital image processing, the most commonly used models are RGB (red, green, blue), CMY (clay, magenta, yellow) and CMYK (cyan, magenta, yellow and black), consistent to how humans describe and interpret primary colors (Azad & Hasan, 2017). The RGB model is based on a Cartesian coordinate system. Each color pixel can be represented by a vector since a color image has, at least, three components. The main limitations of this model are

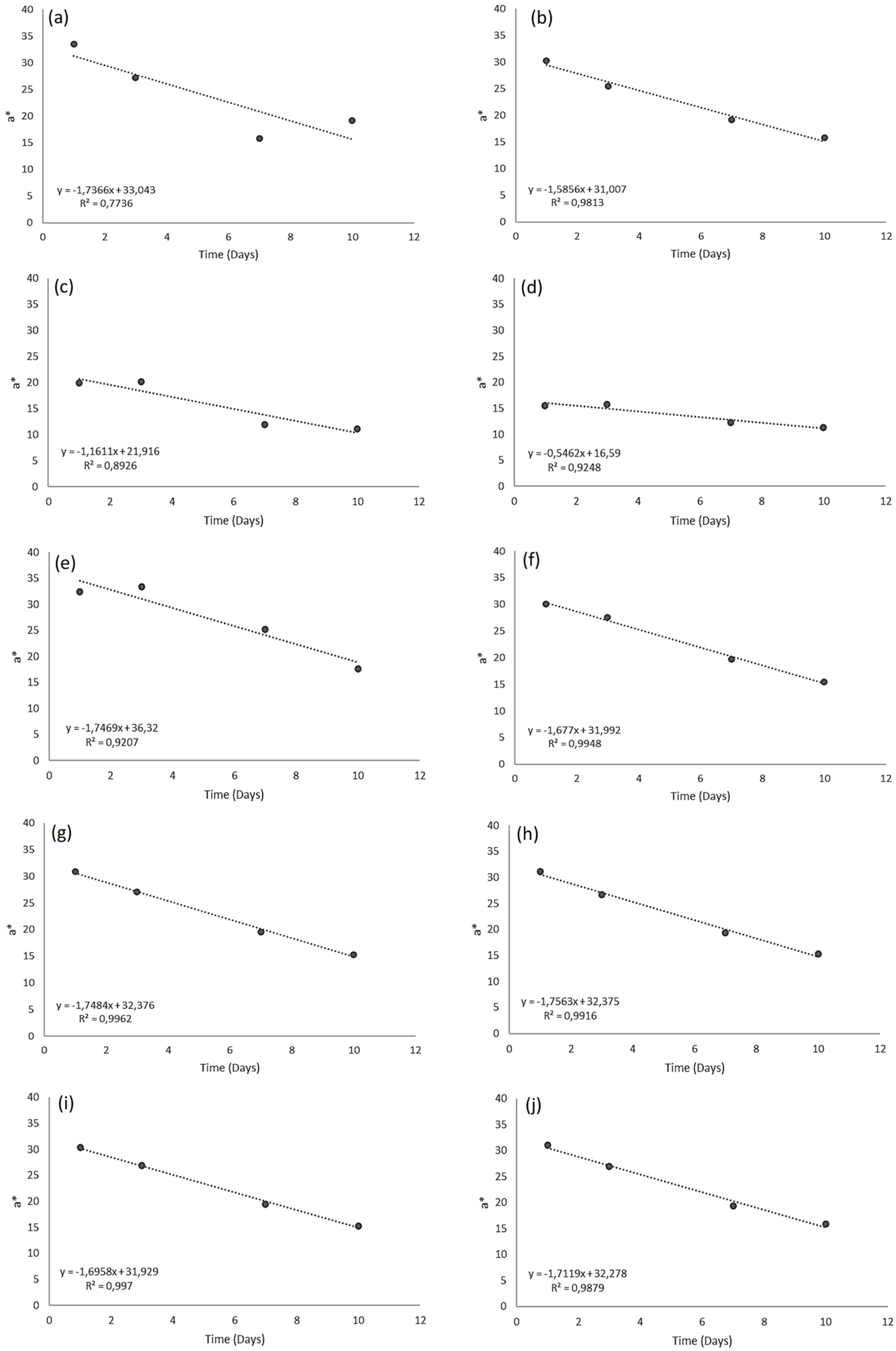

Figure 3. a* scatter diagrams. (a) Sample 1: Meat only, (b) Sample 2: Meat + ajisal (1%) + pepper (0.1%), (c) Sample 3: Meat + ajisal + pepper + 3% goji powder, (d) Sample 4: Meat + ajisal + pepper + 6% goji powder, (e) Sample 5: Meat + ajisal + pepper + 3% goji in extract, (f) Sample 6: Meat + ajisal + pepper + 6% goji in extract, (g) Sample 7: Meat + 3% goji powder, (h) Sample 8: Meat + 6% goji powder, (i) Sample 9: Meat + 3% goji in extract and (j) Sample 10: Meat + 6% goji in extract.

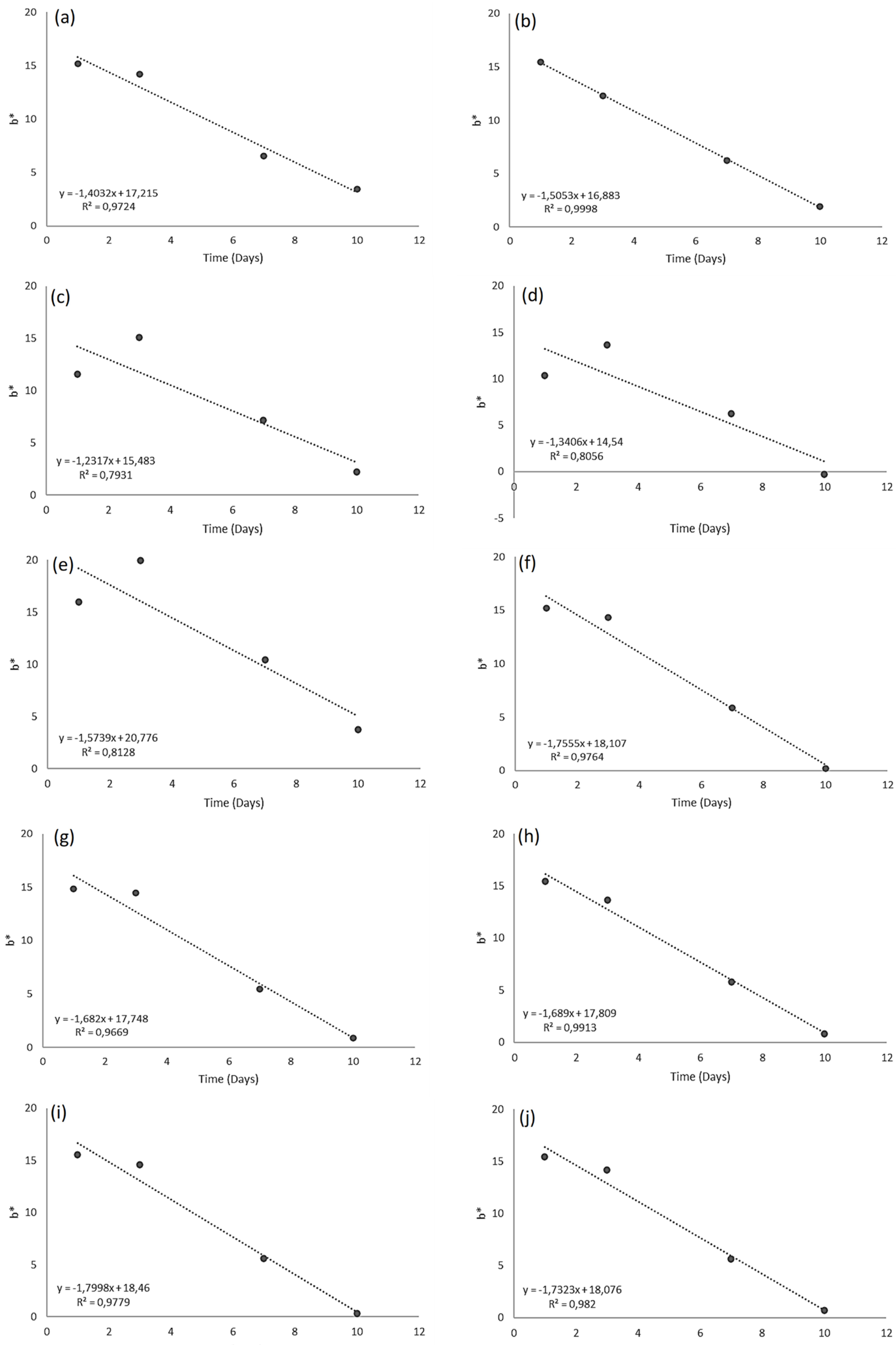

Figure 4. b* scatter diagrams. (a) Sample 1: Meat only, (b) Sample 2: Meat + ajisal (1%) + pepper (0.1%), (c) Sample 3: Meat + ajisal + pepper + 3% goji powder, (d) Sample 4: Meat + ajisal + pepper + 6% goji powder, (e) Sample 5: Meat + ajisal + pepper + 3% goji in extract, (f) Sample 6: Meat + ajisal + pepper + 6% goji in extract, (g) Sample 7: Meat + 3% goji powder, (h) Sample 8: Meat + 6% goji powder, (i) Sample 9: Meat + 3% goji in extract and (j) Sample 10: Meat + 6% goji in extract.

Table 2. Prediction and validation of mathematical models for samples 1, 4 and 5.

Samples	Sample composition	Time/d	*a* observed*	*a* mathematical model*	*b* observed*	*b* mathematical model*
Sample 1 Control	Meat (80%) + fat (20%) a*(t) = -1,7366t + 33,043 b*(t) = -1,4032t + 17,215	1	33.4875	31.3064	15.1556	15.8118
		3	27.1952	27.8332	14.2165	13.0054
		5		24.3600		10.1990
		7	15.8341	20.8868	6.5339	7.3926
		9		17.4136		4.5862
		10	19.1876	15.6770	3.4858	3.1830
Sample 4	Control (92.9%) + commercial salt (1%) + pepper (0.1%) + ***goji berry* powder (6%)** a*(t) = -0,5462t + 16,59 b*(t) = -1,3406t + 14,54	1	15.5809	16.0438	10.3795	13.1994
		3	15.7700	14.9514	13.6817	10.5182
		5		13.8590		7.8370
		7	12.2468	12.7666	6.2336	5.1558
		9		11.6742		2.4746
		10	11.2936	11.1280	-0.2875	1.1340
Sample 5	Control (95.9%) + commercial salt (1%) + pepper (0.1%) + ***goji berry* aqueous extract (3%)** a*(t) = -1,7469x + 36,32 b*(t) = -1,5739x + 20,776	1	32.4025	34.5731	15.9567	19.2021
		3	33.4108	31.0793	19.9517	16.0543
		5		27.5855		12.9065
		7	25.1634	24.0917	10.3987	9.7587
		9		20.5979		6.6109
		10	17.6180	18.8510	3.7438	5.0370

characterized by its dependence on the sensitivity of the catching image device and intolerance to light variations (International Electrotechnical Commission, 1999; Lima, 2020).

The CIE Lab model is a suitable tool for various color management systems (CMS) provided that it does not depend on the device used. Temporal evaluation covering 10 d of experiments shows that samples 2 and 5 presented the highest luminosity values, with an apparent contrast to the other samples from day 3 onwards. Sample 5 (L* ~ 30) displayed a noteworthy luminosity value, clearly far from the luminosity region that encompasses the remaining samples.

Table S1 (supporting information) indicates that experimental errors for L* did not exceed 25%, when comparing all the hamburgers containing additives with control. Sample 4, however, presented a considerable percentage error of 41.46%. The highest error percentages are detected in the first day of data collection and decrease over time. On the tenth day, the highest error value of the samples did not exceed 10.12% (Sample 2).

A well-adjusted mathematical model might be able to represent all the systematic information contained in the sample space and the deviations must relate only to the random errors embedded in the measurements (Bona et al., 2002; Coppo et al., 2014). The mathematical model we propose here can be validated for predictive purposes, i.e., the L* values for non-monitored days can be predicted, since the R^2 values indicate good quality of linear fit and the error values are low.

Studies developed by Minz et al. (2020) applied to the powder bed, an algorithm was developed to process images in high-definition (HD) and provide better accuracy in measurements. Considering that the HD image matrix makes image processing complex and with high utilization of machine resources, algorithms were used for pre-processing and reduction of the image matrix, in addition to the CIE lab colorimeter parameters obtained in the RGB image transformation.

According to Pathare et al. (2013) computer vision has been used to objectively measure the color of different foods since they provide some obvious advantages over a conventional colorimeter, namely, the possibility of analyzing each pixel of the entire surface of the food and quantifying surface characteristics and defects.

4.2 Coloring and antioxidant activity

Myoglobin is the main protein responsible for meat color, although other heme proteins, such as hemoglobin and cytochrome C, also play important roles. According to Mancini & Hunt (2005), the mechanisms of meat coloration and discoloration are:

1. Oxygenation: there is a predominance of deoxy hemoglobin, a substance that belongs to the heme group, with a Fe^{2+} metallic center and its sixth coordination site is vacant. In this case, the color of meat is red/purple or purple/pink; when dioxygen binds to the empty Fe^{2+} site, the color changes to cherry-red, but the valence of iron is maintained.
2. Oxidation: oxidation of myoglobin derivatives, where Fe^{2+} is oxidized to Fe^{3+}.
3. Oxidation + reduction: the color of meat is preserved due to the reduction of metmyoglobin, which is possible by reducing enzyme systems and NADPH. However, after animal death, this supply is no longer available.
4. Formation of carboxy-hemoglobin: this is a not fully elucidated mechanism, but it is known that carbon monoxide (CO) binds to the vacant site of deoxy-hemoglobin, leading to a bright red color.

As detected by computer vision, goji berry is capable of maintaining color parameters at the same intensity as for the control sample or samples containing salt and pepper. In other words, these additive-hamburgers present a color already widely accepted by consumers. During the period of 10 days covered by the experiment, no visual color degradation was observed, indicating a reliable storage time.

The color preservation is a result of rate decrease or inhibition of meat protein oxidation (O'Sullivan et al., 2003). The phenolic antioxidants found in goji berry donate hydrogens and stabilize oxidizable substances likely through mechanistic pathways ii and/or iii (discussed above). Therefore, the antioxidants do not compete with the substrate for oxygen absorption, instead, they deactivate oxidizing species.

It is widely known that oils and fats are susceptible to oxidation, through radical reactions, when in contact with atmospheric oxygen. Oxidation is accelerated by the presence of metal ions, light, temperature, ionizing radiation (Bondioli et al., 2003; Ferrari & Souza, 2009; Galvan et al., 2013) and leads to the formation of acids, aldehydes, esters, ketones, peroxides, hydroperoxides, and alcohols, as well as to polymerization products (Coppo et al., 2014; Xin et al., 2009). It is worth emphasizing the possibility of rancidification provided by fat, that accounts for 20% hamburger composition. Degradation products can damage flavor, but the goji berry phenolics may act as free radical terminators, leading to protection from both fat and meat oxidation (Borsato et al., 2014; Coppo et al., 2014).

Besides both meat color and freshness preservation, the goji berry also depicts other beneficial effects over consumer health, as it neutralizes the effects of free radicals in the body. As a matter of fact, the hamburgers here studied can act as functional food, preventing aging and promoting neuroprotection, diabetes control and cytoprotection, including antitumor activity (Donno et al., 2015).

5 Conclusion

The evaluation of hamburgers with goji berry additives demonstrated a distinguished L*, a*, and b* results for sample 5 (meat + commercial salt + pepper + goji berry aqueous extract) and samples 7-10 (only goji berry, powdered or in aqueous extract). The meat colors of these trials remained visually acceptable during a 10 day-evaluation, proving the role of the antioxidants in goji berry as a good preservative. The addition of goji berry in hamburgers, pioneered in this study, present advantageous characteristics both in terms of storage time and positive effect on human health owing to the polyphenols in the natural additive.

This study also provided an appealing insight on the predictive mathematical model presented, with a fast, low-cost, and reliable homemade system to assess meat color and stipulate a realistic storage time, when the visual characteristics are maintained. In computer vision, some adjustments are necessary to obtain the results with greater accuracy, such as using software with environment control, automating the process of obtaining images and using machine learning.

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Supplementary Material

Supplementary material accompanies this paper.

Table S1. Experimental errors for L* of all the samples of hamburgers.

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