High-protein maize in diets for broilers

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Abstract

The nutritional performance of three high-protein maize hybrids was compared with conventional maize in a 42-day feeding trial in broilers. The following experimental diets were compared: i) control diet (CTR) containing conventional maize; ii) diet containing hybrid IPM1; iii) diet containing hybrid IPM2; iv) diet containing hybrid IPM3. The diets were offered to male broilers (Hubbard Ultra-Yield; 120 birds per treatment) in 3 phases: starter, grower and finisher. All the diets were isonitrogenous and iso-energetic. The IPM2 and IPM3 diets (containing maize grains with the highest protein and essential and non-essential amino acid contents) resulted in a higher final weight in broilers (2622 and 2632 g, respectively, versus IPM1 and CTR diets; P<0.05), a higher average daily gain (60.8 and 61.4 g/d, respectively, versus IPM1 and CTR diets; P<0.05) and better feed to gain ratios (1.70 and 1.69, respectively, versus the CTR diet; P<0.05) throughout the experimental period. The nutritional characteristics of the different maize varieties were also evaluated using a 9-day digestibility trial in male rats (6 rats per treatment). Higher percentages of nitrogen retention were obtained from the IPM2 (54.02%) and IPM3 (53.51%) diets compared with the CTR (44.20%) and IPM1 (41.87%) diets (P<0.05). These results suggest a greater amino acid availability in the diets based on high-protein maize varieties. Therefore, high-protein maize can profitably be included in broiler diets with the advantage of reducing the use of imported protein sources (such as soybean meal) because of its higher protein content and consequently, providing savings on feed costs.

Introduction

Maize is the most commonly used cereal grain in the diets of intensively reared poultry. It contributes approximately 65% of metabolizable energy and 20% of the protein in a broiler starter diet (Cowieson, 2005).

Although maize grain is often the preferred dietary energy source for livestock production systems, the proteins in maize are quantitative-ly and qualitatively poor. For this reason, the use of conventional maize requires protein, lysine (Lys) and tryptophan (Trp) supplements in broiler diets to optimize animal performance. As an alternative to supplements, strategies based on conventional plant breeding methods (e.g. selection, hybridization) and biotechnology (e.g. genetic engineering) have been developed to select maize lines containing improved levels of proteins and essential amino acids (Shewry, 2007). The genetic control of maize protein has been well established. Lines of high-protein maize, with protein contents ranging from 4.4% to 26.6%, resulted from 70 generations of selection experiment (Dudley et al., 1974). Breeding for improved protein quality in maize began in the mid-1960s with the discovery of mutants, such as opaque-2, and led to the development of quality protein maize (QPM) characterized by enhanced levels of Lys and Trp (Prasanna et al., 2001; Sofi et al., 2009). QPM (Obatampa) and lysine maize have been shown to have a better feed to gain ratio compared to normal maize in monogastric animals such as chickens (Lucas et al., 2007; Onimisi et al., 2009).

The introduction of new maize hybrids has resulted in feed raw materials with different nutritional characteristics (Idikut et al., 2009). All stakeholders in poultry production and business are interested in the appropriate quantity and quality of a formulated feed that provides an optimum economic return. Therefore, further feeding trials are necessary to evaluate the nutritional performance of hybrid maize in comparison with that of normal maize in poultry diets. The objectives of this study were to compare the nutritional performance of three commercial hybrids of high-protein maize versus that of conventional maize by comparing the growth performance in growing broilers, and to verify the nutritional characteristics of the different maize varieties using digestibility trials in rats.

Materials and methods

Broiler, housing and experimental design

Animal care and procedures used during this trial conformed to the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 1999).

Four hundred and eighty male commercial-type meat broilers (Hubbard Ultra-Yield) were obtained at one day of age (D0) from a commercial Italian hatchery and were then transported to the CERZOO facility (S. Bonico, Piacenza, Italy). The birds were vaccinated for Mareck’s disease at the hatchery, for Gumboro’s disease on the 14th day, and Newcastle disease on the 16th day of study. The birds’ health was checked and documented throughout the study. Mortality was recorded and complete necropsy examinations were carried out on all broilers found dead.

The experimental design compared four different diets fed to broilers housed in 2 blocks with 6 replicates for each experimental diet. The 480 animals were weighed on arrival (45.1 ± 2.7 g body weight) and divided into 4 homogeneous groups of 120 animals each. The 120 birds for each dietary treatment were distributed into 6 pens (replicates) of 20 subjects...
each. The diets were assigned to the pens in a randomized block design. Animals were housed in two rooms (A and B) of the same facility. Each room was divided into 12 pens of 20 broilers, each providing a density of approximately 0.09 m² of available floor space per broiler; wood shavings were supplied as litter. Room temperature was regulated by a thermostatically controlled system. The rooms were ventilated with an automatic system regulated for temperature and humidity. Temperatures were an average of 30.3°C (room A) and 30.2°C (room B) in the starter phase, 25.4°C (room A) and 24.6°C (room B) in the grower phase, and 21.4°C (room A) and 20.2°C (room B) in the finisher phase. The relative humidity values were an average of 58.45% (room A) and 60.16% (room B) in the starter phase, 66.10% (room A) and 69.43% (room B) in the grower phase, and 71.81% (room A) and 71.14% (room B) in the finisher phase.

The lighting program provided 23 h of light and 1 h of darkness from D1-D4 of the study, 22 h of light and 2 h of darkness from D4-D7, and 18 h of light and 6 h of darkness for the remainder of the study. Lighting was automatically regulated by a timer. Animals had continuous access to feed and water. The animals were fed their respective dietary treatments from time of hatching (D0) to 42 days of age (D42).

Maize grain

All maize grains for this study were supplied by ISTA Veneto Sementi, Loreo, Rovigo, Italy. The hybrids utilized in the experiment were derived from a breeding program developed in Italy with the aim of increasing the protein content in the local germplasm FAO 400. The best inbred lines obtained in the program were: line HP1, a female pedigree derived from a high protein (HP) US hybrid x HP Synthetic (Illinois University, USA) (protein content 22.7%); line HP3, a male pedigree, itself a US HP hybrid (protein content 14.2%); line HP6, a male pedigree, derived from LO933, an Italian line bred by the Istituto Sperimentale per la Cerealicoltura (Bergamo, Italy) x US HP hybrid (protein content 21.2%); IMHP2, derived from a female early Stiff Stalk Synthetic-related line; and IMV4, extracted from the local flint Marano variety.

The hybrids IPM1, IPM2 and IPM3 used in this trial belong to the early-medium 400-500 FAO classes and they were derived from IMHP3 x IMHP6, IMHP1 x IMHP6 and IMHP2 x IMV4 inbred lines, respectively. IPM1 and IPM2 have dent kernels while IPM3 is an Italian flint type widely used for poultry feeding. A normal yellow dent maize (Costanza, Pioneer, FAO class 600) was used as control. All genotypes were grown in isolated plots using agronomic practices common to the area. Hybrids were sown at the CERZOO Research Center (S. Bonico, Piacenza, Italy).

Diets

The experimental diets were produced in the CERZOO facility with a horizontal mixer (500-kg capacity) mixing a basal diet with the maize sources to be tested. The following experimental diets were compared: i) basal diet containing commercial meal of conventional maize as only maize source (control, CTR); ii) diet containing commercial hybrid IPM1 as only maize source (IPM1); iii) diet containing commercial hybrid IPM2 as only maize source (IPM2); iv) diet containing commercial hybrid IPM3 as only maize source (IPM3).

Diets were fed in 3 phases: starter (D0-D18), grower (D19-D36) and finisher (D37-D42). All diets were offered as mash form and fed *ad libitum*. Starter, grower and finisher diets were formulated to meet the nutrient requirements of a commercial broiler diet in accordance with Hubbard S.A.S. guidelines (Hubbard, 2007).

Within each phase, diets were based on maize and soybean meal. Different amounts of soybean meal were used in the control and IPM diets owing to different protein levels of the maize types: lower amounts of soybean meal were added to the diet containing maize with higher protein content and vice versa. Requirements for protein and amino acids were met by adjusting the concentrations of non-maize ingredients. All diets were formulated to the same metabolizable energy (ME) and protein and amino acid levels. All the maize grains and experimental diets were analyzed for moisture, crude protein, ether extract, crude fibre and ash according to ASPA standards. The amino acid content was determined using the model 3A29 amino acid analyzer (Carlo Erba Strumentazione, Corsico, MI, Italy) (Moore, 1963; Eggum, 1968; Moore et al., 1980). The metabolizable energy (ME) of the maize grains and diets was calculated according to the equation reported by the European Commission (2009). All analyses were carried out in duplicate.

Measurements of broiler performance

Animals were individually weighed at the beginning of the study, and after 18, 36 and 42 days. Average daily gain (ADG) and feed intake (FI) were also recorded at these time points allowing calculation of adjusted feed:gain ratio (Feed Efficiency, FE) during the 4 experimental periods (D0-D18, D19-D36, D37-D42 and D0-D42 of trial) for each replicate. The European Production Efficiency Factor (EPEF) was also calculated for each pen using the following mathematical formula:

\[ \text{EPEF} = \frac{\text{ADG (g/d) x % survival rate}}{\text{FE x 10}} \]

The broiler genetic potential reported by Hubbard S.A.S. guidelines (Hubbard, 2011) is 2451 g body weight and feed conversion ratio is 1.72 for 42-day-old broilers.

Nitrogen retention and digestibility study in rats

The study was carried out using 24 healthy male rats (Wistar). The animals were weighed on arrival (106.2 ± 6.6 g body weight) and during the 8-day pre-experimental period. The rats were then divided into 4 homogeneous groups of 6 animals each. During the pre-experimental period, the animals were fed the control diet for two days and respective experimental diets for the remaining six days. After the pre-experimental period, the animals were fed their dietary treatment for nine days. The four experimental diets compared in this study were the same offered to the broilers during the grower phase (D19-D36). Diets and water were offered *ad libitum* during the whole period. Throughout the trial (9 days), excreta (feces and urine) were collected once daily. Samples of feces (total n=24) and urine (total n=24) were pooled each day for the animals and dried or frozen, respectively, at -20 °C until analysis. Nitrogen retention was then evaluated by the ingesta-excreta balance method. The apparent digestibility coefficients of the dry matter and ether extract of the diets were also determined.

To our knowledge, literature lacks research which compares total-tract digestibility in rats with that of cockerels. Nevertheless, Fuller et al. (1994), in their study on the dietary amino acid digestibility in pigs, rats and chickens, using different methodologies of evaluation, obtained true digestibility values in cockerels which were similar to those of pigs and rats.

Statistical analysis

Statistical analyses were carried out on performance measurements. Statistical analysis was performed according to the General Linear Model (GLM) procedure of SAS (2003) with dietary treatments as independent variables in a two-way analysis of variance within a randomized complete block design with 4 treat-
Results and discussion

Maize grain and diet composition

The chemical and amino acid compositions of the grain from conventional maize and commercial hybrids of high-protein maize are reported in Table 1.

As expected, the protein contents of the high-protein maize hybrids were between 17.95% and 42.05% higher than the conventional maize. The hybrids of high-protein maize also had higher oil levels (range 19.38%-53.13%) and lower starch contents (range 2.59%-6.27%) than conventional maize. These results could be explained by a higher germ to endosperm ratio in kernels of high-protein maize. A maize kernel consists of pericarp (6%), endosperm (82%) and germ (12%) (Prasanna et al., 2001). Starch is the main structural component of the endosperm whereas oil is contained in the germ. Both the germ and endosperm contain proteins but the embryo proteins are superior in both quality and quantity (Prasanna et al., 2001; Sohi et al., 2009). Lambert (1994), in his study on high-oil maize hybrids, reported that the increase in oil concentration in the proteins in high-protein maize is associated with an increase in protein quality. In fact, in our study the hybrids of high-protein maize had higher contents of both essential and non-essential amino acids compared with conventional maize. In particular, threonine (Thr), methionine (Met) and Trp levels were of particular interest with higher contents in the hybrids of high-protein maize (range 21.43%-50%, 50%-68.75% and 40%-60% for Thr, Met and Trp, respectively) compared with those detected in conventional maize. Nevertheless, even though Lys levels were from 4.5% to 18.18% higher in high-protein maize than in conventional maize, there was a reduction in Lys concentration in the proteins in high-protein maize: 2.31% in high-protein maize and 2.82% in conventional maize. Furthermore, the higher protein contents and the lower starch levels found in the commercial hybrids of high-protein maize were in accordance with previous works (Harrelson et al., 2008; Idikut et al., 2009). In their recent studies on the effect of hybrids on digestibility and grain, starch and protein yields of maize, these authors reported a negative relationship between starch content and crude protein.

Table 2 shows the ingredient and analyzed nutrient compositions of the broiler starter, grower and finisher diets containing commercial hybrids of high-protein maize and conventional maize. The nutrient requirements (Hubbard, 2007) by feeding phase were satisfied through the formulated diets with maize grain and other ingredients.

Birds in all the groups were in good health throughout the study according to periodical pen observations. Mortality from D0 to D42 was 2.5% in the group receiving conventional maize (total deaths n=3), 0% in those receiving IPM1, 4.17% in those receiving IPM2 (total deaths n=5), and 2.5% in those receiving IPM3 (total deaths n=3). Average mortality recorded during the whole study period was low (2.29%) and not due to obvious pathological causes (data not shown).
A diet/treatment effect was also found on the average daily weight gain (ADG) of the D0-D18 period (P<0.046), D19-D36 (P<0.019) and D0-D42 (P=0.001) periods whereas no treatment effect was observed in the D37-D42 period. In the D0-D18 period, the IPM3 diet reported the highest ADG (37.2 g/d, with P<0.05) in broilers compared with all the other diets (CTR= 35.3 g/d; IPM1= 34.8 g/d; IPM2= 34.9 g/d). Similar ADG were detected in broilers fed diets formulated with conventional, IPM1 and IPM2 maize. In the D19-D36 period, the ADG was higher in broilers treated with IPM2 maize (81.7 g/d; P<0.05) than in those treated with conventional (78.4 g/d) and IPM1 (76.7 g/d) maize. The broilers fed the diet containing IPM3 had higher ADG (80.4 g/d; P<0.05) than the broilers fed the diet containing IPM1 maize. In the D0-D42 period, the IPM2 and IPM3 treatments resulted in broilers with higher ADG (60.8 and 61.4 g/d, respectively) than CTR (59.4 g/d) and IPM1 (58.7 g/d) treatments (P<0.05).

No treatment effect was observed on FI in all the considered periods whereas there was a treatment effect on the feed:gain ratio in the D0-D42 period (P<0.019). In particular, conventional maize recorded a higher feed:gain ratio (1.74) than IPM2 (1.7) and IPM3 (1.69) maize (P<0.05). Furthermore, IPM1 treatment reported a higher feed:gain ratio (1.73; P<0.05) than IPM3 (1.69) treatment. IPM2 and IPM3 diets resulted in better feed:gain ratios at the end of the trial than that reported by the Hubbard S.A.S guidelines (1.72) for broilers of the same type and age (Hubbard, 2007).

Diet/treatment effects were also found on EPEF in the D0-D18 (P<0.044), D19-D36 (P=0.054) and D0-D42 (P=0.040) periods. In the D0-D18 period, a higher EPEF was obtained from the IPM3 (298.2) diet (P<0.05 versus CTR= 275.6, IPM1= 273.8 and IPM2= 267.8); in the D19-D36 period, the IPM2 (475.7) and IPM3 (463.2) diets had higher EPEFs than the CTR (440.1) and IPM1 (273.8) diets (P<0.05). Considering the whole trial period, (D0-D42), a higher EPEF was obtained with the IPM3 (353.2) diet (P<0.05) compared with the CTR (332.8) diet.

In our study, differences (P<0.05) in animal growth performance were found among broilers receiving control and IPM diets. In general, the inclusion of high-protein maize resulted in a higher final (D42) weight in broilers and the IPM3 diet (353.2) resulted in higher ADG throughout the experimental period (D0-D42). These results seem to be due to a higher feed efficiency of the diets containing high-protein maize rather than a higher feed intake by broilers. In fact, broilers fed CTR and IPM diets had similar feed intakes whereas better feed:gain ratios were found in broilers fed diets formulated with high-protein maize. Nevertheless, these observations were true for the IPM2 and IPM3 diets whereas results from the IPM1 diet were similar to the CTR diet for final weight and ADG, and to the CTR and IPM2 diets for feed:gain ratio. On the other hand, IPM2 and IPM3 were the maize grains with the highest protein and essential and non-essential amino acid contents, whereas IPM1 had intermediate levels of proteins and both essential and non-essential amino acids between those of conventional maize and those of the other two high-protein maize grains. Moreover, the IPM3 diet reported a better European Production Efficiency, measured by EPEF, compared with the diet containing conventional maize. These data show that the inclusion of high-protein maize varieties in broiler diets can result in animals that performed better, suggesting a higher nutritional value of these maize varieties in comparison.

Table 2. Ingredients and chemical composition (as-fed basis) of starter (D0-D18), grower (D19-D36) and finisher (D37-D42) diets containing commercial hybrids of high-protein maize (IPM1, IPM2 and IPM3) and conventional maize (CTR).

| Ingredients, % | CTR | IPM1 | IPM2 | IPM3 | CTR | IPM1 | IPM2 | IPM3 |
|---------------|-----|------|------|------|-----|------|------|------|
| Maize meal | 51.40 | 51.10 | 51.61 | 52.32 | 59.90 | 59.48 | 60.47 | 61.50 |
| Soybean oil, 44% | 41.36 | 41.63 | 40.00 | 39.30 | 33.87 | 34.38 | 32.00 | 31.30 |
| L-Lysine HCl | 3.00 | 3.00 | 4.10 | 3.60 | 2.40 | 2.30 | 3.60 | 3.20 |
| DL-Methionine | 0.12 | 0.16 | 0.18 | 0.22 | 0.11 | 0.13 | 0.20 | 0.24 |
| Threonine L | 0.02 | 0.03 | 0.03 | 0.03 | - | - | - | - |
| Limestone | 0.25 | 0.25 | 0.25 | 0.30 | 0.25 | 0.27 | 0.30 | 0.30 |
| Dicalcium phosphat | 2.50 | 2.50 | 2.50 | 2.50 | 2.25 | 2.25 | 2.25 | 2.25 |
| Sodium chloride | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| Sodium bicarbonate | 0.27 | 0.27 | 0.27 | 0.27 | 0.25 | 0.25 | 0.25 | 0.25 |
| Premix<sup>+</sup> | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 |
| Dry matter, % | 88.53 | 88.10 | 88.02 | 88.05 | 87.12 | 87.77 | 87.47 | 87.53 |
| Crude protein, % | 21.91 | 22.50 | 22.49 | 21.90 | 20.20 | 20.33 | 20.71 | 20.33 |
| Ether extract, % | 5.50 | 6.15 | 6.44 | 6.39 | 5.42 | 5.87 | 6.13 | 5.97 |
| Ash, % | 5.70 | 5.83 | 5.84 | 5.85 | 5.35 | 5.38 | 5.08 | 5.25 |
| Starch, % | 34.24 | 33.70 | 33.70 | 33.15 | 40.22 | 39.67 | 39.04 | 40.22 |
| Lys, % | 1.52 | 1.53 | 1.50 | 1.51 | 1.31 | 1.30 | 1.30 | 1.31 |
| Met, % | 0.71 | 0.71 | 0.71 | 0.70 | 0.55 | 0.55 | 0.54 | 0.56 |
| Thr, % | 0.87 | 0.89 | 0.90 | 0.91 | 0.76 | 0.78 | 0.78 | 0.76 |
| Trp, % | 0.27 | 0.27 | 0.27 | 0.26 | 0.24 | 0.24 | 0.23 | 0.22 |
| Metabolizable energy, MJ/kg | 11.66 | 11.87 | 11.89 | 11.78 | 12.25 | 12.36 | 12.34 | 12.39 |

<sup>+</sup>Vitamin and mineral premix (Istituto delle Vitamine S.P.A., Segrate, Milano, Italy) provided the following per kilogram of diet: vit. A, 12,500 U; vit. D3, 3000 U; vit. E, 75 U; vit. K, 6 mg; thiamine, 2 mg; riboflavin, 8 mg; pantothenic acid, 12.5 mg; pyridoxine, 6 mg; biotin, 0.15 mg; folic acid, 1.25 mg; ascorbic acid, 100 mg; niacin, 40 mg; vit. B12, 0.03 mg; Cu, 5 mg; Fe, 50 mg; Mn, 150 mg; Se, 0.2 mg; Zn, 75 mg; I, 1 mg; Co, 0.2 mg; calculated according to the equation reported by the European Commission (2009).
with normal maize. Also, previous studies reported better growth parameters in animals (chicken and pigs) fed improved maize varieties (higher essential amino acids and/or protein contents) than their counterparts fed normal maize (Asche et al., 1985; Sullivan et al., 1989). In their studies on the nutritional value of improved varieties of corn, Douglas et al. (2000) and Zhai and Zhang (2007) reported better availability for certain amino acids in corn with improved protein and essential amino acid contents than those found for the same amino acids in normal maize; but no significant difference was seen for other amino acids. These authors concluded that higher concentrations of some amino acids combined with equal or greater availability indicate that improved maize might contain higher concentrations of digestible amino acids and was, therefore, of higher nutritional value than conventional maize. Therefore, the better growth parameters found in the broilers receiving the IPM2 and IPM3 diets might be due to a greater amino acid availability in these dietary treatments. Moreover, in our study, less soybean meal was needed to supplement the diets based on IPM2 and IPM3 because of their higher protein levels. The lower amounts of soybean meal and the higher feed conversions associated with IPM2 and IPM3 suggest the possibility of reducing the feed costs related to gain by the use of high-protein maize varieties in animal feeding.

### Nitrogen retention and apparent digestibility coefficients

The nitrogen retention and apparent digestibility coefficients of the dry matter and ether extract of the diets containing grain from commercial hybrids of high-protein maize and conventional maize offered to broilers during the grower phase (D19-D36) are shown in Table 4. A diet/treatment effect (P=0.043) was observed on nitrogen retention. The IPM2 (54.02%) and IPM3 (53.51%) diets resulted in higher percentages of nitrogen retention than the CTR (44.2%) and IPM1 (41.87%) diets (P<0.05). The IPM3 diet reported a higher apparent digestibility coefficient for ether extract (63.18%) versus all the other diets (CTR= 55.45%; IPM1= 53.47%; IPM2 = 50.24%; P<0.05).

The results show that nitrogen in the diets containing IPM2 and IPM3 was better retained by the rats than in the diets containing IPM1 and conventional maize. In their study on the digestibility and nutritional performance of high-oil and high-protein corn varieties (similar to those tested in our study) in pigs, Song et al. (2003) also found that the nitrogen in high-oil and high-protein corn varieties was better retained than in normal corn. Nevertheless, in our study the diets offered to the rats were iso-energetic and iso-nitrogenous. Therefore, the higher percentages of nitrogen retention obtained by the IPM2 and IPM3 diets might be due to a greater amino acid availability in conformation of the better growth parameters obtained in the broilers fed the same diets (Douglas et al., 2000; Zhai and Zhang, 2007).

### Conclusions

The inclusion of high-protein maize in broiler diets resulted in animals showing better growth performance than the animals fed diets based on conventional maize. In particular, the broilers receiving diets containing high-pro-

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**Table 3.** Comparison of growth performance of broilers fed diets containing grain from commercial hybrids of high-protein maize (IPM1, IPM2 and IPM3) and conventional maize.

| Growth performance | CTR° | IPM1° | IPM2° | IPM3° | Treatment effect | SE |
|--------------------|------|-------|-------|-------|-----------------|----|
| Average weight, g   |      |       |       |       |                 |    |
| Initial, D0         | 45.1 | 45.1  | 45.3  | 45.2  | 0.626           | 0.15|
| After 18 days, D18  | 680  | 671   | 676   | 710   | 0.179           | 12.9|
| After 36 days, D36  | 2095<sup>a</sup> | 2051<sup>b</sup> | 2148<sup>ab</sup> | 2163<sup>a</sup> | 0.010 | 23.1|
| Final, D42         | 2550<sup>b</sup> | 2512<sup>b</sup> | 2622<sup>b</sup> | 2632<sup>b</sup> | 0.001 | 20.4|
| Average daily gain, g/d |      |       |       |       |                 |    |
| D0-D18             | 35.2<sup>a</sup> | 34.8<sup>a</sup> | 34.9<sup>a</sup> | 37.2<sup>a</sup> | 0.046 | 0.64|
| D19-D36            | 78.4<sup>a</sup> | 76.7<sup>a</sup> | 81.7<sup>a</sup> | 80.4<sup>b</sup> | 0.019 | 1.97|
| D37-D42            | 75.9  | 76.8  | 78.3  | 78.1  | 0.886           | 2.46|
| D0-D42             | 59.4<sup>a</sup> | 58.7<sup>a</sup> | 60.8<sup>a</sup> | 61.4<sup>a</sup> | 0.001 | 0.44|
| Feed intake, g/d   |      |       |       |       |                 |    |
| D0-D18             | 45.2  | 44.2  | 44.7  | 46.1  | 0.085           | 0.52|
| D19-D36            | 137.3 | 133.5 | 137.9 | 137.3 | 0.116           | 1.35|
| D37-D42            | 179.6 | 177.8 | 182.5 | 181.2 | 0.552           | 2.37|
| D0-D42             | 103.5 | 101.6 | 103.5 | 104.0 | 0.227           | 0.87|
| Adjusted feed:gain ratio (feed efficiency)<sup>7</sup> |      |       |       |       |                 |    |
| D0-D18             | 1.28  | 1.27  | 1.28  | 1.24  | 0.196           | 0.016|
| D19-D36            | 1.75  | 1.74  | 1.69  | 1.71  | 0.111           | 0.019|
| D37-D42            | 2.39  | 2.32  | 2.33  | 2.33  | 0.811           | 0.081|
| D0-D42             | 1.74<sup>a</sup> | 1.73<sup>a</sup> | 1.70<sup>a</sup> | 1.69<sup>a</sup> | 0.019 | 0.011|
| European production efficiency factor (EPEF) |      |       |       |       |                 |    |
| D0-D18             | 275.6<sup>a</sup> | 273.8<sup>a</sup> | 267.8<sup>a</sup> | 298.2<sup>b</sup> | 0.044 | 7.42|
| D19-D36            | 440.1<sup>a</sup> | 440.7<sup>a</sup> | 475.7<sup>a</sup> | 463.2<sup>b</sup> | 0.054 | 10.09|
| D37-D42            | 322.1<sup>a</sup> | 331.8<sup>a</sup> | 333.2<sup>a</sup> | 337.2<sup>a</sup> | 0.961 | 20.54|
| D0-D42             | 323.2<sup>a</sup> | 339.8<sup>a</sup> | 342.8<sup>a</sup> | 353.2<sup>a</sup> | 0.040 | 4.65|

<sup>°CTR, IPM1, IPM2 and IPM3 treatment growth performance means represent 6 pens per treatment group with 20 birds per pen; ‘<sup>7</sup>different letters in the same row correspond to statistically significant difference (P<0.05).</sup>

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**Table 4.** Nitrogen retention and apparent digestibility coefficients of dry matter and ether extract of the diets containing grain from commercial hybrids of high-protein maize (IPM1, IPM2 and IPM3) and conventional maize (CTR) offered to broilers during the grower phase (D19-D36).

|                      | CTR  | IPM1 | IPM2 | IPM3 | Treatment effect | SE  |
|----------------------|------|------|------|------|-----------------|-----|
| Nitrogen retention, % | 44.2<sup>b</sup> | 41.8<sup>b</sup> | 54.02<sup>a</sup> | 53.51<sup>a</sup> | 0.043 | 3.407|
| Apparent digestibility coefficients |      |      |      |      |                 |     |
| Dry matter, %        | 80.35| 80.81| 79.76| 80.70 | 0.815           | 0.775|
| Ether extract, %     | 55.45<sup>a</sup> | 53.47<sup>a</sup> | 50.24<sup>b</sup> | 63.18<sup>a</sup> | 0.007 | 2.542|

<sup><sup><sup>8Different letters in the same row correspond to statistically significant difference (P<0.05).</sup></sup></sup>
tein maize had higher (IPM2 and IPM3) or similar (IPM1) average final weights and average daily gains than broilers receiving the diet containing conventional maize. Therefore, high-protein maize can profitably be included in broiler diets with the advantage of reducing the use of imported protein sources (such as soybean meal) because of its higher protein content. Consequently, this provides savings on the cost of feed and production, thus making animal products more affordable.

Moreover, the nitrogen of the diets containing high-protein maize was better (IPM2 and IPM3) retained by the rats than that of the diet containing conventional maize. This suggests a greater amino acid availability in the diets based on high-protein maize varieties.

References

AOAC, 2000. Official Methods of Analysis, 17th ed. Association of Official Analytical Chemists, Washington, DC, USA.
Asche, G.L., Lewis, A.J., Peo, E.R.Jr., Crenshaw, J.D., 1985. The nutritional value of normal and high lysine corns for weanling and growing-finishing swine when fed at four lysine levels. J. Anim. Sci. 60:1412-1428.
ASPA, Commissione Valutazione Alimenti, 1980. Valutazione nutrizionale degli alimenti di interesse zootecnico. Analisi chimica. Zoot. Nutr. Anim. 6:19-34.
Cowieson, A.J., 2005. Factors that affect the nutritional value of maize for broilers. Anim. Feed Sci. Tech. 119:293-305.
Douglas, M.W., Peter, C.M., Boling, S.D., Parsons, C.M., Baker, D.H., 2000. Nutritional evaluation of low phytate and high protein corns. Poultry Sci. 79:1586-1591.
Dudley, J.W., Lambert, R.J., Alexander, D.E., 1974. Seventy generations of selection for oil and protein concentration in the maize kernel. In: J.W. Dudley (ed.) Seventy Generations of Selection for oil and Protein Maize. Crop Sci. Soc. Am. Publ., Madison, WI, USA, pp 181-212.
Eggum, B.O., 1968. A description of the method used at the National Institute of Animal Science. Acta Agric. Scand. 18:127-131.
European Commission, 2009. Commission Regulation of 27 January 2009 laying down the methods of sampling and analysis for the official control of feed, 152/2009/EC. In: Official Journal, L 54, 26/02/2009, pp 1-130.
Federation of Animal Science Societies, 1999. Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching, 1st ed. Federation of Animal Science Societies Ed., Champaign, IL, USA.
Fuller, M.F., Darcy-Vrillon, B., Laplace, J.P., Picard, M., Cadenhead, A., Jung, J., Brown, D., Franklin, M.F., 1994. The measurement of dietary amino acid digestibility in pigs, rats and chickens: a comparison of methodologies. Anim. Feed Sci. Tech. 48: 305-324.
Harrelson, F.W., Erickson, G.E., Klopfenstein, T.J., Jackson, D.S., Fithian, W.A., 2008. Influence of corn hybrid, kernel traits and growing location on digestibility. Nebraska Beef Cattle Report. Available from: http://beef.unl.edu/beefreports/200820.shtml
Hubbard SAS, 2007. Guidelines. Hubbard SAS, Quentin, France.
Hubbard SAS, 2011. Guidelines. Hubbard SAS, Quentin, France.
Idikut, L., Atalay, A.I., Kara, S.N., Kamalak, A., 2009. Effect of hybrid on starch, protein and yields of maize grain. J. Anim. Vet. Adv. 8:1945-1947.
Lambert, R.J., 1994. High-oil maize hybrids. In: A.R. Hallauer (ed.) Speciality maize. CRC Press, Inc., Boca Raton, FL, USA, pp 123-145.
Lucas, D.M., Taylor, M.L., Hartnell, G.F., Nemeth, M.A., Glenn, K.C., Davis, S.W., 2007. Broiler performance and carcass characteristics when fed diets containing Lysine maize (LY038 or LY038 x MON 810), control, or conventional reference maize. Poultry Sci. 86:2152-2161.
Martillotti, F., Antongiovanni, M., Rizzi, L., Santi, E., Bittante, G., 1987. Metodi di analisi per la valutazione degli alimenti di interesse zootecnico. CNR-IPRA Ed., Roma, Italy.
Moore, S., 1963. On the determination of cystine as cystic acid. J. Biol. Chem. 238:235-238.
Moore, S., Spackman, D. H., Stein, W.H., 1980. Official methods of Analysis. 13th ed., AOAC, Arlington, VA, USA.
Onimisi, PA, Omage, J.J., Daowang, L., Bawa, G.S., 2009. Replacement value of normal maize with Quality Protein Maize (Obatampa) in broiler diets. Pak. J. Nutr. 8:112-115.
Prasanna, B.M., Vasal, S.K., Kassahun, B., Singh, N.N., 2001. Quality protein maize. Curr. Sci. 81:1308-1319.
SAS, 2003. Guide for Personal Computers, ver. 9.13. SAS Inst. Inc., Cary, NC, USA.
Shewry, P.R., 2007. Improving the protein content and composition of cereal grain. J. Cereal Sci. 46:239-250.
Sofi, P.A., Wani, A.S., Rather, A.G., Wani, S.H., 2009. Review article: Quality protein maize (QPM): Genetic manipulation for the nutritional fortification of maize. J. Plant Breeding Crop Sci. 1:244-253.
Song, G.L., Li, D.F., Piao, X.S., Chi, F., Yang, W.J., 2003. Apparent digestibility of amino acids and the digestible and metabolizable energy content of high-oil corn varieties and its effects on growth performance of pigs. Arch. Anim. Nutr. 57:297-306.
Sullivan, J.S., Knabe, D.A., Bokholt, A.J., Gregg, E.J., 1989. Nutritional value of quality protein maize and food corn for starter and growing pigs. J. Anim. Sci. 67:1286-1292.
Zhai, S.W., Zhang, M.L., 2007. Comparison of true metabolisable energy and true amino acid availability between normal maize and quality protein maize (Shandan 17). Ital. J. Anim. Sci. 6:289-294.
