Research, Society and Development, v. 9, n. 7, e725974414, 2020
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v9i7.4414

Farias, HFL, Devilla, IA, Silva, AP, Bento, JAC & Bassinello, PZ (2020). Bean color and hardness modeling as a function of storage conditions. ***Research, Society and Development***, 9(7): 1-25, e725974414.

Modelagem da cor e dureza do feijão em função das condições de armazenamento

Bean color and hardness modeling as a function of storage conditions

Modelado del color y la dureza de los frijoles según las condiciones de almacenamiento

Recebido: 11/05/2020 | Revisado: 13/05/2020 | Aceito: 26/05/2020 | Publicado: 07/06/2020

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Resumo

O feijão carioca armazenado geralmente tende a escurecer e endurecer e, portanto, perde qualidade e valor comercial e é rejeitado pelo consumidor. Com isso, o objetivo deste estudo foi avaliar o comportamento de quatro genótipos contrastantes de tegumento leve para o processo de envelhecimento (escurecimento e endurecimento) por seis meses. Adotamos uma modelagem matemática de dados, com base em análises de regressão polinomial das variáveis, cor e textura, nas diferentes condições de armazenamento, para descrever os efeitos do tratamento e do tempo de armazenamento, em todas as amostras de feijão e para selecionar o modelo que melhor descreve a interação entre variáveis. Todos os genótipos tenderam a endurecer, com o aumento da temperatura e do tempo de armazenamento, independentemente do grau de escurecimento. Os menores valores de dureza, após seis meses, foram verificados em grãos de escurecimento lento e rápido. O genótipo mais resistente ao escurecimento foi o que apresentou endurecimento significativo ao longo do tempo. Concluindo, que a cor em si não é o melhor parâmetro a ser considerado para determinar o grau de envelhecimento dos grãos armazenados, que é controlado por mecanismos complexos, físico-químicos, genéticos, bioquímicos, entre outros, que por sua vez são influenciados pelas condições ambientais de armazenamento e genótipo.

Palavras-chave: *Phaseolus vulgaris*; Qualidade; Dureza; Escurecimento.

Abstract

Stored carioca beans usually tend to darken and harden and therefore lose quality and commercial value and are rejected by the consumer. The objective of this study was to evaluate the behavior of four contrasting light tegument genotypes for the aging process (darkening and hardening) for six months. We adopted a mathematical data modeling, based on polynomial regression analyzes of the variables, color and texture, in the different storage conditions, to describe the effects of the treatment and the storage time, in all bean samples and to select the model which best describes the interaction between variables. All genotypes tended to harden, with increasing storage temperature and time, regardless of the degree of browning. The lowest values of hardness, after six months, were verified in both slow and fast darkening beans. The genotype most resistant to darkening was which showed significant hardening over time. In conclusion, the color itself is not the best parameter to be considered to determine the degree of aging of stored beans, which is controlled by complex mechanisms, physicochemical, genetic, biochemical, among others, which in turn are influenced by environmental storage conditions and genotype.

Keywords: *Phaseolus vulgaris*; Quality; Hardness; Browning.

Resumen

Los frijoles carioca almacenados generalmente tienden a oscurecerse y endurecerse y, por lo tanto, pierden calidad y valor comercial y son rechazados por el consumidor.El objetivo de este estudio fue evaluar el comportamiento de cuatro genotipos de tegumento de luz contrastante para el proceso de envejecimiento (oscurecimiento y endurecimiento) durante seis meses.Adoptamos un modelo de datos matemáticos, basado en análisis de regresión polinómica de las variables, color y textura, en las diferentes condiciones de almacenamiento, para describir los efectos del tratamiento y el tiempo de almacenamiento, en todas las muestras de frijol, y para seleccionar el modelo que describe mejor la interacción entre variables.Todos los genotipos tienden a endurecerse, con el aumento de la temperatura y el tiempo de almacenamiento, independientemente del grado de dorado.Los valores más bajos de dureza, después de seis meses, se verificaron en frijoles de oscurecimiento lento y rápido. El genotipo más resistente al oscurecimiento fue el que mostró un endurecimiento significativo con el tiempo.En conclusión, el color en sí mismo no es el mejor parámetro a considerar para determinar el grado de envejecimiento de los frijoles almacenados, que está controlado por mecanismos complejos, fisicoquímicos, genéticos, bioquímicos, entre otros, que a su vez están influenciados por las condiciones ambientales de almacenamiento y genotipo.

Palabras clave: *Phaseolus vulgaris*; Calidad; Dureza; Dorado.

1. Introduction

Beans (*Phaseolus vulgaris* L.) together with rice (*Oryza sativa* L.) form the basis of the diet of Brazilians. Moreover, the dry beans are considered a valuable crop found in diets around the world and in Brazil and in developing countries, in general, this grain is an important and affordable source of protein, dietary fiber, complex carbohydrates, vitamins and minerals (Ferreira et al., 2016).

Consumption of dry beans has many benefits including maintenance and even improvement of human health and wellness. Much like other light varieties, carioca beans are susceptible to darkening while in storage, as affected by exposure to light, elevated temperature and high humidity (Bento et al., 2020; Elsadr et al., 2011).

The color of beans, especially for the carioca type, is an attribute of strong influence at the time of purchase and consumer acceptability due to the tegument darkening during storage (Pereira et al., 2017). The consumer associates this phenomenon to its aging and, therefore, to its hardening, which depreciates the commercial value (Siqueira et al., 2014). This is particularly important for bean growers who store grain for a period before sale (Elsadr et al., 2011; Felicetti et al., 2012).

Depending on the environmental conditions of cultivation and post-production, a grain phenomenon may be known as the “Hard-To-Cook” (HTC) effect, in which there is increased cooking time, changes in texture and taste and decreased nutritional value of beans (Njoroge et al., 2015; Segura-Campos et al., 2014; Matamoros et al., 2010). Given the great economic loss that dark skin grains represent in the bean market, the common bean breeding program has focused on grains with the lighter background and maintaining the light color for as long as possible (Silva et al., 2014).

In view of the above, this work aimed to evaluate the behavior of different genotypes of light tegument bean, carioca type and a Pinto bean strain resistant to browning, regarding the aging processes (darkening and hardening) over the storage time.

2. Methodology

2.1 Sample preparation

This research is of quantitative and qualitative nature as stated by Pereira et al. (2018). Common bean grains of the carioca group genotypes, regular darkening, BRS Estilo and BRS Pontal, slow darkening, BRSMG Madreperola and CNFC 10467 and a Canadian strain (Felicetti et al., 2012) from the Pinto Bean group (1533-15), resistant to darkening, were used. The grains were produced and stored at Embrapa Rice and Beans, located in Santo Antônio de Goiás, 2013/2014 crop. The bean storage began shortly after harvest and drying of the material (13% b.u.). Samples of approximately 0.400 kg of grain were collected and packed in polyethylene bags, identified with labels and stored after purging until the analyses were performed. The water content of the samples was determined in a greenhouse according to Brazil (2009).

The samples were stored for 180 days in an incubator chamber, set at 37 °C (40% average relative humidity), in a cold room set at 15 °C (65% average relative humidity) and in a 21 °C climate-controlled room (79% average relative humidity). Six examples were taken per sample over time, at intervals of 36 days. The control sample was considered as freshly harvested (not stored) beans for each genotype, evaluated immediately after processing.

The experimental design was completely randomized in a 3x5x6 factorial scheme, with three storage temperatures (15, 21, and 37 °C), five genotypes and six storage periods (0, 36, 72, 108, 144 and 180 days). For analysis of quantitative data, analysis of variance and regression were used.

2.2 Grain hardness

Bean grain hardness was evaluated by the TA CT-3 Texture Analyzer puncture test with 50 kg load cell, according to Revilla and Vivar-Quintana (2008) with adaptations. Each grain was evaluated for resistance to penetration by 2 mm (P2) cylindrical geometry at a constant velocity of 1 mm s-1 to 90% of its initial height. Thirty raw bean grains were drilled for each sample and the results expressed in gf (gram force).

2.3 Integument color

The bean grain integument staining was performed on the Color Quest XE (Hunter Lab) Colorimeter with diffused illumination (D65 illuminant, 10 ° angle of view), previously calibrated with the standard white plate using the CIELAB system (L*, a*, b*), (CIE, 1978).

Twenty readings were taken, and each sample (100 g) was constantly homogenized before the readings. The results were presented in terms of brightness (L*), chromaticity a* and b* and total color difference (ΔE*).

2.4 Modeling

For the mathematical modeling of the data, regression analyses of the variables, color, and texture were performed under different storage conditions. Polynomial regression equations were developed to describe the effects of treatment and storage time on all bean samples.

Thus, the general form of the polynomial regression employed in this study is presented in the form of linear equations, and the quality of the regression was evaluated by the coefficient of determination R2 and mean error (P), thus allowing selection of the model that best describes the interaction between the variables.

Tukey test was also used in the comparison of means, with 5% error. Regression analyses were performed using the Statistica software version 12.0.

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3. Results and Discussion

Water contents of genotypes at different temperatures and storage periods are shown in Table 1.

Table 1. Water content (% on a wet basis (w.b.)) of bean cultivars at temperature and storage periods.

Days	Treatment	Cultivars				
		CNFC 10467	**BRS Estilo**	**Madrepérola**	**Pinto Bean**	**BRS Pontal**
0	Control	9.5	9.1	9.6	8.5	9.6
36	15°C	8.4	8.6	9.4	8.6	8.8
	21°C	8.3	8.8	9.4	9.3	9.1
	37°C	5.3	6.1	6.0	6.0	6.0
72	15°C	8.4	8.4	9.6	9.7	7.4
	21°C	8.4	8.8	10.1	10.1	8.3
	37°C	5.8	5.5	5.8	6.2	5.2
108	15°C	10.0	10.1	10.0	9.6	10.4
	21°C	10.2	10.2	10.8	9.2	9.9
	37°C	6.0	6.2	6.3	6.4	6.3
144	15°C	11.0	9.9	10.1	9.6	9.7
	21°C	10.3	10.1	11.0	10.0	10.1
	37°C	6.7	6.1	6.7	7.1	6.3
180	15°C	10.0	10.5	10.8	10.9	10.3
	21°C	12.3	11.7	12.3	11.6	11.0
	37°C	6.6	6.1	6.1	6.5	6.7

Source: Data collected by the authors themselves from the experimental design of the present research.

It was noted that the water content ranged from 5.3 to 12.3% w.b. and that environments with higher RH contents induced an increase of grain equilibrium water content, but still within the range considered adequate for storage. Under higher temperature and low RH, the grains presented greater stability of the equilibrium water content, but much lower than the others.

Results of variance analysis of variables (Table 2) indicated significant interaction for storage time ($p<0.05$), cultivars and storage conditions (variance coefficient 8.34%). That is, each cultivar has a different behavior regarding the conditions and storage time.

Table 2. Summary analysis of variance (ANOVA), hardness and color parameters (L *, a *, b *) of CNFC 10467, BRS Estilo, BRS Pontal, BRSMG Madrepérola and Pinto Bean genotypes for six months storage temperature and temperatures.

FV	GL	QM			
		Hardness	L*	a*	b*
Temperature (T)	2	1551.601159*	1214.77*	255.96*	86.63*
Time (t)	5	1779.772157*	508.58*	114.56*	17.35*
Cultivars (C)	4	613.315626*	6938.89*	627.97*	159.07*
T x t	10	207.794206*	104.19*	19.53*	10.34*
T x C	8	19.335263*	143.19*	40.21*	6.10*
t x C	20	82.684403*	37.84*	15.47*	5.63*
T x t x C	40	12.366075*	17.65*	2.76*	2.35*
Residue	2610	1.465468*	2.37*	0.37*	0.57*
Total	2699	-	-	-	-
CV (%)	-	8.39	2.99	7.75	4.25

* Significant at 5% significance by the F test. Source: Data collected by the authors themselves from the experimental and statistical design of the present research.

3.1 Hardness

It is noted that all genotypes tend to be hardening with increasing temperature and time of storage (Table 3).

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Table 3. Average hardness (Kgf) values of raw bean grains, as a function of temperature and storage time.

Days	Treatment	Cultivars				
		CNFC 10467	**BRS Estilo**	**Madrepérola**	**Pinto Bean**	**BRS Pontal**
0	Control	8.88±0.82d	9.01±0.86cd	9.66±0.65bc	14.89±1.54a	9.83±0.62b
36	15°C	13.63±1.49	11.88±1.12	13.32±1.14	16.16±0.83	13.18±1.24
	21°C	15.07±1.89	12.80±12.12	14.08±1.72	15.83±0.77	14.24±1.40
	37°C	16.33±1.49	14.16±16.15	15.03±1.16	18.07±0.89	15.45±1.77
72	15°C	13.86±0.92	15.09±1.12	14.98±1.09	15.44±1.11	12.98±1.16
	21°C	14.71±2.43	15.98±1.04	15.68±1.18	15.12±0.89	14.14±1.25
	37°C	16.14±2.51	16.13±1.51	16.39±1.21	17.38±1.24	15.45±1.53
108	15°C	13.83±1.19	14.59±1.05	15.27±1.34	16.81±1.06	12.57±1.21
	21°C	12.78±1.76	14.04±1.25	13.97±1.53	15.10±1.06	12.92±1.14
	37°C	16.95±1.61	16.89±1.26	16.40±1.80	19.00±1.06	14.82±1.26
144	15°C	13.16±0.99	14.06±0.97	15.54±0.77	16.43±0.79	15.06±1.20
	21°C	15.29±1.15	15.23±1.03	14.80±0.95	15.37±0.67	15.30±0.86
	37°C	16.45±1.19	18.33±1.54	17.25±1.29	20.31±1.58	16.10±1.00
180	15°C	14.13±1.14	14.80±1.09	15.13±0.89	14.83±0.87	16.47±0.39
	21°C	11.68±0.48	11.20±0.62	12.23±0.55	13.54±0.90	12.08±0.60
	37°C	18.30±0.91	18.60±1.02	19.72±1.53	19.19±1.60	16.98±1.39
Δ%	15° C	59.20	63.10	56.71	-0.36	67.51
	21° C	31.55	23.37	26.69	-9.06	22.87
	37°C	106.12	104.93	104.22	28.92	72.69

Δ% = Variation from initial hardness, %. Source: Data collected by the authors themselves from the experimental design of the present research.

Carbonell et al. (2010) associated the increase in hardness of some cultivars with genetic characteristics of the grain or the susceptibility in the interaction of genetic and environmental factors. One of the theories that explain the grain hardening phenomenon over storage time is the lignification of cotyledon tissues. This theory links the development of hardening with the polymerization of phenolic compounds, mainly derived from the integument rich in these substances, mediated by oxide-reducing enzymes, and the formation of cross-links between phenolic compounds and cotyledon cell wall proteins (Nasar-Abbas et al., 2008).

Although genotypes are known to differ in color intensity, which could reflect different culinary behavior, it was not exactly what was observed over time between samples. In other words, genotypes with slow darkening (BRSMG Madrepérola) or resistant to darkening (Pinto Bean) presented higher grain hardness (Table 3). And in the first 36 days of storage, in all samples, there was a significant increase in hardness compared to the newly harvested. As storage temperature increased, the hardness of genotypes was generally increased to varying degrees. BRSMG Madrepérola, Pinto Bean, and BRS Estilo presented higher hardness values, at 180 days, at 37 °C.

At 15 °C, BRS Pontal and BRS Estilo, considered fast and intermediate darkening cultivars, respectively, registered the largest variations in relation to the initial hardness, of 67.51% and 63.10%, respectively. The Pinto Bean strain, in addition to obtaining the smallest hardness variation (-0.36%), also presented negative values for texture variation, indicating that the behavior observed at temperatures of 15 and 21 °C was contrary to the normal trend. That is the hardness of beans that should increase as a function of storage time eventually decreased, possibly due to the variation in grain water content, Table 1. However, it presented the highest hardness values throughout the experiment, with little variation during storage.

Almeida et al. (2017) evaluated the effects of cool storage (15 ° C and 45% RH) for 108 days on cooking time, integument color, phytate content and minerals of the same genotypes of this study (BRSMG Madrepérola, BRS Estilo, BRS Pontal and CNFC 10467) and observed better results of the parameters studied in this condition, in other words, grain quality stability.

The smallest variations in grain hardening were recorded at 21 °C, which can be identified as the best storage temperature for uncooked bean grains (Table 3).The Pinto Bean (28.92%) and BRS Pontal (72.69%) genotypes stood out for presenting the smallest hardening variations for storage at 37 °C, in other words, they suffer less the hardening effect as a function of time and temperature storage conditions. This phenomenon may be explained by the fact that these two materials already have the highest initial hardness values.

Regarding genotype offsets versus storage time (Table 4), the initial hardness of bean grains ranged from 8.879 (CNFC 10467) to 14.899 kgf (Pinto Bean). All suffered a hardening over time; however, the Pinto Bean strain showed the highest hardness values in all periods, compared to other genetic materials, followed sometimes by BRSMG Madrepérola, sometimes by CNFC10467, also slow darkening genotypes.

The faster darkening genotypes had an intermediate profile regarding hardening at different times. The lowest hardness values at six months of storage were observed in the grains of cultivars CNFC 10467 (slow browning) and BRS Estilo (intermediate browning).

Table 4. Breakdown of the variable hardness (kgf) as a function of time and cultivar.

Time	Cultivar				
	CNFC 10467	BRS Estilo	Madrepérola	Pinto Bean	BRS Pontal
0	8.8795 Bc	9.0778 Dc	9.6550 Db	14.8885 Da	9.8351 Db
36	15.0135 Ab	12.9511 Cd	14.1410 Cc	16.6845 Ba	14.2918 Bc
72	14.9055 Ab	15.7348 Aa	15.6825 Aba	15.9824 Ca	14.1897 Bc
108	14.5216 Ac	15.1747 Bb	15.2142 Bb	16.9672 Aba	13.4365 Cd
144	14.9521 Ac	15.8736 Ab	15.8616 Ab	17.3725 Aa	15.4892 Ab
180	14.7065 Ab	14.8694 Bb	15.6935 Aba	15.8563 Ca	15.1812 Ab

Means followed by the same letter, lowercase in the line and uppercase in the column do not differ statistically by Tukey test, at 5% probability. Source: Data collected by the authors themselves from the experimental and statistical design of the present research.

Figure 1 shows the average hardness values of all cultivars as a function of temperature and storage time. It can be noticed a linear and increasing behavior of grain hardness in all cultivars over time.

Research, Society and Development, v. 9, n. 7, e725974414, 2020
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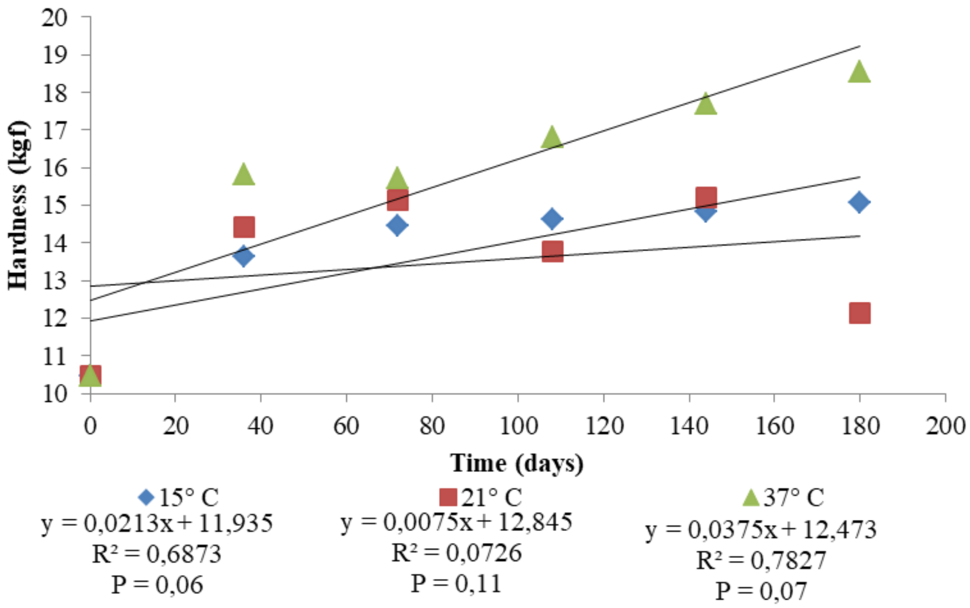
Figure 1. Average hardness of cultivars evaluated under different temperatures and storage time.



Source: Data collected by the authors themselves from the experimental and statistical design of the present research.

At the highest storage temperature (37 °C), the highest hardness values were observed, indicating that the variable is sensitive to high temperatures and that the lower temperatures are more favorable for storage, as shown in Figure 1. The temperatures of 15 and 37 °C presented coefficients of determination of 0.68 and 0.78, respectively, and relative average error (P) below 10%, showing that the model describes well the behavior of the hardness variable as a function of time.

In the mathematical modeling of hardness as a function of temperature and storage time of each genotype, the coefficient of determination (R2) ranged from 0.12 to 0.92 (Table 5).

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Table 5. Coefficient of determination (R^2) and relative mean error (P), calculated to verify the fit of the mathematical models to the experimental hardness values of raw common bean (*Phaseolus vulgaris* L.) stored at temperatures of 15, 21 and 37 °C.

Cultivar	Treatments	Models	R^2	P
CNFC 10467	15° C	y= 11.1425 + 19.7051 * x	0.66	0.10
	21° C	y= 12.1612 + 10.0916 * x	0.27	0.16
	37° C	y= 12.0624 + 38.3153 * x	0.60	0.12
BRS Estilo	15° C	y= 10.7755 + 27.5101 * x	0.79	0.09
	21° C	y= 11.9171 + 12.65003 * x	0.33	0.15
	37° C	y= 11.1842 + 48.3287 * x	0.92	0.08
Madrepérola	15° C	y= 11.5289 + 27.255 * x	0.81	0.08
	21° C	y= 12.4502 + 10.5821 * x	0.33	0.12
	37° C	y= 11.6693 + 45.2254 * x	0.82	0.08
Pinto Bean	15° C	y = 15.6227 + 1.5359 * x	0.12	0.04
	21° C	y = 15.5548 + (-6.4599) * x	0.56	0.03
	37° C	y = 16.0081 + 1.5359 * x	0.72	0.05
BRS Pontal	15° C	y= 10.6046 + 30.5064 * x	0.90	0.06
	21° C	y= 12.14340 + 10.4865 * x	0.36	0.12
	37° C	y= 12.1276 + 29.4108 * x	0.78	0.09

Source: Data collected by the authors themselves from the experimental and statistical design of the present research.

For all genotypes, low determination coefficients were obtained in storage at 21 °C, due to atypical variations of hardness values, probably due to variations in product water content. With higher water content the product is hydrated and consequently the hardness will be lower than with the dry product. As for storage time, the product may suffer changes in water content due to changes in T and RH of the storage environment. Thus, the higher the storage temperature, the lower the relative humidity of the grain, causing the reduction of water content.

3.2 Color parameters (L*, a* and b*) and ΔE

The values of the axes L*, a*, b* and ΔE, of the colorimetric profile analysis of carioca beans, are presented in Tables 6 and 7. According to Ribeiro, Storck, and Poersch (2008), luminosity values close to 55 are satisfactory for beans to be valued in the market. Thus, it can be considered that the genotypes present satisfactory initial L * luminosity values. Already during the six months of storage, all samples became darker (Table 6). The temperature factor also shows influence on the darkening since all cultivars presented a decrease of L* brightness with the storage temperature increase.

The cultivar BRS Pontal presented the highest darkening rates for all temperatures, ranging from 5.34 to 23.19%, followed by BRS Estilo, which only showed high darkening rates at 21 °C. The Pinto Bean linage presented the lowest light variation rates, indicating that it is the cultivar less susceptible to darkening.

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Table 6. L* Luminosity values of bean grains as a function of temperature and storage time and genotypes.

Days	Treatment	Cultivars				
		CNFC 10467	**BRS Estilo**	**Madrepérola**	**Pinto Bean**	**BRS Pontal**
0	Control	53.13±1.29	52.16±1.38	53.71±1.68	59.30±1.22	49.54±1.19
36	15°C	52.87±1.20	51.91±1.67	52.76±2.12	58.39±0.69	49.11±1.35
	21°C	52.01±1.41	50.25±2.14	52.72±1.62	58.08±1.07	48.56±1.10
	37°C	51.88±1.80	50.56±1.07	52.63±1.72	57.94±0.87	45.55±0.97
72	15°C	53.00±1.19	51.69±2.03	53.87±0.86	57.50±1.70	48.75±1.96
	21°C	52.37±2.16	51.19±1.40	53.75±1.66	57.75±1.57	48.65±0.74
	37°C	51.02±1.13	44.27±1.41	51.38±1.82	57.04±1.98	43.27±1.48
108	15°C	51.56±1.22	51.44±1.65	53.66±1.15	58.02±1.21	47.27±1.81
	21°C	51.43±1.77	49.19±1.82	52.30±1.55	57.82±1.20	43.69±2.34
	37°C	50.43±1.18	45.12±1.32	52.23±1.23	57.85±1.53	43.35±1.46
144	15°C	52.72±1.58	51.39±1.57	52.46±0.98	58.79±1.55	48.90±1.02
	21°C	50.91±0.85	49.46±2.14	52.83±1.61	58.01±1.48	44.81±1.52
	37°C	50.20±1.34	43.05±1.51	49.63±1.98	57.19±0.88	42.11±1.90
180	15°C	52.22±0.58	50.96±2.62	52.30±1.01	57.54±2.65	46.90±2.04
	21°C	50.49±1.09	48.64±1.32	50.52±1.68	57.71±1.53	43.38±1.69
	37°C	48.50±2.03	42.19±1.89	50.28±1.71	56.14±1.49	38.05±1.72
Δ%	15° C	1.70	2.30	2.63	2.96	5.34
	21° C	4.96	6.75	5.94	2.69	12.43
	37°C	8.72	19.12	6.39	5.32	23.19

Source: Data collected by the authors themselves from the experimental design of the present research.

Storage at lower temperatures provided the highest light values, indicating that under these storage conditions the grains are less darkened.

This result corroborates those found by Almeida et al. (2017), who indicated that the cold storage condition was an effective method to maintain the physicochemical characteristics of beans for a period of 108 days.

Research, Society and Development, v. 9, n. 7, e725974414, 2020
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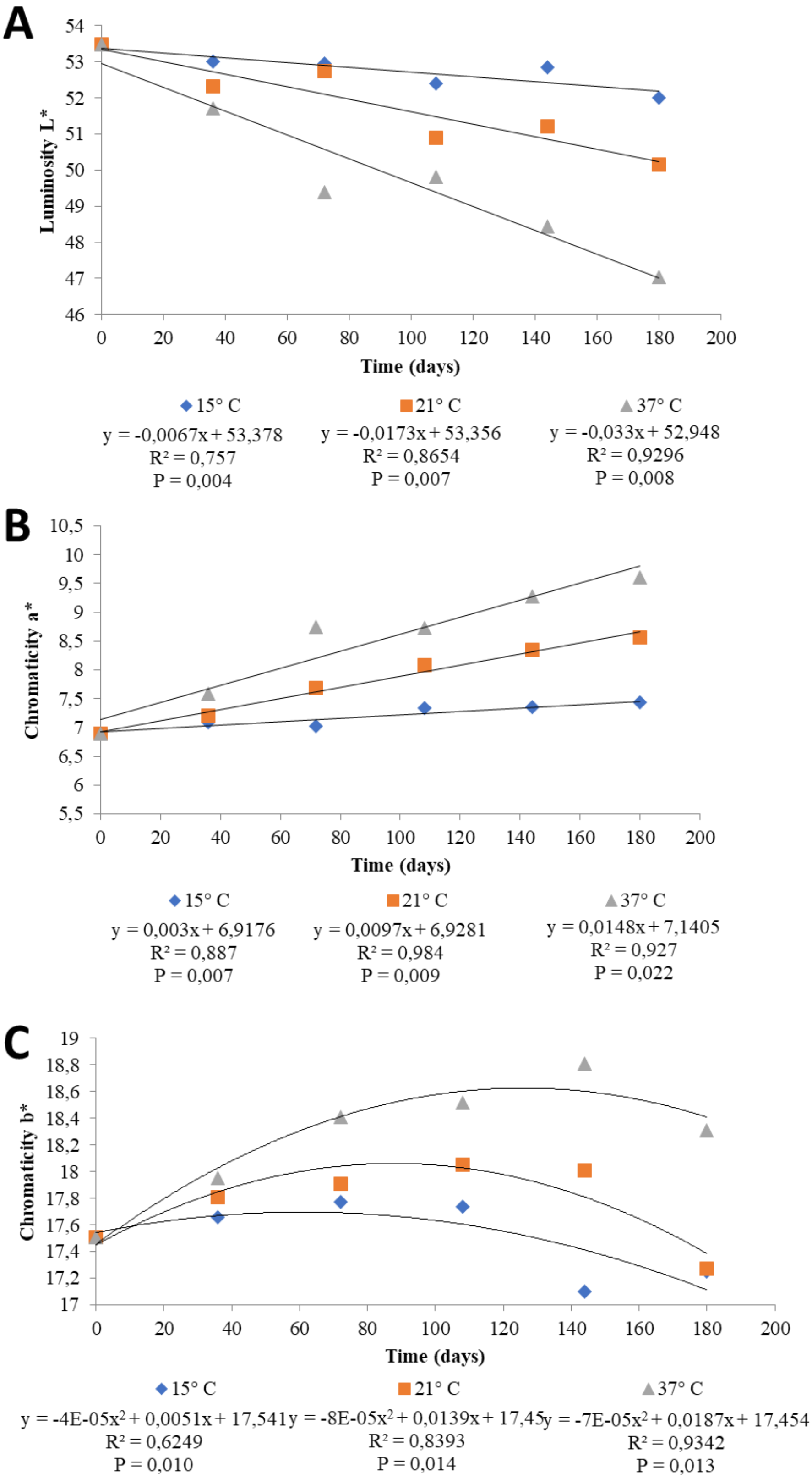
Regardless of the initial grain luminosity, all genotypes became darker over time to varying degrees. That is, postharvest darkening was followed by the gradual reduction of grain integument luminosity values during storage (Tables 6 and 8).

There are statistical differences in freshly harvested grains for most genotypes, indicating that these samples have genetic characteristics that differentiate them in color. As expected, the Pinto Bean strain was always significantly lighter than the others, especially when recently harvested. Following, there are the other genotypes of slow darkening, such as BRSMG Madrepérola and CNFC10467.

Figure 2. Regression of color parameters: (A) L* luminosity, (B) chromaticity a* and (C) b* of common carioca and Pinto Bean beans under different storage temperatures.



Source: Data collected by the authors themselves from the experimental and statistical design of the present research.

In Figure 2A, the variation in brightness L * as a function of storage time is shown. It's observed that the brightness has decreased over time for all storage temperatures. Also, beans grain darkens faster when stored at higher temperatures.

Table 7. Average values of chromaticity a *, b * and ΔE of raw bean grains, as a function of temperature and storage time.

		Chromaticity a*				
Days	**Treatment**	**Cultivars**				
		CNFC 10467	**BRS Estilo**	**Madrepérola**	**Pinto Bean**	**BRS Pontal**
0	Control	6.33±0.44	6.99±0.46	6.31±0.33	6.77±0.33	8.01±0.42
36	15°C	6.66±0.39	7.10±0.34	6.41±0.36	6.93±0.33	8.39±0.41
	21°C	6.79±0.38	7.24±0.49	6.59±0.38	6.98±0.50	8.48±0.37
	37°C	7.03±0.39	8.30±0.38	6.48±0.41	6.56±0.23	9.62±0.31
72	15°C	6.39±0.87	7.29±0.43	6.06±0.33	6.91±0.35	8.50±0.31
	21°C	6.88±0.36	7.84±0.64	6.47±0.47	6.89±0.46	9.66±0.37
	37°C	7.52±0.38	11.06±0.38	6.79±0.32	6.93±0.42	11.39±0.56
108	15°C	6.71±0.71	7.45±0.29	6.56±0.29	6.80±0.36	9.10±0.50
	21°C	7.38±0.29	8.67±0.21	7.18±0.36	7.01±0.40	10.16±0.64
	37°C	7.57±0.50	10.37±0.41	7.16±0.53	6.85±0.48	11.70±0.54
144	15°C	6.92±0.49	7.45±0.32	6.10±0.40	6.86±0.40	8.92±0.34
	21°C	7.96±0.55	9.06±0.65	7.10±0.29	7.05±0.46	10.60±0.55
	37°C	8.37±0.44	11.81±0.41	7.32±0.24	6.88±0.27	12.03±0.63
180	15°C	6.70±0.25	7.71±0.55	6.18±0.28	6.76±0.29	9.78±0.52
	21°C	7.65±0.47	9.08±0.53	7.69±0.33	7.04±0.27	11.33±0.30
	37°C	8.47±0.51	11.21±0.63	8.14±0.60	6.91±0.62	13.33±0.47
		Chromaticity b*				
0	Control	17.65±0.42	16.18±0.83	17.71±0.75	18.07±0.74	17.92±0.86
36	15°C	17.74±0.94	16.36±0.66	17.36±0.70	18.68±0.57	18.15±0.70
	21°C	17.79±0.71	16.86±0.61	17.84±0.71	18.31±0.70	18.25±0.55

	37°C	18.47±0.45	16.85±0.46	17.94±0.93	18.16±0.55	18.39±0.62
	15°C	18.09±0.54	16.67±0.72	17.73±0.55	18.50±0.77	17.85±0.58
72	21°C	18.44±0.70	17.17±0.73	17.75±0.82	17.83±0.91	18.36±0.54
	37°C	18.07±0.67	18.61±0.92	18.42±0.86	17.91±0.61	19.03±0.47
	15°C	18.29±0.78	16.33±0.43	17.88±0.55	17.81±0.82	18.39±0.85
108	21°C	18.71±0.37	17.32±0.69	18.56±0.35	18.51±0.31	18.67±0.78
	37°C	18.40±1.02	17.39±0.46	18.73±0.62	18.86±0.57	19.20±0.41
	15°C	17.78±0.88	15.86±0.46	16.48±0.96	17.60±0.57	17.79±0.80
144	21°C	19.18±0.91	16.79±0.79	17.91±0.62	18.49±0.58	17.68±0.52
	37°C	19.28±0.66	17.96±0.66	18.54±0.52	18.74±0.83	19.53±0.75
	15°C	17.62±0.63	15.08±0.80	16.85±0.76	17.37±0.45	18.57±0.68
180	21°C	18.37±0.84	15.66±0.78	17.71±0.84	17.18±0.58	18.22±0.59
	37°C	18.68±0.69	17.46±0.80	18.28±0.83	18.83±1.14	19.29±0.69
Color diference - ΔE						
	15°C	0.98	1.78	1.66	1.89	3.25
ΔE	21°C	3.03	4.13	3.47	1.84	7.00
	37°C	5.21	10.90	3.93	3.25	12.74

Source: Data collected by the authors themselves from the experimental design of the present research.

Table 7 shows that the chroma a* is more pronounced for faster darkening genotypes (BRS Pontal and BRS Estilo) at all temperatures and storage times. The Pinto Bean strain was also more stable for this color component under all conditions, presenting the smallest color differences (ΔE), followed by BRSMG Madrepérola and CNFC10467. This shows that the tendency to increase reddish-brown placement is more evident for darker genotypes, which is consistent with expectations. Nasar-Abbas et al. (2009) reported that during the bean grain darkening process, there is an initial change of grain color to reddish-brown, followed by loss of light. The positive effect of temperature increases on chroma a* is also observed.

Regarding chroma b *, there seems to be less influence of temperature and storage time. There is a slight increase in yellow intensity for most genotypes under all conditions (Tables 7 and 9). Total color difference is the parameter that involves the joint evaluation of brightness and chromaticity a* and b*. Substantial changes were observed in this parameter

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during storage for all genotypes, ranging from 0.98 (CNFC 10467) to 12.74 (BRS Pontal). Considering the color difference for each storage temperature (15, 21 and 37 °C), it can be inferred that storage at low temperatures minimized the grain darkening effect in all cultivars analyzed, according to Table 7. The smaller the color difference of a carioca bean cultivar during storage, the higher its market value (Siqueira et al., 2014).

Table 8. Unfolding of the luminosity variable L * as a function of time and genotype.

Time	Cultivars				
	CNFC 10467	BRS Estilo	Madrepérola	Pinto Bean	BRS Pontal
0	53.12 Ab	52.15 Ac	53.71 Ab	59.30 Aa	49.05 Ad
36	52.25 Bb	50.90 Bc	52.70 Bb	58.13 Ba	47.74 Bd
72	52.13 Bc	49.04 Cd	53.00 ABb	57.42 BCa	46.89 Ce
108	51.27 Cc	48.58 CDd	52.73 Bb	57.90 BCa	44.77 De
144	51.27 CDb	47.96 DEc	51.64 Cb	58.00 Ba	45.27 Dd
180	50.40 Db	47.26 Ec	51.03 Cb	57.13 Ca	42.77 Ed

Means followed by the same letter, lowercase in the line and uppercase in the column do not differ statistically by Tukey test, at 5% probability. Source: Data collected by the authors themselves from the experimental and statistical design of the present research.

Figures 2B and 2C show the behavior of variables a* and b* as a function of the storage conditions studied. For a*, an increasing linear behavior was recorded, directly proportional to the temperature increase and storage time. For chroma b*, the best fit was obtained by polynomial equations.

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Table 9. Splitting the chromaticity variable a * and b * as a function of time and bean genotype.

Time	CNFC 10467	BRS Estilo	Madrepérola	Pinto Bean	BRS Pontal
	Chromaticity a*				
0	6.33 Dc	6.99 Db	6.36 Cc	6.77 Ab	8.01 Ea
36	6.82 Cc	7.54 Cb	6.49 Cc	6.82 Ac	8.82 Da
72	6.93 Cc	8.73 Bb	6.44 Cd	6.90 Ac	9.85 Ca
108	7.22 Bc	8.83 Bb	6.96 Bd	6.89 Ad	10.31 Ba
144	7.74 Ac	9.44 Ab	6.83 Bd	6.93 Ad	10.51 Ba
180	7.60 Ac	9.33 Ab	7.33 Ad	6.90 Ae	11.48 Aa
	Chromaticity b*				
0	17.65 Db	16.17 Cc	17.71 Bb	18.07 Aa	17.92 Dab
36	18.00 CDbc	16.69 Bd	17.71 Bc	18.38 Aa	18.26 CDab
72	18.20 BCab	17.48 Ac	17.96 Bb	18.08 Aab	18.41 ABCa
108	18.46 ABab	17.01 Bc	18.39 Ab	18.39 Ab	18.75Aa
144	18.75 Aa	16.87 Bd	17.64 Bc	18.27 Ab	18.33 BCb
180	18.21 BCb	16.06 Cd	17.61 Bc	17.45 Bc	18.69 ABa

Means followed by the same letter, lowercase in the row and uppercase in the column do not differ statistically by Tukey's test, at 5% probability. Source: Data collected by the authors themselves from the experimental and statistical design of the present research.

There was a wide variation in the correlation between H and ΔE at temperatures evaluated during bean storage (Table 10).

Table 10. Correlation between hardness and color difference (ΔE) at different storage temperatures of cultivars evaluated during storage (p<0.05).

Temperature (°C)	Cultivars				
	CNFC 10467	BRS Estilo	Madrepérola	*Pinto Bean*	BRS Pontal
15	0.6222	0.7863	0.5478	-0.0228	0.6842
21	-0.4274	0.3809	-0.9630	-0.9538	-0.5215
37	0.8243	0.9350	0.7332	0.2564	0.8259

Source: Data collected by the authors themselves from the experimental and statistical design of the present research.

It was obtained from a relatively weak and negative correlation (Pinto Bean) to an extraordinarily strong and positive correlation (BRS Estilo). The low and negative correlation found for the Pinto Bean strain reinforces that it is a darkening resistant material, but that the maintenance of light color is not associated with hardening of the stored grain, which hardens significantly, regardless of temperature conditions. The same behavior is observed even more intensely for the other light-colored carioca beans (BRSMG Madrepérola and CNFC10467), but the temperature already interferes with this profile, as well as the humidity.

These samples are more sensitive to storage conditions, showing a more significant hardening over time, despite the slow darkening. On the other hand, for faster darkening genotypes (BRS Estilo and BRS Pontal), the correlation between H and ΔE is generally positive, resembling those of slow darkening beans at extreme temperatures. It seems that at 21ºC there was an influence of the high relative humidity of the environment (79%) on the quality parameters. And that the interactions between RH and T ºC and RH and genotype possibly affect the behavior of the samples, since there was no standard profile between the different beans.

Based on the results presented, it can be noted that among the genotypes of the carioca group, the cultivar BRSMG Madrepérola darkened less during storage, followed by CNFC10467, however, both hardened as quickly and as fast as intermediate darkening genotypes. Pinto Bean strain, known to be resistant to darkening during storage, was, in fact, stable to variations in color components at six months, but since the beginning it has already presented a more resistant grain in texture, increasing hardness progressively. This reinforces the idea that color is not always the best parameter to define or determine the culinary quality of beans, and yet it has still been the most widely used and well-known attribute of the bean and consumers' production chain, at the time of choosing a product and value it in the domestic market.

Producers with low investment in technology to control environmental conditions in storage and subject to temperature and humidity fluctuations can avail themselves of the choice of darker-stable genotypes over time, such as BRSMG Madrepérola, provided their shelf life is respected: may be shorter due to hardening. If appropriate measures are taken, this effect may be minimized.

4. Final Considerations

All bean genotypes studied tend to harden, with increasing storage temperature and storage time, and the lowest hardness values, at six months of storage, were observed in the grains of samples CNFC 10467 (slow dark bean) and BRS Estilo (fast dark bean). The luminosity and chromaticity a* and b* increased as a function of storage time for all studied genotypes, and Pinto Bean strain presented the lowest light variation and chroma rates a* and b*. This indicates that Pinto Bean is the genotype less susceptible to darkening; however, as it suffered significant hardening after six months, color is not a parameter to be considered in isolation to determine the degree of aging of stored beans. It seems that the darkening and hardening phenomena of stored beans are controlled by complex mechanisms, physicochemical, genetic, biochemical, among others, and which, in turn, are influenced by environmental storage conditions and genotype.

Acknowledgements

The authors thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and the National Council for Scientific and Technological Development (CNPq) for the scholarships support and Embrapa for the research financial of the project Darkbean approved at the Call 07/2011 – Macroprograma 2 – code 02.11.07.010.00.00.

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