Growth performance and total tract digestibility in broiler chickens fed different corn hybrids

D. Melo-Durán,* J. F. Perez,* G. González-Ortiz,† S. Villagómez-Estrada,* M. R. Bedford,† H. Graham,† and D. Sola-Oriol*,[1]

*Servei de Nutricio i Benestar Animal (SNiBA), Department de Ciencia Animal i dels Aliments, Universitat Autonoma de Barcelona (UAB), Barcelona 08193, Spain; and †AB Vista, Marlborough, Wiltshire, SN8 4AN, United Kingdom

ABSTRACT The aim of the present study was to investigate the variability in nutrient digestibility associated with corn genetic background and its influence on the feeding value for broiler chickens. A total of 960 1-day-old male broiler chicks (Ross 308) were distributed in eight treatments, with 12 pens per treatment and 10 birds per pen in a 42-day study. Eight corn samples (Variety 1 to Variety 8) were selected based on their nutrient composition. A fixed amount of each corn (577 g/kg in the starter diets and 662 g/kg in the finisher diets) was used to formulate feeds. Diets were offered *ad libitum* in pellet form. Performance parameters were determined at d 21 and d 42, and excreta samples collected at d 21 to determine energy, organic matter and dry matter (**DM**) whole-tract digestibility. The results revealed a decrease ($P < 0.05$) in body weight (**BW**) and feed intake in birds fed variety 8 compared to other varieties at d 21. The lowest whole tract DM and energy apparent digestibility were also observed for the variety 8 diet ($P < 0.05$), together with varieties 3 and 5. Energy digestibility was higher in varieties 2, 4 and 7 ($P < 0.05$). Multivariate analysis revealed that corn protein concentration was positively correlated with vitreousness ($r = 0.60$, $P = 0.054$) and the arabinose:xylose ratio ($r = 0.67$, $P < 0.05$) and negatively correlated with starch ($r = -0.62$, $P < 0.05$). Soluble non-starch polysaccharide content was negatively correlated with the protein solubility index ($r = -0.88$, $P < 0.05$). In addition, corn protein concentration was negatively correlated ($P < 0.05$) with 21-d BW ($r = -0.71$) and weight gain ($r = -0.62$). In conclusion, the corn genetic background influenced the nutrient digestibility and growth performance of broiler chickens. The content and nature of the non-starch polysaccharides were found to be two of the main factors affecting the solubility and availability of nutrients in corn, and could be the reason for the negative effects on the performance of broiler chickens as shown in the present study.

Keywords: corn, near-infrared spectroscopy, total tract digestibility, chickens

2021 Poultry Science 100:101218
https://doi.org/10.1016/j.psj.2021.101218

INTRODUCTION

Corn is the most common energy source used in commercial animal diets, especially in American, Southern European and Asian countries, where corn grain is the primary cereal for all poultry feed (Larbier et al., 1994; Dei, 2017). Due to its high dietary inclusion rate, corn can contribute up to 65% of metabolizable energy and 20% of protein in poultry diets (Gehring et al., 2013; Naderinejad et al., 2016). Although corn has a high and consistent nutritional value for livestock, its feeding value can be very variable (Summers, 2001; Cowieson, 2005). Genetics, agronomic conditions, proximate composition, and pre- and post-harvest processing are considered major factors affecting the nutrient variability. Of these, genetics has been demonstrated to be an important source of biochemical and nutrient variability (Uribelarrea et al., 2004; Reynolds et al., 2005). Phenotypic characteristics such as the grain-filling duration, related to physiological maturity, and composition, growth rate and moisture of the kernel are specific for each genotype and could affect the nutrient value (Seebauer et al., 2010; Prado et al., 2014). The main differences in corn composition include protein solubility, zein content, amylose to amylopectin ratio, and vitreousness (Gehring et al., 2013). Moreover, the apparent metabolizable energy (**AME**) value of corn can fluctuate by more than 470 kcal/kg from batch to batch (Cowieson, 2005).

Received April 17, 2020.
Accepted April 14, 2021.

[1]Corresponding author: David.Sola@uab.cat

Near-infrared spectroscopy (**NIRS**) is an efficient tool for assessing the nutritive value of raw ingredients before manufacturing the feed, and thus it enhances precision feed formulation (Pujol et al., 2007). In addition to predicting the conventional composition, NIRS can also be used to predict the non-conventional composition, including anti-nutritional factors (Rahman et al., 2015). The anti-nutritional factors of corn include non-starch polysaccharides (**NSP**), phytate, lectins, and resistant starches (Englyst, 1989; Eeckhout and De Paepe, 1994; Cowieson, 2005). In this context, it was hypothesized that the corn genetic background could influence energy and nutrient digestibility, and thus broiler performance. Therefore, the aim of the present study was to research the differences in growth performance and energy and nutrient digestibility in broilers fed diets based on eight different corn hybrids harvested in the same field/area and under similar environmental growing and fertilizing conditions.

MATERIALS AND METHODS

Birds and Housing

A total of 960 Ross 308-day-old male broilers were purchased from a local hatchery. Upon arrival, birds were individually weighed and assigned to 96 floored pens in an environmentally controlled room, with ten birds per pen. Each pen (150 cm x 75 cm) was equipped with a bell feeder and drinker. Test diets and water were provided *ad libitum* throughout the trial. During the first 2 d, the temperature was set at 32°C and was gradually reduced to 20°C until the end of the trial (d 42). For the first 10 d, 23 h of light were provided and this was reduced to 18 h from d 11 onwards.

Corn Samples

Sixteen corn varieties were sowed in the same field with the same environmental growing conditions (Gimenells, Catalunya, Spain), including fertilizer and harvesting. The rainfall of the area was 207 mm in the cultivation period and the average minimum/maximum temperatures varied between 15.2 and 29.3°C (AEMET, 2020). The planting density was 92,000 seeds/ha. Fixed cane sprinkling was used for irrigation from sowing until an average plant height of 50 cm, at a rate of 1 h of watering per day, applied at night. From 50 cm until the plants had 12 to 14 leaves, they were watered according to the need for soil moisture, based on rainfall and visual assessment of the plants. From 12 to 14 leaves until the flowering spike was lost, water was applied for 30 min daily; and from flowering to harvest, plants were watered for 1 h daily at a rate of 50 min at night and 10 min at the time of maximum heat during the day. No pesticide was applied during cultivation, the fertilizer scheme was 170 kg of N/ha before sowing, 50 kg of liquid N/ha at 8 leaves, and 50 kg of liquid N/ha plus 5 L of organic fertilizer, through the irrigation system, at 12 leaves. The maize hybrids were sown in April 2018 and harvested in October 2018. The size of the land area and the harvest weights of each variety were used to calculate maize yield per hectare. The plot for each variety consisted of 8 rows with 17 cm of separation between plants within the row, and 70 cm of separation between rows of the same variety. The cobs used in the present study were collected at random from the experimental field. Briefly, for each variety a total of 50 cobs were obtained from groups of five cobs in 10 sampling points that followed a diagonal pattern along the 4 central rows from the plot of each variety. Eight corn samples (variety 1 to variety 8) were selected considering their nutrient composition, in order to cover a wide range of nutrient variation, mainly focused on protein, starch and NSP content. The corn proximate and physiochemical analyses are the averages from 10 cobs of each hybrid selected randomly from the experimental field, analyzed by NIRS and expressed on a fresh weight basis.

Experimental Diets

The experimental diets based on corn and soybeanmeal were formulated to meet all nutrient requirements recommended by FEDNA (2018) (Table 1). Broilers were fed in 2 different phases: starter, from 0 to 21 d of age; and finisher, from 22 to 42 d of age. A fixed amount of each corn (577 g/kg in the starter diets and 662 g/kg in the finisher diets) was used in the formula regardless of their chemical composition. The nutrient contents of each corn hybrid, determined by NIRS, are shown in Table 2. Diets were formulated to have the same content of protein (starter: 200 g/kg and finisher: 180 g/kg), ether extract (starter: 7.7 g/kg and finisher: 5.5 g/kg) and corrected nitrogen AME (AMEn) (starter: 2,900−2,940 kcal/kg and finisher: 3,045−3,087 kcal/kg). In order to include the same quantity of corn and be isonitrogenous, an ingestible ingredient (silicon dioxide; IBERSIL) was added to the diets as required. Diets were pelleted at 70°C using a pellet press (Pellet Mill 3020-4) with a capacity of 4,500−5,500 kg/h and using a 2.2 mm die for starter diets and 3.3 mm die for finisher diets. Diets contained 5 g/kg of titanium dioxide as an indigestible marker for estimating nutrient digestibility.

Experimental Procedures

The experimental procedures were approved by the Animal Experiment Committee of the Universitat Autònoma de Barcelona, and were in compliance with the European Union guidelines for the care and use of animals in research (European Parliament, 2010).

Birds were weighed individually at d 0, 21 and 42, and feed consumption was determined by pen per diet. Body weight (**BW**) uniformity was evaluated as the BW coefficient of variation. Mortality was monitored twice daily, and the weights of dead birds were used to adjust the feed conversion ratio. Excreta samples were collected at d 21 to determine energy, organic matter (**OM**) and dry matter (**DM**) digestibility. The excretas were collected in plastic containers and immediately frozen at -20°C. Excretas

Table 1. Ingredients and calculated composition of the experimental diets[1].

Diets	d 0−21		d 22−42	
Ingredients, (g/kg)	Mean	Range	Mean	Range
Corn	577	-	662	-
Soybean meal 47	317	311−331	263	256−269
Soy oil	53	50−55	33	30−36
DL-Methionine	3.3	3.2−3.4	2.8	2.7−2.9
Lysine HCl	3.6	3.3−3.8	2.8	2.6−3.1
Threonine	1.3	1.2−1.4	1	0.9−2.0
L-Valine	1.2	1.1−1.3	0.3	0.2−0.5
Salt	3	-	3	-
Limestone	11	-	11	-
Monodicalcium phosphate	10	-	9	-
Vitamin premix[2]	4	-	4	-
Sepiolite	14	0−24	8	0−17
Phytase[3]	0.1		0.1	
Calculated composition (g/kg)				
AMEn kcal/kg	2,920	2,900−2,950	3,064	3,032−3,087
Crude protein	200	-	180	-
Calcium	9.3	-	9.0	-
Available P	4.5	-	4.3	-
Fat	77	-	55	-
D Met+Cys	8.6	-	7.6	-
D Lys	11.8	-	10.0	-
Analyzed composition, (g/kg)				
Gross energy, Kcal/kg	4,150	4,075−4,224	3,938	3,914−3,958
Dry matter	910	906−922	870	864−874
Crude protein	196	190−199	170	168−179
Ether extract	74	71−76	50	48−52
Ash	110	104−138	90	61−103
Crude fiber	20	14−24	20	15−22
NFD	60	50−63	60	55−65

[1]Eight diets with different corn hybrid varieties were obtained; using NIRS predictions, all diets were formulated in order to contain the same calculated nutrient composition.

[2]Provided per kg of feed: vitamin A (retinol acetate) 10,000 UI; vitamin D (vitamin D3) (cholecalciferol) 4,800 UI; vitamin E/tocopherol) 45 mg; vitamin K3 (MNB, menadione nicotinamide bisulfate) 3 mg; vitamin B1 (tiamin mononitrate) 3 mg; vitamin B2 (riboflavin) 9 mg; vitamin B6 (piridoxin chlorohydrate) 4.5 mg; vitamin B12 (cyanocobalamine) 0.04 mg; nicotinamide 51 mg; pantothenic acid (calcium D-pantothenate) 16.5 mg; biotin (D-(+)-biotin) 0.15 mg; folic acid 1.8 mg; choline chloride 350 mg; iron (iron sulfate monohydrate) 54 mg; zinc (Zn, zinc oxide) 66 mg; manganese (Mn, manganese oxide) 90 mg; iodine (I, calcium iodine anhydrate) 1.2 mg; selenium (Se, sodium selenate) 0.18 mg; copper (Cu, copper sulfate pentahydrate) 12 mg; ethoxiquin 4 mg; D,L-malic acid 60 mg; fumaric acid 75 mg; sepiolite 907 mg; vermiculite 2001 mg; colloidal silica 45 mg.

[3]Quantum Blue 5G, AB Vista, Marlborough, UK; 5,000 FTU/g.

were then oven-dried and ground to pass through a 0.5 mm screen in a grinder before the analyses.

Sample Analyses

Corn Proximate and Physiochemical Analyses The fresh weight proximate and physiochemical characteristics of corn samples (10 per variety) included AMEn, crude protein, starch, crude fat, crude fiber, neutral detergent fiber, acid detergent fiber, protein solubility index (**PSI**), vitreousness, total NSP, total arabinoxylan (**AX**), and soluble AX. These were determined with NIRS (Foss DS2500, Hilleroed, Denmark) using calibrations provided by AB Vista (Feed Quality Service). To validate the NIRS predicted data, 16 corn samples were also analyzed for moisture, protein, starch and fat bywet chemistry, and NSP components using high performance liquid chromatography, following the method of Englyst et al. (1994).

Diet and Excreta Nutrient Analyses The contents of DM, ash, and gross energy (**GE**) were analyzed in feed and excreta, as well as crude protein (CP) in feed. Proximate analyses were performed according to AOAC (2005) Official Methods: Method 968.06 (CP), Method 934.01 (DM), Method 942.05 (ash). GE was determined using an isoperibolic calorimeter (Parr Instrument Company, Moline, Illinois, USA).

Whole-tract apparent digestibility of crude protein, energy, DM, and OM were calculated with the index method using the following equation:

$$\text{Whole Tract Apparent Digestibility} = 1 - (([Ti_D]/[Ti_E]) \times ([N_E]/[N_D]))$$

Where $[Ti_D]$ is the concentration of Ti in the diet, $[Ti_E]$ is the concentration of Ti in excreta, $[N_E]$ is the nutrient content in the excreta, and [N] is the nutrient content in the diet.

DM Solubility and Water Retention Capacity The hydrolysis capacity of the nutrients and the ability to retain water by the fiber components (NSP) were determined using the solubility of the DM (solDM) and water retention capacity (**WRC**), respectively. All corns and diets (n = 5) were analyzed using a modification of the protocol described by Anguita et al. (2006). Samples were treated following an *in vitro* procedure that simulates gastric pH. In short, 0.5 g of each sample was weighed into a 10 ml screw cap tube and incubated with 5 ml of 0.1M sodium phosphate buffer and 2 ml of 0.2M hydrochloric acid (pH = 2.5). Tubes were kept at 41°C for 2 h in a horizontal shaking water bath. The amount of sample submitted to analysis was recorded (W0) as well as the weight of the screw cap tube plus the sample (W1). After incubation, the tubes were centrifuged for 20 min at 2000 × g. The supernatant was carefully removed and tubes were kept upside down for 10 min to ensure that the non-retained water was drained. Tubes with sample were weighed (W2) then dried in the oven at 100°C for 16 h to ensure the complete drying of the insoluble residue, and then weighed again (W3). The solubility of the DM was calculated as follows:

$$SolDM = \left\{\frac{W1 - W3}{W0}\right\}$$

WRC determined after centrifugation is expressed as gram of water retained by the total amount of sample incubated:

$$WRC_{DM} = \left\{\frac{W2 - W3}{W0}\right\}$$

Statistical Analysis

Corn sample and pen were considered the experimental unit for all variables. The nutrient composition of all

Table 2. Proximate and physiochemical analysis (g/kg fresh weight) of corn hybrid samples measured by near-infrared spectroscopy (NIRS)[1].

Varieties	Trial Code	AMEn[2] (kcal/kg)	Protein (g/kg)	Starch (g/kg)	Fat (g/kg)	Crude Fiber (g/kg)	NDF[3] (g/kg)	ADF[4] (g/kg)	PSI[5] (%)	Vitreou.[6] (%)	Total-NSP[7] (g/kg)	Total-AX[8] (g/kg)	Soluble-AX[8] (g/kg)
Kws-16772	Variety 1	3,599^{b}	73.7^{d}	698.0^{a}	43.1^{b}	14.8^{c}	94.9^{ab}	37.5^{bc}	40.2^{bc}	57.1^{d}	54.8^{d}	38.7^{cd}	2.7^{e}
Kws-7569	Variety 2	3,439^{d}	80.4^{cd}	676.5^{bc}	36.3^{c}	21.5^{ab}	81.1^{c}	31.0^{d}	33.9^{d}	58.9^{c}	67.5^{b}	41.3^{bcd}	4.6^{b}
Kws-7554	Variety 3	3,432^{de}	80.9^{cd}	672.5^{cd}	36.7^{c}	24.7^{a}	98.5^{ab}	37.9^{bc}	33.9^{d}	58.6^{cd}	77.8^{a}	49.6^{a}	5.1^{ab}
Kws-2679yg	Variety 4	3,526^{c}	82.6^{cd}	679.4^{bc}	37.8^{c}	21.6^{ab}	76.4^{c}	33.7^{cd}	42.7^{b}	63.2^{a}	60.1^{bcd}	39.4^{cd}	4.0^{c}
Kerubino	Variety 5	3,390^{e}	82.7^{bc}	676.1^{bc}	32.1^{d}	21.7^{ab}	87.4^{bc}	35.9^{bcd}	29.4^{e}	57.2^{d}	66.5^{bc}	42.9^{bc}	5.2^{a}
Kws-7661	Variety 6	3,694^{a}	85.6^{abc}	687.7^{ab}	49.7^{a}	20.6^{b}	102.9^{a}	46.1^{a}	47.4^{a}	62.1^{ab}	57.6^{cd}	42.9^{bc}	2.1^{f}
Kefrancos	Variety 7	3,471^{d}	90.3^{ab}	668.0^{cd}	37.2^{c}	24.6^{a}	88.2^{bc}	38.1^{bc}	37.3^{cd}	60.7^{b}	69.7^{ab}	45.8^{ab}	4.8^{ab}
Kws-7562	Variety 8	3,457^{d}	93.2^{a}	660.3^{d}	36.9^{c}	21.4^{ab}	81.6^{c}	39.6^{b}	40.5^{bc}	63.1^{a}	50.7^{d}	36.6^{d}	3.2^{d}
	SEM[8]	10	1.94	3.21	0.83	0.78	2.89	1.31	0.78	0.35	2.23	1.09	0.11
P value													
Variety		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[1]Data are means of 10 replicates from each corn hybrid.
[2]Apparent metabolizable energy for poultry.
[3]Neutral detergent fiber.
[4]Acid detergent fiber.
[5]Protein solubility index.
[6]Vitreousness.[6]Non-starch polysaccharides.
[7]Arabinoxylans.
[8]Standar error mean[9a-f]Values in the same column not sharing a common letter are significantly different ($P < 0.05$).

corns, broiler performance, solDM, WRC and coefficients of digestibility were analyzed by one-way ANOVA to identify treatment effects, using PROC GLM (SAS 9.4). Significantly different means were separated using Tukey adjust. Significance was declared at a probability $P \leq 0.05$ and tendencies were considered when P values were between >0.05 and <0.10. Spearman's non-parametric correlation analysis was used to explore the associations between NIRS nutrient predictions, solDM, WRC and performance. A regression analysis between NIRS and wet chemistry of NSP and AX values, and correlation plot between NIRS nutrient content predictions and performance, nutrient digestibility and *in vitro* corn and feed results were created using a linear model function and the corrplot package of R 3.6.1., respectively.

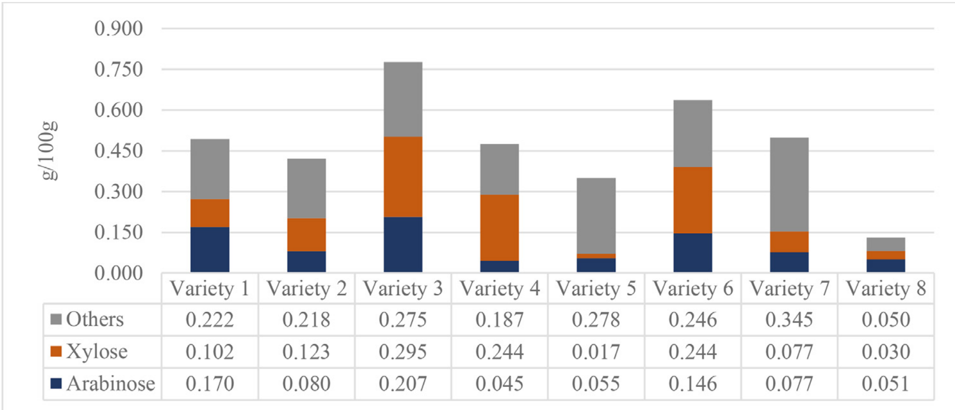
RESULTS

Corn and Diets Analyses

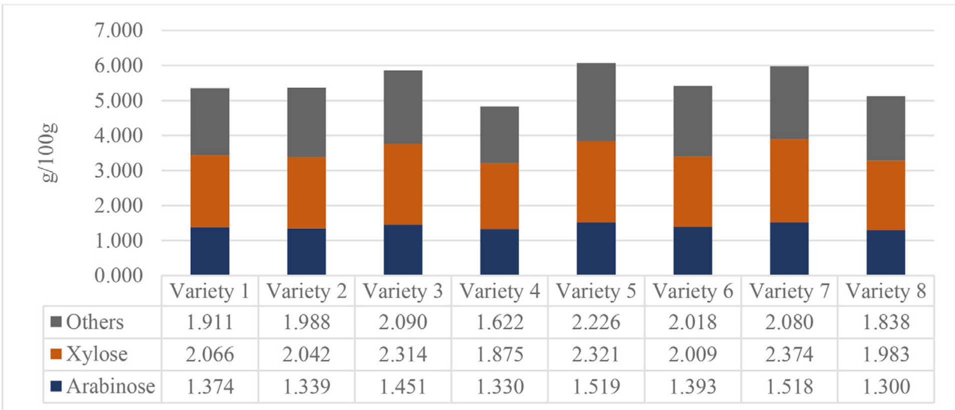
The corn hybrid samples differed in nutritional composition (Table 2). The average contents of the main components were: AMEn 3,501 kcal/kg; starch 677 g/kg; crude protein 83.7 g/kg; crude fiber 21.4 g/kg; crude fat 38.7 g/kg; total NSP 63.1 g/kg; total AX 42.2 g/kg; soluble AX 4.0 g/kg; ratio A:X 0.73; PSI 38.2%; and vitreousness 60.2%. The non-starch polysaccharide content in the corn samples is shown in Figure 1. Overall, the sum of components (crude protein + starch + crude fat + total NSP) came to approximately 863 g/kg of fresh weight, with the remaining presumably being mainly moisture and sugars (mono-, di- and oligosaccharides + fructans). The regression analyses between NIRS and wet chemistry values for moisture, protein, starch, fat, NSP and AX are shown in Figure 2. The proximate analyses of starter diets were in accordance with the expected values for protein and ether extract. Minor differences in GE were observed, in a range from 4,075 to 4,224 kcal/kg. In the finisher diets, the CP showed higher variability (range 168−179 g/kg), as the analyzed contents in all diets were lower than the calculated value. Diet GE showed less variability, with a range from 3,925 to 3,958 kcal/kg.

DM Solubility and WRC

Results from the SolDM and WRC of corn and feed after *in vitro* incubation are shown in Table 3. The SolDM and WRC were influenced by corn variety ($P < 0.05$ and $P < 0.001$, respectively). Variety 2 had a higher WRC compared to varieties 1 and 5. The other varieties were intermediate. Variety 8 had the highest solDM followed by variety 1, with no statistically significant differences between other varieties. In the starter diets, no differences were observed in WRC ($P = 0.11$). Differences in solDM of the starter diets were observed ($P = 0.0001$), as those formulated with varieties 1 and 8 had higher levels of solDM than the other diets. In the finisher diets, significant differences were observed for WRC ($P < 0.0001$) and solDM ($P < 0.0001$). Diets



A



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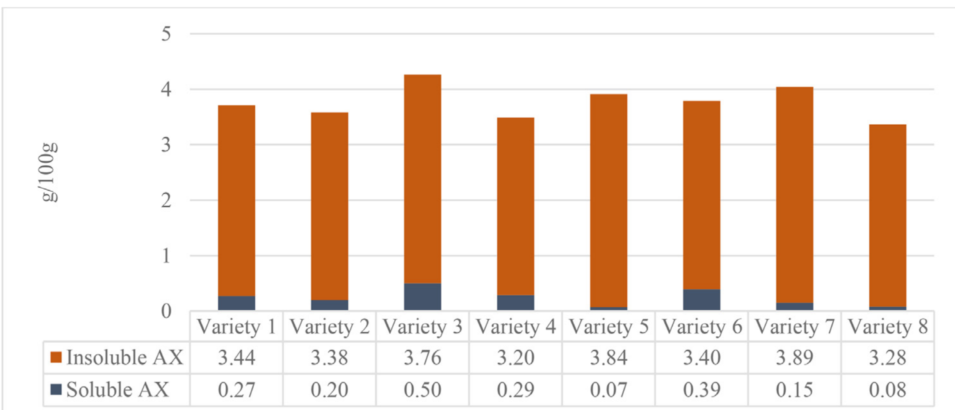

C

Figure 1. Soluble (A) and insoluble (B) non-starch polysaccharide and arabinoxylan (C) content in the corn samples.

containing varieties 3, 4, 5, and 6 had the highest WRC, varieties 1 and 2 had intermediate results, and varieties 7 and 8 had the lowest values. The solubility of the DM in variety 8 finisher feed was higher compared to the others except for the variety 1 diet.

Growth Performance

The effect of diets based on the individual corn hybrids on broiler chicken BW and growth performance is described in Table 4. Overall broiler mortality was 8.1% (data not shown), and no differences were observed between the experimental treatments ($P > 0.05$). Although no significant effects of feeding broiler chickens different corn varieties were observed for the whole period or the finisher phase ($P > 0.10$), a significant trend was observed in weight gain ($P = 0.096$). Birds fed varieties 2 and 6 had the highest BW gain, and those fed with varieties 1, 3, and 8 had the lowest BW gain. Overall feed intake was not influenced by corn variety ($P > 0.10$); however, it is interesting to highlight that birds

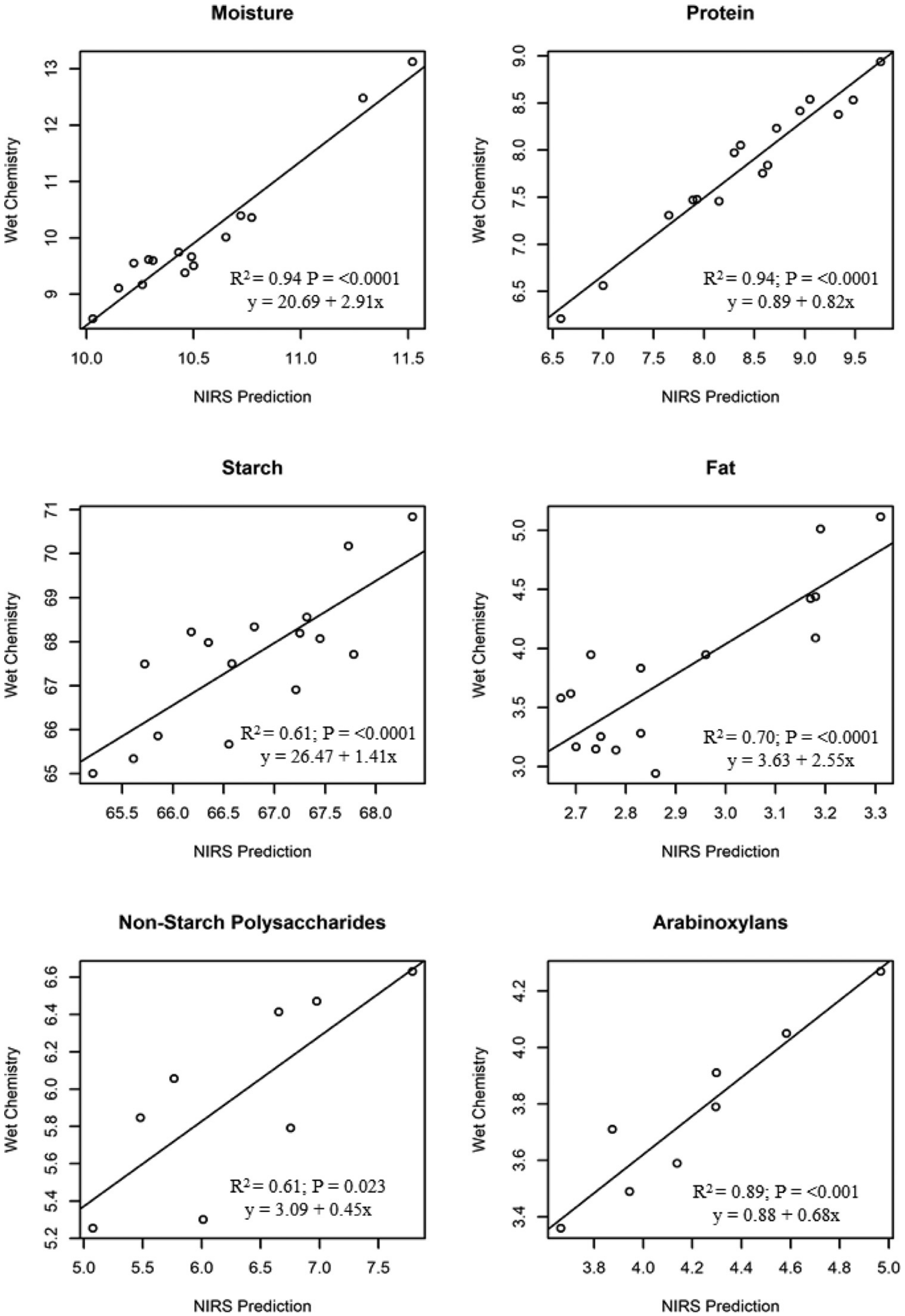

Figure 2. Regression analysis between wet chemistry and NIRS predicted values for moisture, protein, starch, fat, NSP and AX using the 8 corn varieties.

Table 3. Effect of corn hybrid samples and feeds on water retention capacity (WRC, g:g) and dry matter solubility (SolDM, g:g) at pH 2.5[1].

	Variety 1	Variety 2	Variety 3	Variety 4	Variety 5	Variety 6	Variety 7	Variety 8	SEM[2]	*P* value
Corn										
WRC	1.23^{b}	1.39^{a}	1.32^{ab}	1.26^{ab}	1.25^{b}	1.27^{ab}	1.32^{ab}	1.30^{ab}	0.031	0.020
SolDM	0.116^{b}	0.099^{c}	0.100^{c}	0.101^{c}	0.103^{c}	0.102^{c}	0.101^{c}	0.123^{a}	0.0012	<0.0001
Feed d 0−21										
WRC	2.17	2.16	2.18	2.23	2.24	2.19	2.20	2.11	0.029	0.110
SolDM	0.139^{a}	0.130^{b}	0.123^{b}	0.129^{b}	0.129^{b}	0.126^{b}	0.127^{b}	0.139^{a}	0.0021	0.0001
Feed d 21−42										
WRC	1.88^{ab}	1.90^{ab}	1.92^{a}	1.94^{a}	2.00^{a}	1.96^{a}	1.77^{b}	1.77^{b}	0.032	<0.0001
SolDM	0.170^{ab}	0.159^{c}	0.164^{bc}	0.165^{bc}	0.156^{c}	0.166^{bc}	0.163^{bc}	0.175^{a}	0.0023	<0.0001

[1]Data are means of 5 replicates per sample.
[2]Standard error of the mean.[3abc]Values in the same row not sharing a common letter are significantly different ($P < 0.05$).

Table 4. Effect of corn hybrid sample on body weight (BW), weight gain, feed intake and feed conversion ratio (FCR).[1]

	Variety 1	Variety 2	Variety 3	Variety 4	Variety 5	Variety 6	Variety 7	Variety 8	SEM[2]	*P* value[3]
d 0−21										
BW (g)	1,036[ab]	1,039[ab]	998[ab]	1,043[a]	1,018[ab]	1,011[ab]	993[ab]	949[b]	21	0.033
Weight gain (g/d)	994	997	956	1,001	976	966	960	907	21	0.056
Feed Intake (g/d)	1,253[ab]	1,233[ab]	1,216[ab]	1,286[a]	1,210[ab]	1,203[ab]	1,256[ab]	1,168[b]	23	0.021
FCR (g/g)	1.263	1.238	1.273	1.285	1.241	1.246	1.309	1.291	0.0183	0.065
d 21−42										
BW (g)	3,028	3,140	3,016	3,070	3,042	3,095	3,068	2,975	38	0.100
Weight gain (g/d)	1,984	2,084	2,018	2,027	2,024	2,113	2,067	2,019	33	0.130
Feed Intake (g/d)	3,695	3,778	3,677	3,663	3,603	3,814	3,755	3,668	53	0.113
FCR (g/g)	1.866	1.816	1.825	1.807	1.782	1.807	1.818	1.819	0.0253	0.544
d 0−42										
Weight gain (g/d)	2,978	3,081	2,974	3,028	3,001	3,080	3,028	2,926	40	0.096
Feed Intake (g/d)	4,949	5,011	4,892	4,949	4,813	5,016	5,011	4,836	64	0.147
FCR (g/g)	1.662	1.626	1.644	1.634	1.606	1.630	1.655	1.654	0.015	0.205

[1]Data are means of 8 pens each with 10 birds in the starter and finisher periods.
[2]Standard error of the mean.
[3ab]Values in the same row not sharing a common letter are significantly different ($P < 0.05$)

Table 5. Effects of corn variety on total tract digestibility and intake of energy, dry matter (DM) and organic matter (OM) at d 21.[1]

	Total tract apparent digestibility			Intake of digestible nutrients		
	DM	OM	Energy	DM(g)	OM(g)	Energy (kcal)
Variety 1	0.69[ab]	0.72[abc]	0.73[ab]	868[a]	901[a]	3,824[a]
Variety 2	0.68[ab]	0.72[abc]	0.74[a]	844[ab]	899[a]	3,747[ab]
Variety 3	0.67[abc]	0.70[cd]	0.71[bc]	820[ab]	858[ab]	3,678[ab]
Variety 4	0.69[ab]	0.73[ab]	0.74[a]	896[a]	940[a]	3,979[a]
Variety 5	0.67[bc]	0.70[bcd]	0.72[ab]	817[ab]	860[ab]	3,693[ab]
Variety 6	0.68[ab]	0.72[abc]	0.73[ab]	821[ab]	870[ab]	3,679[ab]
Variety 7	0.70[a]	0.73[a]	0.74[a]	862[a]	908[a]	3,777[ab]
Variety 8	0.65[c]	0.69[d]	0.70[c]	764[b]	812[b]	3,404[b]
SEM[2]	0.087	0.081	0.091	20.9	21.4	91.9
P value[3]						
Variety	0.008	0.048	0.003	0.0004	0.001	0.001

[1]Data were obtained by pooling 10 birds per pen, with 8 pens per treatment.
[2]Standard error of the mean.
[3abcd]Values in the same column not sharing a common letter are significantly different ($P < 0.05$).

fed varieties 5 and 8 tended to have low feed consumption for the entire period compared to the other diets. BW and FI were influenced by treatments in the starter period ($P < 0.05$). Birds fed the variety 8 diet had a lower BW and FI than those fed with the variety 4 diet, while the other corns gave intermediate performances.

Whole-Tract Apparent Digestibility and Intake of Digestible Nutrients

The effects of corn source on energy, DM and OM whole-tract apparent digestibility and intake of digestible nutrients at d 21 are shown in Table 5. The variety 8 diet had lower apparent digestibility of DM, OM and energy compared to diets with varieties 1, 2, 4, 6 and 7 ($P < 0.05$). Intakes of digestible DM, OM and energy were lower with variety 8 compared to varieties 1 and 4 (764 g vs 868 and 896 g; 812g vs 901 and 940g; 3404 kcal vs 3824 and 3979 kcal, $P < 0.05$). Variety 7 gave a higher intake of digestible DM and OM, and variety 2 gave a higher intake of digestible OM than variety 8.

Correlations

Figure 3 shows the correlation matrix and significance for the relationships between all parameters. Significant correlations ($P < 0.05$) were observed among physiochemical corn values. For example, AMEn was positively correlated with PSI (r = 0.88) and fat (r = 0.98), and negatively correlated with soluble NSP (r = -0.83) and soluble AX (r = -0.88). Protein was positively correlated with the total arabinose:xylose ratio (A:X) (r = 0.67) and vitreousness (r = 0.60, $P = 0.054$) and negatively correlated with starch (r = -0.62). Soluble AX was negatively correlated with PSI (r = -0.88), fat (r = -0.83) and AMEn (r = -0.88).

In addition, significant correlations ($P < 0.05$) between physiochemical corn values and *in vitro* analysis, 21-d performance and digestibility were observed. DM solubilities of corn and starter feeds were negatively correlated with total NSP (r = -0.79 & -0.76, respectively). DM solubility of the starter feed was negatively correlated with crude fiber content (r = -0.69), total AX (r = -0.88), phytic phosphorus (r = -0.90) and corn yield (r = -0.81). DM solubility of finisher feeds was negatively correlated with soluble NSP (r = -0.80). BW and weight gain at d 21 were negatively correlated with corn protein content (r = -0.71 & -0.62, respectively), while BW at d 21 was positively correlated with corn starch content (r = 0.74). DM solubility of corn hybrids was negatively correlated with BW at d 42 (r = -0.57) and overall weight gain (r = -0.57). Corn harvest yield was positively correlated with phytic phosphorus (r = 0.83),

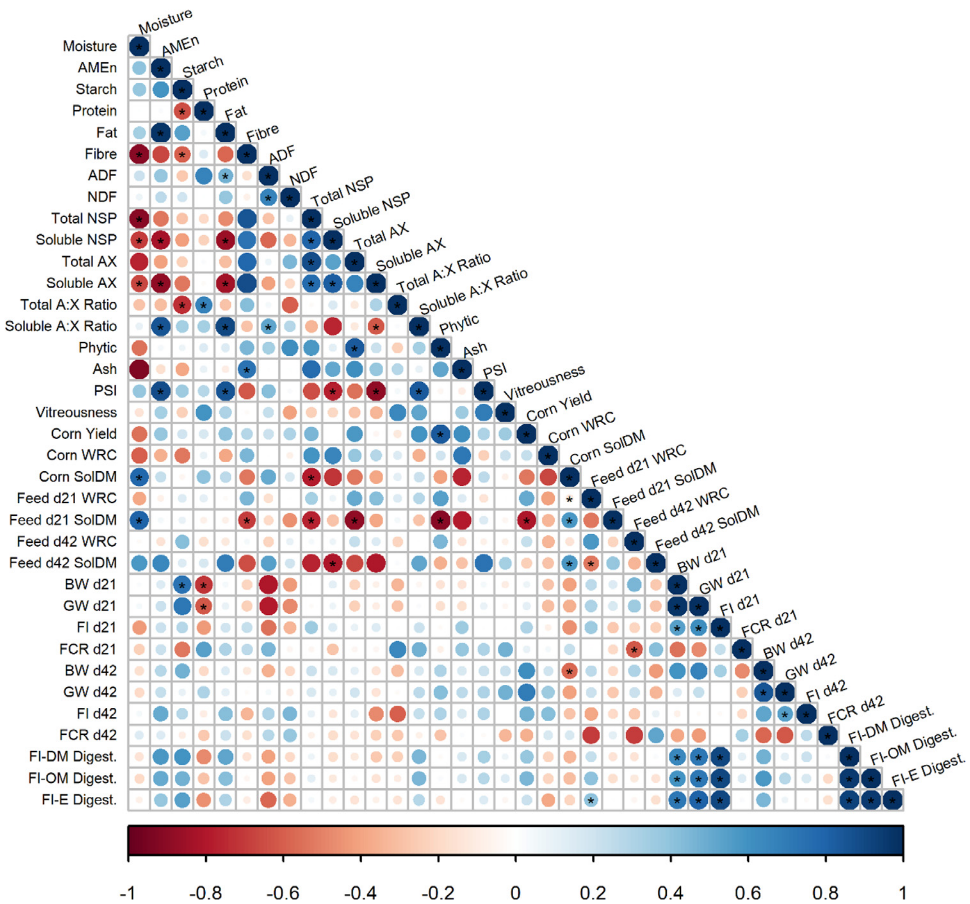

Figure 3. Correlations between NIRS predicted nutrient content and broiler performance, nutrient digestibility and *in vitro* corn and feed results (WRC and solDM). The * ($P < 0.05$) symbol indicate a statistically significant correlation. The scale colors (Spearman's ρ from -1 to +1) indicate whether the correlation is positive (blue) or negative (red) between factors.

and DM (r = 0.79), OM (r = 0.79), and energy (r = 0.74) digestibility.

DISCUSSION

Corn nutrient composition can be influenced by many factors, such as genetics and environmental conditions. Genetic selection can influence several kernel characteristics and thus the high heritable parameters, including kernel weight, volume, endosperm type, degree of damage, density and kernel breakage (Johnson and Russell, 1982; LeFord and Russell, 1985; Chen et al., 2016). In addition, the genetic background can also produce variation in the nutritional and anti-nutritional components in corn (Reynolds et al., 2005). Potentially antinutritional factors of corn, such as NSP, could interact with major nutrients, reducing their availability and consequently impairing bird digestibility and performance. Based on these considerations, the aim of the present study was to test the effects of anti-nutritional factors and nutrient availability of corn hybrids on broiler performance and nutrient digestibility.

In the current study, the proximate analysis by NIRS of 8 corn varieties showed a range in nutrient content of CP (73−93 g/kg), starch (660−698 g/kg) and crude fiber (14.8−24.7 g/kg). Masey O'Neill et al. (2012) reported nutritional variation within one hybrid harvested in different regions of China with similar ranges of CP, starch and crude fiber (76−85 g/kg, 742 −757 g/kg and 25.9−26.5 g/kg, respectively). Although the range in nutrients reported here was low, it revealed that the genetic background is a consistent source of nutrient variation, which is probably as important as the geographical factors. The results of the present study also showed differences in total NSP (50.7−77.8 g/kg), PSI (29.4−47.4%) and total AX (36.6−49.6 g/kg). Some expected correlations were observed, such as a negative correlation between protein and starch, as previously described in other studies (Uribelarrea et al., 2004; Masey O'Neill et al., 2012), while the positive correlation between crude protein and A:X ratio might suggest a relationship between AX structure and protein. A higher A:X ratio indicates more arabinose single-sugar side chains on the xylan backbone, and has been related to the solubility of AX (Rosicka-Kaczmarek et al., 2016).

AX physicochemical characteristics, such as gelling capability, depends on many characteristics, including molecular weight, side-chain ferulic acid concentration and A:X ratio (Izydorczyk and Biliaderis, 1995). AX-protein associations can also play an important role, especially the nature and quantity of the protein fraction (Méndez-Encinas et al., 2019). Furthermore, the negative correlation between PSI and soluble NSP and AX suggests that protein solubility is affected by these soluble fiber components. Thus, the availability for digestion of corn protein could depend on the interaction with other corn kernel components, including fiber AX. In addition, the results from this study showed a positive correlation between protein content and vitreousness, with varieties 8 and 1 having the highest and lowest vitreousness and protein contents, respectively. Genotype, maturity at harvest and growing environment are factors that affect corn vitreousness (Corona et al., 2006; Masoero et al., 2011). Therefore, cereal endosperm vitreousness or hardness can influence the particle size distribution of subsequent diets (Lentle et al., 2006; Amerah et al., 2008) and thus the nutritional value of corn for chickens (Kaczmarek et al., 2013). In addition, corn diet particle size distributions have been related to the development of the gastrointestinal tract, performance and digestibility in broiler chickens (Jacobs et al., 2010). However, a negative correlation between corn solDM and d 42 BW and weight gain was observed in this study. This suggests that soluble corn compounds such as soluble NSP could decrease nutrient availability and consequently performance. This would explain why birds fed the variety 8 diet, which has the highest solDM, had a lower BW and FI at d 21 and a decrease in whole tract DM, OM and energy digestibility compared to those fed the other corns. Corn variety 8 also showed the highest CP content. In this regard, zeins, or corn prolamins, and starch have been related to endosperm texture (Lee et al., 2006). Thus, the amount and packing of this protein within the kernel could affect physical properties such as vitreousness (Paulsen et al., 2019) and access to digestive enzymes (Liu et al., 2016; Pan et al., 2017). Overall, these factors could explain part of the effects observed in the current study on broiler performance and digestibility when the animals were fed different corn hybrids.

Corn solubility could be affected by the nature of the zeins, which are divided into several subclasses with different molecular weights and solubilities (Esen, 1986; Lee et al., 2006). It is thought that the matrix in the endosperm is associated with the nature of the protein/starch interactions, and this may influence the nutritional value of the cereal (Kaczmarek et al., 2013), and thus affect the protein and amino acid digestibility (Kaczmarek et al., 2011). It is plausible that the negative correlation observed between protein content and d 21 BW and weight gain could be related to the profile of corn zeins, given that the high-protein variety 8 had a negative effect on nutrient digestibility and bird performance. It is clear that an interaction between nutrients and other compounds influences the physicochemical characteristics and nutrient value of corn and, consequently, their behavior in feed processing and digestion processes.

Despite the small number of samples in this study, regression results between NSP and AX, predicted by NIRS, and the wet chemistry values showed that NIRS is an effective nutrient prediction tool. This is supported by there being no differences in the 42-d bird performances when they were fed eight different diets formulated with NIRS data to be iso-nitrogenous and iso-energetic. NIRS could also be used to make decisions about adding carbohydrase, such as xylanase, in order to prevent the negative effects of AX, the major component of NSP.

In conclusion, the results from the present study show that corn genetic background influenced nutrient digestibility and growth performance of broiler chickens fed diets based on these corns. The content and nature of the NSP are shown as two of the main factors affecting the solubility and availability of nutrients in corn, with possible negative effects on the performance of broiler chickens. The NIRS prediction for NSP and AX could be useful for improving feed formulation or the efficiency of any fiber utilization enhancer in corn-based diets.

ACKNOWLEDGMENTS

The authors acknowledge the financial support of the SENESCYT (Secretary for Higher Education, Science, Technology and Innovation of Ecuador), AB Vista Laboratory Services (UK) for their assistance with the NIRS analysis and KWS Semillas Ibérica, S.L.U. (Spain) for the provision of corn varieties.

DISCLOSURES

On behalf of the authors, we wish to confirm that all authors have read and approved and that there are no other persons who satisfied the criteria for authorship but are not listed. Moreover, we confirm that all the authors listed in the manuscript have been approved one to each other.

We also wish to confirm that there are known conflicts of interest associated with this publication and that there has not been financial support for this work that could have influenced its outcome.

We also assume that although the corresponding author is the sole contact with the Editor in chief, he is responsible for communicating with the other co-author about the submission and the progress of the manuscript revision and final approval of proofs.

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