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Effect of Maize Hybrid in Complete Feed on the Production Performance and Economic Considerations in Laying Hens

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Abstract: The nutritional value of maize grain can be influenced by its genetic background, which can lead to differences that could affect laying hens due to the high proportion of maize hybrids in the complete feed. This study aimed to investigate the effects of modern maize hybrids on hen production and egg quality. Dietary treatments differed only in a grain of 15 high-yielding maize hybrids, added at a fixed proportion of 600 g kg^{-1} and without additional pigments. By 3 in each cage, 225 Lohmann Brown hens were allocated to 15 dietary treatments in a completely randomized block design (15 treatments $\times$ 5 cages). The experiment lasted 10 weeks, during which the number and weight of eggs were recorded daily, and diet intake was recorded weekly. Eggs for quality analysis were collected once per week during the last five weeks of the experiment. Dietary treatments differed (p < 0.05) in complete feed intake (119.7–123.1 g), egg weight (58.02–61.51 g), daily egg mass (56.17–60.16 g), and feed conversion ratio (2.01–2.19). As expected, dietary treatments did not affect egg traits such as shape index, albumen height, Haugh units, shell strength, thickness, and weight, but differed (p < 0.05) in yolk color (6.28–8.76) and yolk (14.74–16.03 g) and albumen (34.39–39.29 g) weights. The findings suggest that using different maize hybrids in complete feeds used in egg production systems may lead to small but significant differences in some hen production and egg quality traits, which in turn affect farmers' income.

Keywords: laying hen; maize hybrid; production performance; feed conversion ratio; economic calculations

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1. Introduction

Animal nutrition affects the health, welfare, and production of animals, as well as the quality and safety of the product, but also the sustainability of the animal production system [1]. Numerous factors affect the total cost of animal production, but feed costs are the most important component, accounting for up to 70% of total production [2]. Any increase in feed costs leads to a decrease in farmers' income and forces them to optimize feed use in order to maintain the profitability of the production system. The changes in feed prices over the last decade, and especially the increase in recent years due to adverse weather conditions and political situations in some regions, have led farmers to reevaluate their feed use and look for solutions to improve their overall income. These solutions consist of techniques like modifying feed specifications for optimal net gain, feeding as closely as feasible to set standards or requirements, incorporating alternative (or even multifunctional) ingredients, or increasing the diet's digestibility [3]. Regardless of the solution adopted, the feeding strategy today must aim to balance animal performance with environmental protection, animal welfare, and economic profit.

Climate change and the growing human population pose a challenge to any animal production system, and it is in this context that the concept of a sustainable animal diet is defined. According to Makkar [4], in addition to the currently accepted nutritional criteria for providing economically viable and safe animal products through the production of safe feeds, the concept also includes the importance of efficient use of natural resources, environmental protection, sociocultural benefits, and ethical integrity and sensitivity. In addition, he stated that the efficient use of feed resources and the application of appropriate feeding strategies are crucial to meeting the requirements of all four dimensions of the concept of sustainable animal diets.

The profitability of an animal production system depends on the performance of the animals in relation to the feed input. In this context, feed efficiency is one of the most important factors, as its increase helps to balance animal performance with environmental protection, animal welfare, and economic profit [2]. Even small changes in feed efficiency can have a significant impact on the economic benefits of the animal production system. Different processing technologies for feeds and complete feeds as well as supplementation with different additives could be applied to achieve higher digestibility and therefore higher feed efficiency [5–7]. However, even small changes in complete feed ingredients, such as the feed genotype, could also be a potential factor in improving feed efficiency [8].

Egg production is an important animal production system because eggs are an important food worldwide [9]. Modern laying hen hybrids used on farms nowadays have high egg production, and complete feeds must provide the required nutrients for optimal egg production, health, and welfare. Laying hens have a preference for certain nutrients in the diet, such as protein, fiber, and calcium, and they are able to balance their diet by selecting nutrients and increasing consumption of feed particles rich in the deficient nutrient [10]. Furthermore, laying hens prefer coarser particle sizes in complete feeds and cereals are the main energy feed in their diet [11]. In addition, laying hens have the ability to deposit nutrients in the yolk, and supplementing their diet with nutrients has a positive effect on the nutritional value of eggs [12–15].

Maize grain is a multifunctional feed that provides energy, slowly digestible and resistant starch, and carotenoids that act as provitamin A vitamins, antioxidants, and pigments [16–18]. However, differences between maize genotypes may result in variable chemical composition [19]. Commercially available hybrids differ in their chemical and physical properties. According to the feed tables of Sauvant et al. [20], the crude protein of 2634 maize samples varied between 74 and 88 g kg^{-1}, while starch content varied between 622 and 660 g kg^{-1}. Moreover, grain hardness, expressed as a flotation test value, ranged from 1391 to 3505 in 36 commercial hybrids tested by Kljak et al. [21], while test weight varied from 74.1 to 82.3 kg hL^{-1}. These differences could affect properties directly related to nutrient utilization, such as starch digestibility kinetics [22], and consequently affect animal production performance. Although Moore et al. [23,24] concluded that the differences between six maize hybrids used in complete feed preparation were not large enough to affect the production performance of broilers, layers, and pigs, a recent study by Melo-Durán et al. [8] showed that maize genotype affects nutrient digestibility and growth performance of broilers and that this effect was related to the content and the nature of non-starch polysaccharides. In all these studies, the proportion of grain in the complete feeds was the same and they differed only in the maize hybrid. It should be noted, however, that studies evaluating the effects of maize hybrids on hen production performance are lacking because differences among commercial maize hybrids were not thought large enough to result in significant differences in hen production performance. Recent studies have focused on quality protein maize and transgenic maize, but the production performance of laying hens was mostly similar to the control with commercial maize hybrids [25–27].

Although further studies should be conducted to investigate the reasons why maize hybrids might affect animal production performance, the possibility that only a change in hybrids used in the preparation of complete feeds could positively affect feed utilization and animal performance could increase the profitability of the animal production system. Therefore, the aim of the present study was to investigate the effects of modern commercially available maize hybrids on the production performance of laying hens and to determine what economic impact they could have on the egg production system.

2. Materials and Methods

The animal experiment was conducted in accordance with the Croatian directives (Animal Protection Act, OG 102/17 and 32/19, and Regulation on the Protection of Animals Used for Scientific Purposes, OG 55/13, 39/17 and 116/19), which correspond to the European guidelines for the care and use of animals used for scientific purposes. The animal procedures used in this study were approved by the Ethics Committee for the protection of animals used in scientific research within the Ministry of Agriculture of the Republic of Croatia (EP 349/2022).

2.1. Maize Hybrids and Treatment Diets

Fifteen high-yielding yellow maize hybrids (*Zea mays* L.) belonging to various maturity groups (Table 1) were selected for this study based on grain physical and chemical properties. In the preliminary study, 103 commercial maize hybrids were screened for numerous properties and selected for this study to ensure variability in endosperm microstructure and thus nutrient utilization [22,28].

Table 1. Tested modern maize hybrids belonging to various maturity groups.

Hybrid	Abbreviation	Type	FAO Maturity Group
Hybrid 1	H1	Semi-flint	330
Hybrid 2	H2	Dent	350
Hybrid 3	H3	Dent	350
Hybrid 4	H4	Dent	390
Hybrid 5	H5	Hard dent	380
Hybrid 6	H6	Dent	400
Hybrid 7	H7	Dent	410
Hybrid 8	H8	Dent	450
Hybrid 9	H9	Dent	450
Hybrid 10	H10	Quality dent	460
Hybrid 11	H11	Quality dent	500
Hybrid 12	H12	Quality dent	510
Hybrid 13	H13	Quality dent	510
Hybrid 14	H14	Dent	570
Hybrid 15	H15	Dent	580

Maize hybrids were produced in the growing season of 2021 on the experimental field in central Croatia near Zagreb (45°51′00″ N, 16°10′01″ E). The soil texture was silty clay with 59.6% silt, 39.3% clay, and 1.1% sand, 4.2% organic matter with pH of 7.7. Each hybrid was planted in a 6 m wide (8 rows) and 50 m long plot, following the recommendations of their seed companies for optimum planting density. All hybrids were grown under the same environmental conditions using an intensive production system [29]. The daily average minimum and maximum temperatures (°C) and precipitation (mm/day) for the vegetation season were the following: 2.66, 13.87, and 1.2 for April; 8.20, 20.15, and 2.70 for May; 13.25, 28.25, and 3.55 for June; 15.73, 29.51, and 0.85 for July; 13.49, 27.72, and 2.95 for August; 9.40, 23.94, and 2.20 for September; and 4.71, 14.15, and 2.35 for October, respectively [30]. After physiological maturity, ears were hand-harvested from five places of the central six rows representing five replicates. The remaining six inner rows were combine-harvested for the production of complete feeds. The harvested ears and grains were dried at 40 °C to approximately 120 g kg^{-1} moisture and stored in bags until preparation of the experimental complete feeds.

The complete feeds were formulated to contain the same ingredients and differed only in the maize hybrid. All complete feeds were formulated according to recommendations of the National Research Council [31] and adapted to Lohmann Brown laying hens according to the management guide [32] for nutrient supply to laying hens in the initial phase of egg production (19 to approximately 50 weeks of age; Table 2) with table values for the chemical composition of maize grain and soybean meal containing 45% of crude protein. To reduce compositional differences, the basal mixture contained all the ingredients for laying hen complete feeds from the same batch, except for the maize grains. Immediately prior to the preparation of the complete feeds, the maize grain was ground through a 6 mm sieve and mixed with the basal mixture to the same percentage (60%). No additional pigment was added. All diets were mixed immediately before the start of the dietary experiment and packed in feed bags with a capacity of 10 kg. A total of 200 kg of each complete feed was prepared. A composite sample of each complete feed was prepared and the chemical composition determined using standardized methods (Table 3).

Table 2. Composition of complete feeds.

Ingredient	**Content (g kg^{-1})**
Maize	600
Soybean meal	262
Sunflower oil	30
Calcium carbonate	88
Monocalcium phosphate	12
Sodium chloride	4
DL methionine	1.5
Vitamin premix [1]	1.2
TRT Poultry Pack [2]	1.3
Calculated composition	
Apparent metabolic energy/MJ kg^{-1}	11.51
Crude protein/%	16.91
Crude fat/%	5.55
Crude fiber/%	2.81
Starch/%	40.65
Lysine/%	0.88
Methionine/%	0.42
Ca/%	3.8
p total/%	0.6
p available/%	0.43
Linolenic acid/%	3.16

[1] The vitamin premix provided per kg of diet: vitamin A 10,000 IU, vitamin D3 2500 IU, vitamin E 200 mg, vitamin K3 3 mg, vitamin B1 1 mg, vitamin B2 45 mg, vitamin B3 30 mg, vitamin B5 10 mg, vitamin B6 3 mg, vitamin B7 50 mg, vitamin B9 0.5 mg, vitamin B12 25 mg, choline 400 mg, antioxidant (BHA, EQ) 50 mg. [2] TRT Poultry Pack (Alltech Ireland Ltd., Dunboyne, Ireland) provided per kg of diet: I 1 mg, Fe 5 mg, Cu 5 mg, Mn 30 mg, Zn 30 mg, Se 0.2 mg.

Table 3. Chemical composition of experimental complete differing in maize hybrid.

Hybrid	**Moisture**	**Ash**	**Ca**	**Crude Protein**	**Crude Fat**	**Starch**	**NDF [1]**
				g kg^{-1}			
H1	87	129	155.8	39.6	58	403	87.4
H2	88	119	161.1	37.6	54	411	92.2
H3	84	127	161.3	40.0	51	417	82.2
H4	85	126	159.8	39.3	57	421	78.3
H5	83	117	156.1	35.7	53	425	79.6
H6	79	127	158.3	40.3	54	436	74.6
H7	86	122	158.0	38.3	57	439	84.3
H8	89	120	163.2	38.5	57	405	76.9
H9	92	123	152.8	38.7	56	411	75.5
H10	93	121	156.3	39.0	51	429	90.3

Table 3. *Cont.*

Hybrid	Moisture	Ash	Ca	Crude Protein	Crude Fat	Starch	NDF [1]
				g kg^{-1}			
H11	94	122	159.0	37.5	57	407	75.2
H12	92	118	165.0	37.0	53	430	88.1
H13	87	119	163.0	37.3	59	431	78.5
H14	88	116	164.5	39.1	57	439	87.1
H15	86	118	166.4	38.5	57	431	88.3

[1] NDF—neutral detergent fiber.

2.2. Hens, Housing, and Experimental Design

A total of 225 Lohmann Brown laying hens (18 weeks old) were randomly assigned in groups of 3 to 1 of 75 metal battery cages designed for the experiments (1269 cm^2 for each hen in each cage). Diets and water were provided ad libitum to the hens. The room temperature was 20 ± 3 °C and the light period consisted of 16 h of light per day throughout the experimental period.

After allocating hens to the cages, a 4-week period for adaptation to experimental conditions and the beginning of egg production peak began. All hens were fed a diet based on barley instead of maize grain and with the same calculated nutrient composition as the experimental diets (Table 2). After adaptation, cages were randomly assigned to 1 of 15 dietary treatments (15 diets differing in maize hybrid; 5 replicates per dietary treatment). The experimental period lasted ten weeks. Hens were weighed at the beginning and at the end of the experimental period. Throughout the experimental period, the number of eggs laid was recorded daily, while complete feed intake was recorded weekly [33]. Egg production was calculated as the total number of eggs per cage divided by the number of hens per cage. Daily egg mass was calculated by multiplying egg weight and egg production [15]. Feed conversion ratio (FCR) was calculated by dividing the amount of complete feed consumed per day by the egg mass produced daily [7]. Assuming that the first three weeks were used for adaptation to the diet, the fourth week of the experimental period was considered as the sampling period and the values recorded during this period were used for statistical analysis. In addition, during the last five weeks of the experimental period, all eggs were collected once a week for analysis.

2.3. Analyses of Maize Grain

Grain samples were ground in a laboratory mill (Cyclotec 1093, Foss Tocator, Hoganas, Sweden) with a 1 mm sieve immediately before analysis. All samples were analyzed for crude chemical composition using standard methods. Dry matter (DM) was determined according to the ISO 6496:1999 method [34]. Briefly, 3 g of the sample was dried at 103 °C for 4 h. Ash was determined according to the ISO 5984:2002 method [35]. Briefly, 1 g of the sample was ashed at 550 °C for 4 h. Crude protein was determined according to the ISO 5983-2:2009 method [36]. The sample (1 g) was digested at 420 °C with the addition of concentrated sulfuric acid and a mixture of potassium sulfate and copper sulfate pentahydrate. The digested sample was distilled in an automatic Kjeltec 8200 system (Foss, Hilleroed, Denmark) with the addition of a 35% sodium hydroxide solution. The released ammonia was collected in a 4% boric acid solution and titrated with a 0.1 mol L^{-1} hydrochloric acid. The nitrogen content in the sample was calculated from the acid consumption. Crude protein content was calculated by multiplying the nitrogen content by a factor of 6.25. Crude fat was determined according to the ISO 6492:1999 method [37]. Briefly, 1 g of the sample was extracted with diethyl ether using the Soxtec 1040 automated system (Foss Tecator, Höganäs, Sweden). Starch was determined using a commercial test kit, Total Starch Assay (K-TSTA; Megazyme International, Wicklow, Ireland), according to the AOAC 996.11 method [38]. The sample (0.1 g) was incubated with 3 mL of thermostable α-amylase in acetate buffer (100 mM, pH 5.0) in a boiling water bath for 6 min. Then, 0.1 mL of amyl-glucosidase was added and the mixture was vortexed and incubated in the bath at 50 °C for 30 min. The entire contents were then quantitatively transferred to 100 mL volumetric flasks. An aliquot of the solution was centrifuged at 3000 rpm for 10 min (Centric 322 A, Tehtnica, Železniki, Slovenia) and an aliquot of 0.1 mL of the solution was incubated with 3 mL of GOPOD at 50 °C for 20 min. The absorbance of the solution was measured at 510 nm on a UV/vis spectrophotometer (Heliosγ, Thermo Electron Corporation, London, UK), and the amount of starch in the sample was calculated using the obtained absorbance values of the samples and the glucose standard included in the test kit.

2.4. Egg Quality Analysis

All collected eggs were analyzed for quality traits immediately after collection. Firstly, the weight and length of the eggs were determined with a caliper and used to calculate the shape index. Then, whole eggs were placed in the Digital Egg Tester (DET 6000, Nabel, Kyoto, Japan), and the strength of the shell was determined. After the eggshell was broken, the albumen and egg yolk were placed on the plate of the instrument, and the height of the albumen, the Haugh units and the color of the yolk were measured. After measurement, the yolk was separated from the albumen and the weight of each was recorded. Finally, the eggshell was rinsed and dried at room temperature for 24 h, weighed, and the thickness of the shell was determined using the same Digital Egg Tester.

2.5. Economic Calculations

Calculations of complete feed costs were based on costs identified in the present study. Additional costs that were not made (pigments) were calculated based on the costs provided by the Croatian feed mills. The purchase value of eggs used was the value provided by the Croatian farmers. All calculations were based on a farm with 5000 laying hens, as farms with more than 5000 hens account for more than 70% of farms in the European Union [39]. In addition, the dietary costs of egg production were calculated based on egg production, daily intake, and the cost of complete feed identified in the present study. This cost was considered 70% of the total cost of egg production and was used to calculate the total cost of egg production.

2.6. Statistical Analysis

The obtained results were analyzed using SAS statistical software (version 9.4; SAS Institute Inc., Cary, NC, USA). The dietary experiment was conducted in a randomized complete block design with 15 dietary treatments with 5 replicates, defining a cage with three hens (replicate) as the experimental unit. Differences between the treatment diets were subjected to repeated measurement analysis using the MIXED procedure, with maize hybrid as fixed effects. Differences between hybrids in chemical composition were determined using analysis of variance with hybrid as a fixed effect using the MIXED procedure. Mean values were defined using the least squares means statement and compared using the PDIFF option; letter groups were determined using the PDMIX macro procedure. The threshold for statistical significance was defined as $p < 0.05$.

3. Results and Discussion

3.1. Maize Hybrids

In the present study, complete diets of the experimental treatments were formulated according to the values in the standard feeding tables, so that each diet contained 600 g kg^{-1} of maize grains. Possible differences in the chemical composition of the tested hybrids were not taken into account before the preparation of the complete feeds, as the intention of this study was to follow standard practices on farms. In addition, the tested maize hybrids were grown on the same test field to minimize the effects of agroclimatic conditions on their chemical composition, i.e., that the differences between the tested hybrids could be attributed to genotype. Genotype is the most important factor determining the chemical and physical properties of maize grain [19], but management and environmental conditions during the growing season can also influence these properties [40,41]. The maize hybrids were analyzed for moisture, ash, crude fat, and starch content (Table 4) and differed in the contents of all these nutrients. The greatest difference among the hybrids tested was in the crude fat content; the hybrid with the highest content (H7) had a content approximately 40% higher than the hybrid with the lowest content (H3). Crude protein content ranged from 81.26 to 86.69 g kg^{-1} DM, while most hybrids had starch content below 700 g kg^{-1} DM (651.1–694.7). Six hybrids had starch content above this value, ranging from 712.6 to 749.0 g kg^{-1}. Tested hybrids had contents of all these nutrients that were within the range reported by Zurak et al. [28] for 103 commercial maize hybrids (ash from 9.62 to 16.43 g kg^{-1}, crude protein from 71.43 to 110.00 g kg^{-1}, crude fat from 22.76 to 51.83 g kg^{-1}, and starch from 612.23 to 793.93 g kg^{-1}). The content of these nutrients affects the nutritional value of maize since they represent potential nutrients that laying hens can utilize. Although maize has low protein content, it provides about 20% of the protein in poultry diets due to its high proportion in the diet [41].

Table 4. Chemical composition of grains from commercial maze hybrids used in this study [1].

Hybrid	Moisture	Ash	Crude Protein	Crude Fat	Starch
	g kg^{-1}	g kg^{-1} DM [2]			
H1	112.0 c	15.77 a	81.26 d	42.34 ab	667.4 cd
H2	110.2 cd	13.94 cdef	83.45 bcd	37.09 efg	678.3 cd
H3	105.2 ef	13.63 cdefg	81.85 cd	31.29 j	675.9 cd
H4	97.0 g	14.40 bc	81.77 cd	35.21 gh	671.4 cd
H5	100.6 fg	13.12 fg	81.41 d	32.46 ij	694.7 bc
H6	87.6 h	13.81 cdefg	81.80 cd	37.92 def	712.6 b
H7	101.0 fg	13.57 cdefg	85.21 ab	44.05 a	746.4 a
H8	110.0 cd	13.50 defg	82.42 cd	34.42 hi	654.1 d
H9	110.6 cd	13.04 g	82.15 cd	40.02 cd	665.8 cd
H10	130.0 a	14.94 ab	86.69 a	38.16 cdef	694.4 bc
H11	113.4 c	13.98 cde	86.68 a	40.37 bc	673.7 cd
H12	119.6 b	14.31 bcd	83.25 bcd	38.84 cde	723.1 ab
H13	120.6 b	14.10 cd	84.11 bc	37.76 def	749.0 a
H14	107.0 de	13.22 efg	81.38 d	37.18 efg	746.8 a
H15	103.6 ef	14.06 cd	82.62 cd	36.15 fgh	721.8 ab
p	<0.001	<0.001	<0.001	<0.001	<0.001
SE	1.65	0.30	0.91	0.82	10.33

a–j: Different letters indicate a statistically significant difference in the content of nutrients between maize hybrids at $p < 0.05$. [1] Each hybrid had five repetitions. [2] DM—dry matter.

When comparing the chemical composition of the tested hybrids with the values in the standard feed tables reported by Sauvant et al. [20], the values of the tested hybrids in the upper range of the contents of crude fat and starch were comparable to the values in the feed tables (37 and 641 g kg^{-1}, i.e., 42.8 and 741.9 g kg^{-1} DM, respectively). Crude protein content was lower than the average value in the feed tables (81 g kg^{-1}, i.e., 93.4 g kg^{-1} DM) for all hybrids tested. These differences were most likely the result of high yields and genotype variations since the hybrids in the present study were grown according to the manufacturer's recommendations for cultivation and agrotechnical measures. On the other hand, the values in the standard feed tables of the National Academies of Sciences, Engineering, and Medicine [42] are closer to the values of the hybrids used in the present study. More than 11,000 maize samples contained an average of 8.5, 3.84, and 70.4 g kg^{-1} DM of crude protein, crude fat, and starch, respectively.

3.2. Production Performance of Laying Hens

The laying hens used in the present study were at peak egg production during the sampling period, so no differences between dietary treatments in this performance trait were expected (Table 5). Hens fed all treatment diets had egg production greater than 94%. In addition, hen weights were similar for all treatments at both the beginning and end of the experimental period. At the beginning of the experimental period (at 22 weeks of age), the average weight of the hens was 1786 g, which corresponds to the performance target weight according to the management guide for Lohmann Brown hens (1760 g) [32]. At the end of the experimental period (32 weeks old), the average weight of the hens was 1824 g, which was 100 g below the performance target weight. Despite the lower body weight than expected, the similarity of the treatments suggests that the hens used the nutrients for egg production rather than weight gain.

Table 5. Production performance of laying hens fed dietary treatments differing in maize hybrid [1].

Hybrid	Daily Intake	Egg Production	Egg Weight	Egg Mass	FCR [2]	Hen Weight	
						At the Beginning	At the End
	g	%	g	g		g	g
H1	122.02 ab	94.11	59.87 abc	57.01 de	2.156 ab	1808	1785
H2	121.67 b	94.94	61.51 a	59.41 ab	2.069 abc	1802	1825
H3	123.15 a	95.30	59.40 bc	58.57 abcd	2.112 abc	1805	1804
H4	121.77 ab	95.99	60.52 ab	58.81 abcd	2.079 abc	1754	1782
H5	121.53 b	96.10	60.66 ab	58.74 abcd	2.098 abc	1823	1873
H6	121.74 ab	97.65	59.15 bc	58.07 bcde	2.119 abc	1748	1780
H7	121.62 b	96.97	60.25 ab	59.21 abc	2.059 bc	1807	1904
H8	119.72 c	96.09	60.00 ab	58.34 abcd	2.009 c	1735	1836
H9	121.96 ab	95.85	59.75 abc	57.90 bcde	2.105 abc	1766	1838
H10	121.55 b	94.30	59.38 bc	57.06 de	2.161 ab	1737	1770
H11	121.81 ab	97.23	61.44 a	60.16 a	2.056 bc	1801	1837
H12	121.09 bc	95.89	60.99 ab	59.56 ab	2.018 c	1792	1813
H13	122.42 ab	96.92	60.16 ab	57.31 cde	2.186 a	1818	1851
H14	121.69 ab	96.09	58.02 c	56.17 e	2.164 ab	1808	1836
H15	122.18 ab	95.88	61.25 a	59.43 ab	2.095 abc	1759	1768
p	0.035	0.408	0.024	0.014	0.045	0.230	0.389
SE	0.644	1.83	0.661	0.745	0.033	26.4	37.4

a–e: Different letters indicate a statistically significant difference in the content of nutrients between maize hybrids at $p < 0.05$. [1] Each dietary treatment was allocated to six cages (repetitions) and observations per cage were recorded weekly from the fourth week to the end of the experiment. [2] FCR—feed conversion ratio.

Dietary treatments differed in daily intake of complete feed, egg weight, egg mass, and FCR (Table 5), and since the complete feeds of dietary treatments differed in the maize hybrid, these differences can be attributed to the maize hybrid used in the complete feeds. However, it should be noted that most hybrids were similar in these production traits and significant differences were observed between dietary treatments resulting in the highest and lowest values. For example, the lowest daily intake was 119.72 g (H8), and hens fed this complete feed consumed 3.43 g less than hens fed dietary treatment H3. In addition, the lowest egg weight and egg mass were found in hens fed dietary treatment H14 (58.02 and 56.17 g), which were 3.49 g lower than the egg weight of dietary treatment H2 and 3.99 g lower than the egg mass of dietary treatment H11. The lower FCR implies a better utilization of the complete feed and, accordingly, dietary treatments H8 and H12 were the most efficient, although significant differences between these treatments were observed only for H1, H10, H13, and H14.

According to the performance goals [32], the daily complete feed intake in peak production of Lohmann Brown hens is 110–120 g per day. The values determined in the present study were only up to 3 g above this range. A possible reason for this discrepancy could be the slightly lower crude protein content of the complete feeds than calculated using the standard values of the feed table (Table 3). The hens are able to regulate protein intake depending on the crude protein content offered [43], so they compensated for the lower crude protein content by consuming more complete feed. However, the values for complete feed intake in the present study are similar to those reported by Pérez-Bonilla et al. [44] for Lohmann Brown hens with a body weight of 1860 g fed complete feeds based on a combination of maize, wheat, and barley with 185 g kg^{-1} of crude protein and added oil (36 or 18 g kg^{-1}) from 22 to 55 weeks of age. The authors compared different levels of crude protein in complete feeds (185, 175, and 165 g kg^{-1}) and found no effects on the hen production performance. In addition, Moore et al. [23] showed that change in maize hybrids in Hy-Line W-36 laying hens at 53 to 67 weeks of age can lead to differences in intake of complete feed, although the levels were lower, which is consistent with the results of the present study. The average egg weight for the sampling period was 60.08 g, which was within the range of egg weight targeted as a performance goal (from 58.59 at 26 to 62.0 g at 32 weeks of age) [32]. In contrast to the egg weight, the average egg mass during the sampling period for all dietary treatments (58.09 g) was closer to the value corresponding to the performance goal for 32-week-old hens (59.1 g). This observation was expected, as almost all hens were at peak production at the beginning of the experimental period. Compared to previous studies, the hens in the present study laid eggs up to 5 g lighter than those fed complete feeds based on cereals [11,44,45]. However, egg production was lower in the abovementioned studies, resulting in FCR values that were slightly lower or similar to the present study (1.98 to 2.09). Furthermore, the tested hybrids resulted in higher egg weight and egg mass compared to hens fed diets containing 472 g kg^{-1} of maize grain in a study by Lázaro et al. [6] (57.4 and 54.3 g) but resulted in higher FCR than hens fed diets containing 466.9 g kg^{-1} of maize grain and 88.5 g kg^{-1} of wheat, in mesh or crumble form, (1.82–1.96) in a study by Ege et al. [5].

3.3. Egg Quality

The tested dietary treatments affected some egg quality traits, namely yolk color and the weight of yolk and albumen (Table 6). The eggs were analyzed immediately after egg collection, and no effect on albumen height or Haugh units was expected. The values obtained in the present study were comparable to those obtained in previous studies: 7.7 mm for albumen weight and 85.65 for Haugh units in a study by Ege et al. [5], 80.8 for Haugh units in a study by Safaa et al. [11], and 70.07–74.96 for Haugh units in a study by Wu et al. [46]. Since the shell strength could be influenced by the calcium source and its content in the complete feed [47] and all dietary treatments contained the same calcium source in the same proportion, no effect of the dietary treatments was expected either. The range of values obtained in the present study is in the higher range of values reported in previous studies (3.83–5.31) [48,49]. Although previous studies have shown that changing the grain or its processing in the complete feed had no effect on egg quality traits [11,45], the differences between the maize hybrids in the present study appear to be large enough to affect some egg properties. The most prominent effect was on the yolk color.

Maize grains are the only cereal with a high content of carotenoids [50], and since no additional pigments were added to the complete feeds, the yolk color in the present study is the result of maize carotenoids. Maize hybrids differ significantly in carotenoid profile [51], resulting in a different carotenoid profile and color of yolk [52], which is consistent with the results of the present study. Although the maize hybrids in the present study did not achieve as high yolk color values as supplementation with synthetic pigment containing canthaxanthin in the study by Kljak et al. [14], the contribution of maize carotenoids to yolk color is not negligible. In the case of dietary treatments used in the present study, this could be used to reduce the amount of supplemental pigments and thus the cost of complete feeds. In addition, it is possible that the selection of maize hybrids for sustainable egg production also takes into account carotenoid content and profile, suggesting that maize hybrids could be the only source of carotenoids for desirable yolk color [52].

Weights of yolk and albumen are also influenced by nutrition [53–56], so differences among maize hybrids in chemical traits led to differences among dietary treatments in these egg traits. Differences in the contents of crude protein and crude fat, as shown in Table 4, and most likely in the content of linoleic acid [57], of the maize hybrids contributed to the variations in the weights of yolk and albumen. The effect of maize hybrids on these two egg traits is consistent with the effect found for egg weight (Table 5).

Table 6. Quality traits of eggs from laying hens fed dietary treatments differing in maize hybrid [1].

Hybrid	Shape Index	Albumen Height	Yolk Color	Haugh Units	Shell Strength	Shell Thickness	Shell Weight	Yolk Weight	Albumen Weight
	%	mm			kg cm^{-2}	mm	g	g	g
H1	79.55	7.81	7.36 cdef	87.75	5.05	0.401	7.69	14.74 c	38.87 ab
H2	78.14	7.72	7.84 bc	86.50	5.12	0.405	7.85	15.30 abc	39.29 a
H3	79.16	7.38	6.28 g	85.41	5.02	0.387	7.42	15.17 abc	36.79 abcd
H4	79.11	7.29	6.64 efg	84.73	5.03	0.381	7.54	15.22 abc	38.12 abc
H5	80.06	7.24	7.10 cdefg	82.80	5.36	0.392	7.57	16.03 a	37.75 abc
H6	78.89	7.78	6.69 efg	88.03	4.85	0.386	7.74	15.55 abc	35.95 cd
H7	81.40	7.11	7.51 cde	83.56	5.16	0.392	7.49	14.96 bc	37.12 abcd
H8	79.03	7.37	7.35 cdef	85.50	5.04	0.387	7.64	15.44 abc	36.53 abcd
H9	80.70	6.80	6.80 defg	80.07	5.41	0.391	7.44	15.62 abc	37.91 abc
H10	79.74	7.44	7.82 bc	85.49	4.94	0.378	7.47	15.36 abc	37.19 abcd
H11	80.15	7.18	8.48 ab	83.76	4.60	0.388	7.62	15.85 ab	37.29 abc
H12	79.34	7.15	8.76 a	82.86	5.38	0.396	7.73	15.30 abc	38.72 abc
H13	80.73	7.27	7.60 cd	84.67	5.30	0.403	7.67	15.66 abc	36.26 bcd
H14	80.30	6.93	6.59 fg	82.66	4.86	0.391	7.58	14.96 bc	34.39 d
H15	81.14	7.24	7.64 bcd	82.66	4.66	0.382	7.68	15.66 abc	38.12 abc
p	0.203	0.708	<0.001	0.691	0.11	0.334	0.978	0.038	0.036
SE	0.768	0.33	0.31	2.42	0.21	0.007	0.20	0.339	1.00

a–g: Different letters indicate a statistically significant difference in content of nutrients between maize hybrids at $p < 0.05$. [1] Each dietary treatment was allocated to six cages (repetitions) and samples were collected and analyzed weekly during the last five weeks of the experimental period.

3.4. Economic Considerations

As mentioned above, the observed differences in production performance between the different dietary treatments are a result of maize hybrids. It appears that a high proportion of maize grains in the complete feeds could lead to the effects of maize genotype on the production performance of laying hens. However, these differences appear to be small when evaluated on a small scale. On a large scale, i.e., on farms with more than 5000 hens, these differences could help to reduce the egg production costs without significantly changing the current production and by simply selecting the maize hybrid to produce the complete feed. Based on the results of this study, 5000 hens consume between 218.5 and 224.7 tons of complete feed over a year. Based on the costs used to produce complete feed in the present study, this difference in consumption results in a cost reduction of EUR 4300 if the hybrid with the lowest complete feed intake from the present study is to be used. This cost reduction is even higher when egg costs are considered. When considering the production cost of one egg, the difference is EUR 0.005 between the hybrid with the highest (EUR 0.128) and the one with the lowest (EUR 0.123) egg production cost (Figure 1). However, on a large scale, this difference could be EUR 6378 if only the cost of complete feed is considered.

On the other hand, the eggs of all tested dietary treatments were classified as M grade eggs (53 to 63 g), which means that the differences between treatments in egg weight do not necessarily contribute to overall income. However, in terms of total egg production, dietary treatments with the highest daily egg mass could result in 7.3 tons higher annual egg mass production on a farm with 5000 hens compared to the dietary treatment with the lowest daily egg mass. With further adjustments to the composition of the complete feed based on the chemical analysis of the main feeds, the weight of the eggs could be higher and classified as L eggs, which could contribute to the overall revenue of the egg production system due to the higher purchase price of L eggs compared to M eggs. If the energy intake in the complete feed is constant, higher egg weight could be achieved with higher protein content [58].

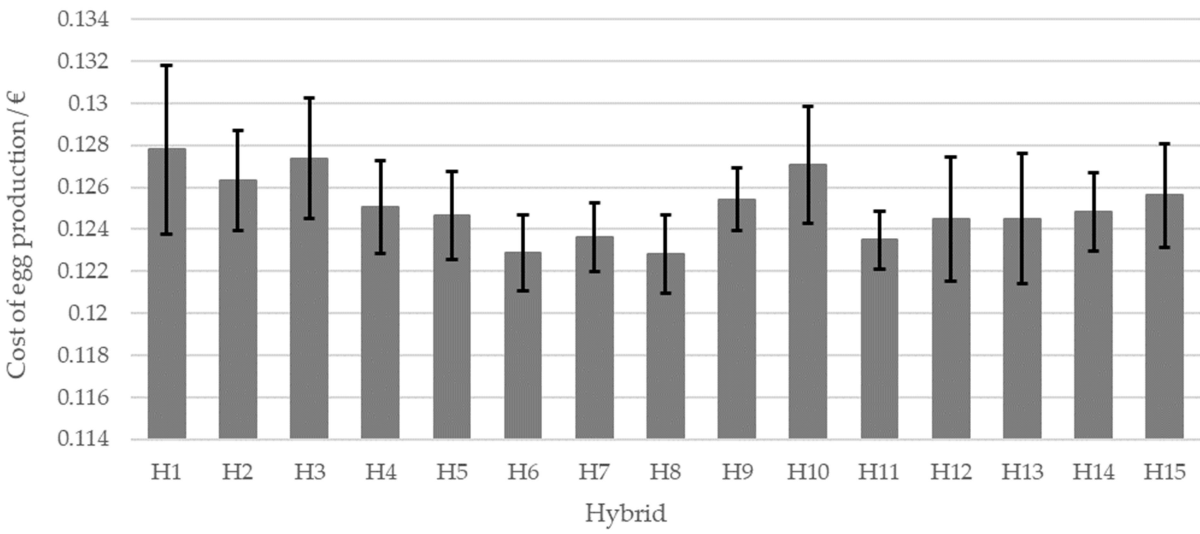

Figure 1. Calculated cost of egg production for eggs laid by laying hens fed dietary treatments differing in maize hybrid. Calculations are based on the complete feed costs identified in the present study and the assumption that feed costs represent 70% of the total cost of egg production.

Although the egg production system depends on numerous factors that could affect hen performance and the nutritional value of the complete feed, the present study was conducted to evaluate whether only a difference in maize hybrid in the complete feed would have an effect on the egg production system. Based on differences in hen performance and economic benefits, some of the hybrids used in this study were identified as more suitable for a more efficient egg production system. Based on complete feed consumption, H8 resulted in the lowest FCR and egg cost, indicating that this hybrid was most suitable for cost-effective egg production among the tested hybrids. Hybrids H6 and H7 achieved similar egg costs, regardless of the higher FCR. On the other hand, H11 had the highest egg weight and egg mass, and the resulting egg cost was similar to the three previously mentioned hybrids.

From the standpoint of yolk color and costs to achieve desirable yolk color value, the cost reduction could not be achieved when considering synthetic pigments due to their low price. Still, it could be achieved when considering natural sources, of which only the extract of marigold (*Tagetes erecta*) is commercially available [59]. Consumers today are concerned about the use of synthetic additives, and achieving egg yolk color with natural sources could be used to market eggs from a particular egg production system. The price of marigold extract depends on the content of the extract and can be up to EUR 300. Then, the proportion of the added extract depends on the carotenoid content. Assuming that up to 1 g of this extract was added per kg of complete feed, up to 6.3 kg less of this pigment source could be used in dietary treatments with the lowest complete feed intake compared to the highest intake. Skřivan et al. [60] achieved a yolk color of 10.55 with supplementation of 950 mg kg^{-1} commercial marigold extract containing 21.26 g lutein and 9.65 g zeaxanthin per kg of extract. If the desired value for yolk color is higher, even higher supplementation should be applied, which further increases the amount of pigment necessary for the production of complete feeds.

4. Conclusions

Differences among modern commercial maize hybrids used to produce complete feeds for laying hens resulted in differences in the production performance of the hens. The traits that differed in the experiment conducted were complete feed intake, egg weight and mass, and FCR. Compared to the hybrid with the highest result, the hybrid with the lowest result had 3.43 g higher complete feed intake, 3.49 g higher egg weight, and 3.99 g higher daily egg mass. Overall, the hybrid with the best feed consumption ratio required 177 g less complete feed to produce 1 kg of eggs compared to the hybrid with the highest ratio.

Since the eggs of all dietary treatments were of the same grade, the increase in egg weight found in the present study most likely would not contribute to the profit from egg sales. On the other hand, the selection of maize hybrids could contribute to a reduction in feed costs due to the potentially lower total complete feed intake and contribute to the profitability of the egg production system. These annual cost reductions on a large scale (i.e., on a farm with 5000 hens) could be as high as EUR 4300 when considering complete feed intake or up to EUR 6378 if egg cost is considered. The second contribution of the maize hybrid selection for egg production could be in yolk color that is produced by natural pigments, which could be used for marketing products containing natural ingredients.

Although the egg production system depends on numerous factors, the results of the present study have shown that only one modification of the maize hybrid used for the complete feeds for laying hens should be considered in the economic calculations of the animal production system. Egg farms could identify the most suitable maize hybrids for the specific needs of their production system and use them in the preparation of complete feeds.

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Institutional Review Board Statement: This study was conducted according to the European guidelines for the care and use of animals used for scientific purposes and approved by the Ethics Committee for the protection of animals used in scientific research within the Ministry of Agriculture of Republic of Croatia (EP 349/2022; date of approval 31 January 2022).

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author. The data are not publicly available due to the use of commercial maize hybrids in this study and intellectual property rights of the hybrid producers.

Conflicts of Interest: The authors declare no conflict of interest.

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