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Relationship among color, physicochemical traits, and ruminal *in situ* dry matter digestion of corn grains from Argentina, Brazil, and the U.S.

González[1,2,3], L., Schroeder[4], G.F., DiLorenzo[5], N., Jaurena[3], G., Méndez[1], D.G., Elizalde[6], J.C., Ceconi[1], I.

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Introduction

Corn-derived starch and rumen-degradable protein (**RDP**) available for rumen microbial fermentation vary significantly with corn hybrid and environmental conditions. Identifying corn physicochemical traits potentially correlated with ruminal DM digestibility (**DMD**) would facilitate the prediction of its nutritional value compared with more time-consuming determinations.

We assessed **(1)** the effect of corn origin on color, physicochemical traits, and 22-h *in situ* DMD (**22h-DMD**) and **(2)** the relationship of color and physicochemical traits with 22h-DMD using Argentinian, Brazilian, and North American corn samples.

Materials and Methods

Corn samples, treatments

Forty-eight commercially available corn samples (*Zea mays ssp. Indentata*) from Argentina (**AR**, n=29), Brazil (**BR**, n=4), and the U.S. (**US**, n=15) were evaluated.

Hardness-associated properties

Color (Hue angle [**H**]) and physicochemical traits (crude protein [**CP**], thousand kernel weight [**TKW**], test weight [**TW**], floaters [**FLO**], kernel density [**KD**], vitreousness [**VIT**], and coarse-to-fine milling ratio [**C:F**]).

Soluble fraction (0h-DMD) and in situ 22h DM digestibility

Samples were ground through a 0.625-cm screen for 10 s.

Statistical analyses

PROC CORR, REG, GLM, and MIXED

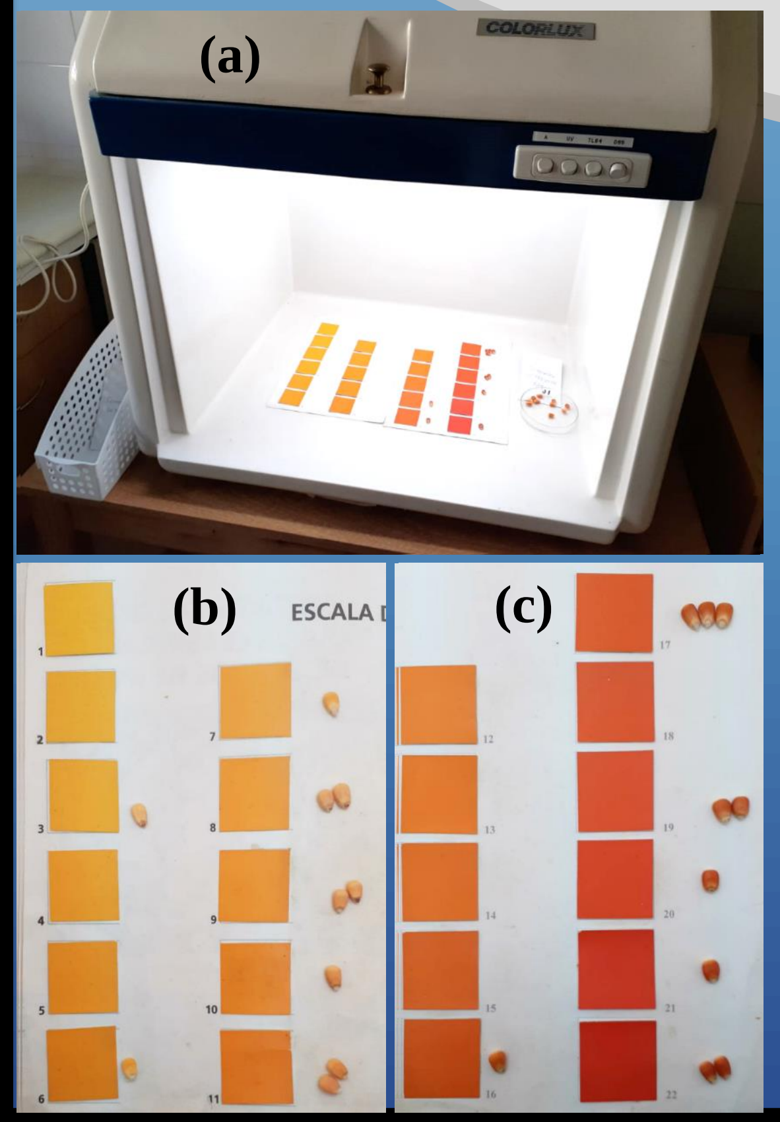

Fig. 1. Color determination. **(a)** 22 colored swatch-grid placed on the floor of a light box with a D65 illuminant (Di Martino, 2007); **(b)** American corn, and **(c)** Argentinian corn.

Fig. 2. Ruminally cannulated steers and housing facilities.

Results

All traits differed ($P < 0.01$; **Table 1**) among corn origins, being AR corns intermediate in hardness-associated properties between BR and US samples, though more similar to BR ones.

Compared with BR and AR samples, 0h-DMD and 22h-DMD of US corn samples were 116.1 and 72.6% and 30.6 and 21.3% greater, respectively.

22h-DMD (%) = 160.31 – 1.16 × TW (kg/hL) – 7.49 × C:F (g/g; RMSE = 3.54, R^2 = 0.74)

Discussion

Luebbe et al. (2009) reported average values of 9.2 and 48.4% for 0h-DMD and 22h-DMD, respectively, for simulate masticated US dry corn genotypes. Conversely, we measured 12.1 and 61.5% for the same traits performed on US corn.

Differences between studies may arise from the number of samples evaluated, the environmental effect, the potential slight differences in particle size derived from mechanical mastication simulation, and the high variability of results across studies obtained with the *in situ* method.

Conclusion

Softer kernels with higher FLO and lower TW, KD, C:F, and CP, demonstrated greater 0h-DMD and 22h-DMD than harder samples.

TW in combination with C:F resulted in reliable predictors of 22h-DMD to describe corn samples' nutritional value.

We hypothesized that greater CP and lower 0h-DMD and 22h-DMD of harder genotypes may reduce or eliminate the need for RDP supplementation when those grains are included in beef cattle finishing rations; however, more research is warranted on this topic.

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Introduction

Corn (*Zea mays ssp. Indentata*) is incorporated into finishing diets due to its great starch content. Corn-derived starch and rumen-degradable protein (**RDP**) available for rumen microbial fermentation vary significantly with grain texture (*i.e.*, endosperm traits and starch-protein matrix structure), which, in turn, differs among corn hybrids and environmental conditions. Identifying corn physicochemical traits, different from kernel hand-dissection vitreousness [**VIT**] measure, and potentially correlated with ruminal DM digestibility (**DMD**), would facilitate the prediction of its nutritional value compared with more labor-intensive and time-consuming determinations (*i.e.* ruminal *in situ* technique).

We assessed,

(1) the effect of corn origin on color, physicochemical traits, and 22-h *in situ* DMD (**22h-DMD**) and,

(2) the relationship of color and physicochemical traits with 22h-DMD using Argentinian, Brazilian, and North American corn samples.

Keywords: beef cattle, corn hardness-associated properties, ruminal digestion.

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Materials and methods

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Hardness-associated properties

- Color (Hue angle [**H**]; **Fig. 1**)
- Physicochemical traits (crude protein [**CP**], thousand kernel weight [**TKW**], test weight [**TW**], floaters [**FLO**], kernel density [**KD**], estimated VIT, and coarse-to-fine milling ratio [**C:F**]).

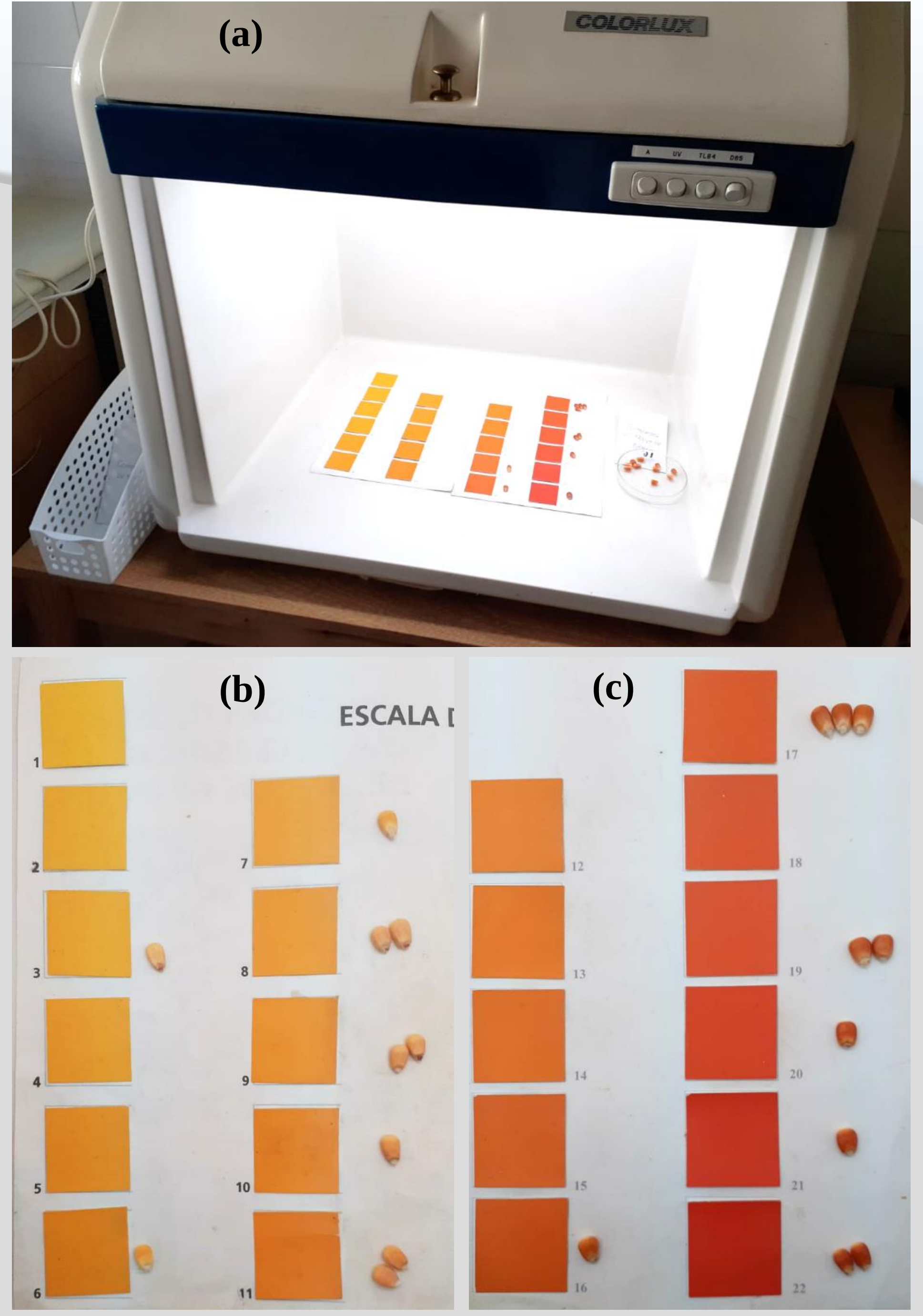

Fig. 1. Color determination. **(a)** 22 colored swatch-grid placed on the floor of a light box with a D65 illuminant (Di Martino, 2007); **(b)** American corn, and **(c)** Argentinian corn.

In situ DM and CP digestibility at 22 h

- Two ruminally cannulated steers received a 53:47 forage-to-concentrate ratio diet (**Fig. 2**)
- Mastication was simulated by grinding a 100-g sample for 10 s using a 0.625-cm screen
- For each steer, three sets of 4-g (DM basis) of each corn sample were placed into R1020 Ankom bags and introduced in the ventral sac of the rumen at two independent incubation events separated by 48 h
- Four bags per sample were placed in a water bath (39 °C, 15 min) to determine the soluble fraction (**0h-DMD**).

Fig. 2. Ruminally cannulated steers and housing facilities.

Statistical analyses

- PROC GLM was used to test the corn origin effect on color and physicochemical traits.
- PROC MIXED was performed to evaluate corn origin effect on 0h-DMD and 22h-DMD.
- Means were compared by Tukey-Kramer test.
- Relationships among variables were studied using a correlation matrix (PROC CORR) and stepwise multiple linear regression (PROC REG).

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Results

All traits differed ($P < 0.01$; **Table 1**) among corn origins, being AR corns intermediate in hardness-associated properties between BR and US samples, though more similar to BR ones.

Compared with BR and AR samples, 0h-DMD and 22h-DMD of US corn samples were 116.1 and 72.6% and 30.6 and 21.3% greater, respectively.

Table 1. Color, physicochemical traits, and 22-h *in situ* DM digestion for Brazilian (BR), Argentinian (AR), and North American (US) corn kernels.

	Corn origin[1]			
Traits	BR	AR	US	*P*-value
n[2]	4	29	15	-
Hue angle[3], °	70.7(3.27)^{ab}	66.7(1.22)^{a}	75.4(1.97)^{b}	0.0019
Crude protein, %	8.2(0.34)^{a}	9.3(0.13)^{b}	7.4(0.18)^{a}	<0.0001
Thousand kernels weight, g	358(11.5)^{a}	286(4.3)^{b}	310(5.9)^{c}	<0.0001
Test weight, kg/hL	81.6(0.83)^{a}	77.4(0.31)^{b}	73.3(0.43)^{c}	<0.0001
Floaters, %	5(5.7)^{a}	21(2.1)^{b}	79(3.5)^{c}	<0.0001
Kernel density, g/cm^3	1.29(0.014)^{a}	1.28(0.005)^{a}	1.21(0.007)^{b}	<0.0001
Vitreousness[4], %	75.0(3.93)^{a}	73.2(1.46)^{a}	53.4(2.03)^{b}	<0.0001
Coarse-to-fine milling ratio[5], g/g	2.54(0.108)^{a}	2.59(0.040)^{a}	1.60(0.056)^{b}	<0.0001
0-h DM disappearance, %	5.6(0.40)^{a}	7.0(0.32)^{b}	12.1(0.33)^{c}	<0.0001
22-h *in situ* DM digestion, %	47.1(1.89)^{a}	50.7(1.74)^{b}	61.5(1.77)^{c}	<0.0001

[1] Numbers within parentheses represent standard error of treatment means

[2] Four US samples were ruled out for Hue angle and floater analyses due to the presence of few superficial fungi colonies; measurements were carried out in duplicate

[3] Measured visually by contrasting the kernels with a color card (DiMartino et al., 2003) provided with 22-coordinates according to Hunter Lab three-dimensional (L, a, and b) color space. Hue angle was calculated as $\tan^{-1}(b/a)$ and ranged from 0° to 90°, indicating a progressive change from pure red to pure yellow

[4] Estimated based on observed kernel density (KD) as follow: $-283.2 + 278.2 \times \text{KD}$ ($R^2 = 0.76$, $P < 0.001$; KD ranged from 1.169 to 1.292 g/cm^3; Correa et al., 2002)

[5] Tested grounding 50-g of whole grains for 12 s in a Stein mill, sifting for 1 min, and weighing coarse material retained by the 1.0-mm sieve and fine material passing through the 0.5-mm sieve

[abc] Means with uncommon letters differ ($P \le 0.05$)

Hue angle was related ($P \le 0.07$; r = 0.43, −0.35, −0.28, −0.41, and −0.51) with FLO, CP, TW, KD, and C:F, respectively; however, TKW was unrelated ($P = 0.44$) to H.

Correlation coefficients ($P < 0.01$) of 22h-DMD with H, FLO, TW, KD, C:F, and CP, were 0.43, 0.80, −0.77, −0.71, −0.82, and −0.72, respectively; TKW was unrelated ($P = 0.26$) to 22h-DMD.

22h-DMD (%) = 160.31 – 1.16 × TW (kg/hL) – 7.49 × C:F (g/g; RMSE = 3.54, R^2 = 0.74)

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Discussion

Upon analyzing corn samples that ranged from orange-reddish semi-flint to light yellow distinctly dent corn, our study found:

- A high correlation between color (H ranged from 49.0 to 76.7°) and the majority of hardness-associated traits, in agreement with San Martín (2003), Dillon (2005), and Saenz et al. (2020). In this regard, carotenoids have been correlated with maize kernels' color attributes, and considering the well-documented increased concentration of carotenoids in the vitreous endosperm, lower H values would be expected in harder genotypes with respect to softer ones.
- A positive relationship between H and 22h-DMD, as predicted from the previous point.
- A high negative relationship among CP, TW, KD, and C:F with DMD as in Correa et al. (2002), San Martín (2003), Dillon (2005), and Seifried et al. (2016).
- A high positive correlation of FLO with 0h-DMD and 22h-DMD, but no association between TKW and DMD or any other hardness-related traits in agreement with San Martín (2003) and Dillon (2005). Conversely, Philippeau et al. (1999) and Harrelson et al. (2009) reported a positive relationship between TKW to DMD.
- An average KD of 1.21, 1.28, and 1.29 g/cm^3 for the US, AR, and BR corn samples, respectively. Similarly, Correa et al. (2002) declared a mean KD of 1.20 and 1.27 g/cm^3 for 14 US and 5 BR flint hybrids, respectively.
- TW and C:F as the most suitable predictors for 22h-DMD estimation. Despite KD was correlated ($r = -0.71$; $P < 0.01$) with 22h-DMD, the stepwise algorithm ruled it out from the final model, which conflicts with previous research by Philippeau et al. (1999), Correa et al. (2002), and Seifried et al. (2016) that reported accurate equations to predict ruminal starch digestibility using KD and TKW, KD, and KD or CP, respectively.

Several US studies evaluate the genotype effect on nutrient disappearance of simulate masticated dry corn samples. Harrelson et al. (2009) and Jaeger et al. (2006) observed means of 39.2 and 59.9% for 22h- and 24h-DMD. Luebbe et al. (2009) reported average values of 9.2 and 48.4% for 0h-DMD and 22h-DMD, respectively. On the contrary, we obtained means of 12.1 and 61.5% for the same measurements. Differences among studies may arise from the number of samples evaluated, the environmental effect on the genotype, the potential slight differences in particle size derived from mechanical mastication simulation, and the high variability of results across studies with the *in situ* method.

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Conclusion

- **Argentinian and Brazilian corn samples' hardness-associated properties contrasted with North American ones.**
- **Softer kernels with higher Hue angle and floaters and lower test weight, kernel density, milling ratio, and CP, demonstrated greater 0h-and 22h-DM disappearance than harder samples.**
- **Test weight in combination with coarse-to-fine milling ratio resulted in reliable predictors of 22h-DM disappearance.**

We hypothesized that greater CP and lower 0h- and 22h-DM disappearance of harder genotypes may reduce or eliminate the need for rumen degradable protein supplementation when those grains are included in beef cattle finishing rations; however, more research is warranted on this topic.

Bibliography

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