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Assessing the efficiency of using a local hybrid of rye for broiler chickens aged 1–42 d, with emphasis on performance and meat quality

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ABSTRACT

This study was conducted to test the hypothesis that a new rye hybrid produced in Romania (Suceveana variety) could not impair the performance and meat quality of broiler chickens. A total of 360-day-old male Ross 308 broiler chicks (40.1±2.3 g) were randomly assigned to 3 dietary treatments replicated 6 times having 20 birds per replicate. Experimental diets were formulated to replace 25 and 50% of corn with rye (RYE 25 and RYE 50, respectively) as energy-yielding sources, whereas the control diet (CON) was 100% corn-based. All diets were formulated to be isocaloric and isonitrogenous, with similar total lysine and total sulfur amino acids. The results indicated similar outcomes of the local rye hybrid to commonly used corn-containing diets in terms of performance and carcasses. There were no differences in fundamental physicochemical (i.e., pH, protein, fat, moisture) or textural attributes of breast muscles due to dietary treatment, as well. However, the substitution of corn with rye reduced (P = 0.008) abdominal fat associated with an increase in CIE color (P< 0.001). Thus, the Suceveana rye hybrid can be included in broiler diets, from hatching to day 42, without any adverse effects on the bird's performance.

Keywords: broiler, rye hybrid, performance, meat traits

INTRODUCTION

Approximately 60% - 70% of broiler feed inputs are constituted of corn as the main energy source. Due to stiff competition for corn amongst different industries, arises the need to find local alternative feed ingredients with similar nutrients (Ciurescu et al., 2022).

Rye (*Secale cereale* L) can be an attractive alternative to growing corn or wheat, especially on infertile sandy soils (Paraschivu et al., 2021). Advances in crop breeding have led to newly developed rye landraces with greater yields, good overwintering ability, fungal disease resistance, and improved drought tolerance (Gontariu et al., 2011; Matei et al., 2021; Paraschivu et al, 2021). In new types of rye hybrid, the amount of anti-nutritional factors, especially arabinoxylans, is limited (Jürgens et al., 2012), thereby their inclusion level in the broiler (Milczarek et al. 2020) and pigs diets (Schwarz et al., 2015) may be increased without the risk of a reduction in performance indices. One such rye variety developed in Romania is known as Suceveana. It is a new product (year of registration 2021) that has a protein content of 11.8 (N × 6.25 g/100 g), total phenols of 0,214 μg GAE/ml, and a total antioxidant capacity of about 10 μg GAE/ml (Serea and Barna, 2011). Due to its high fiber content, rye is a nutritionally interesting cereal and is mainly cultivated as bread grain and other bakery products. Although the local Suceveana rye variety has been tested for its potential as food (Banu and Moraru, 2007; Banu and Vasilean, 2009; Aprodu and Banu, 2017), its prospective use in broiler-based diets, especially during the first weeks of life, has not yet been evaluated.

The tested hypothesis is: The use of a local hybrid rye in diets for broiler chicken, especially during the first week of the broiler's life, has an effect on the performance and meat quality.

Therefore, the objective of the current study was to investigate the effects of the inclusion of local Suceveana rye hybrid on the growth performance, carcass characteristics, and meat quality in broiler diets at ages 1-42 d.

MATERIALS AND METHODS

The Animal Ethics Committee of the National Research and Development Institute for Animal Biology and Nutrition (INCDBNA-IBNA) Balotești, Romania, approved under the EU Directive 2010/63/EU and Romanian Law on Animal Protection the experimental protocol. The slaughter of birds was carried out following the applicable rules on handling animals at the time of slaughter, including humane treatment. Also, the methods used in the meat quality tests were carried out by the current and commonly used methodology described in the Material and methods section. The study was conducted in compliance with the ARRIVE guidelines.

Rye Grain

The new rye hybrid (*Secale cereale*, Suceveana variety) was obtained from a plant breeding station (Research and Development Station for Plant Culture on Sandy Soils, Dăbuleni, DJ, Romania).

Experimental Design, Animals, Diets, and Management

A total of 360-day-old male Ross 308 broiler chicks with average body weight (BW) of 40.1±2.3 g, were purchased from a local commercial hatchery. Chicks were randomly assigned to a completely randomized design with three dietary treatments replicated 6 times having 20 birds per replicate. The trial lasted for 6 weeks. Chickens were reared in pens on a litter floor (wood shavings, 10 cm height) and placed in a climate-controlled room where the ambient temperature was maintained at thermoneutrality according to bird age (Ross Broiler Guide). Lighting was provided for 23 h/d from 1D to 7D, and from 8D, the light decreased by 1 h a day until 20 h, according to EU legislation (EU Council Directive 2007/43/EC). Broilers were vaccinated at the hatch for Marek's, Newcastle, and Infectious Bronchitis Disease.

Feed (in mash form) was offered *ad libitum* as follows: starter - grower (d 1 to 24), and finisher (d 25 to 42) feeding phases. The feeding trial was designed to partially substitute corn with rye as energy-yielding sources. Experimental diets were formulated to replace 25 or 50% of corn with rye (RYE 25 and RYE 50, respectively) whereas the control (CON) was 100% corn-based diet without rye. Diets for each feeding phase have been formulated to be isocaloric, and isonitrogenous, with similar total lysine, total sulfur amino acids (TSAA; Table 1), calcium, and available phosphorous, and to meet or exceed breeder guidelines (Ross 308, Aviagen Ltd., Midlothian, UK). Phytase (Axtra PHY 5,000 L, Danisco Animal Nutrition, Marlborough, UK) as exogenous enzymes were included in premixes of diets. Metabolizable energy calculations were based on chemical analyses using the formula and digestion coefficients according to European tables of energy values of feeds for poultry (WPSA, 1989).

Feed chemical analyses

Samples of ingredients and feeds were analyzed in duplicate for DM, CP, EE, CF, and ash content, using standard procedures by the methods of the European Commission Regulation (EC) no. 152 (OJEU, 2009). Nitrogen-free extract (NFE) content was calculated as follows: NFE (%) = dry matter % – (crude protein % + crude fat % + crude ash % + crude fibre %). The content of dietary fiber fraction – neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) – was determined with the classical semi-automatic Fibertec method (FOSS – Tecator AB, Höganäs, Sweden) as previously described by Ciurescu et al. (2018).

Criteria of Response

The chickens' body weight was measured at 1, 24, and 42 d of age. Feed intake (FI) was recorded for starter-grower (1–24 d), finisher (25–42 d), and the entire feeding period (1–42 d of age). Mortality was registered daily to calculate body weight gain (BWG) and feed conversion ratio (FCR).

Table 1. Ingredient and nutrient composition of diets (as-fed basis)

Diets	Rye levels as a substitute for corn (%)					
	Starter-grower (1–24 days)			Finisher (25–42 days)		
	CON	**RYE 25**	**RYE 50**	**CON**	**RYE 25**	**RYE 50**
Ingredients, %						
Corn	57.98	44.00	29.60	64.09	48.22	32.50
Rye	0.00	14.80	29.60	0.00	16.30	32.50
Soybean meal, 45.6% CP	31.00	30.00	29.08	25.20	23.90	22.79
Corn gluten meal, 62% CP	4.00	4.00	4.00	3.50	3.50	3.50
Soy oil	2.00	2.20	2.70	2.60	3.55	4.20
Monocalcium phosphate	1.67	1.54	1.50	1.45	1.28	1.22
Calcium carbonate	1.45	1.54	1.56	1.27	1.36	1.37
Salt	0.28	0.28	0.28	0.28	0.28	0.28
L-lysine, 78%	0.29	0.30	0.33	0.28	0.28	0.31
Dl-methionine, 99%	0.25	0.26	0.27	0.25	0.25	0.25
Choline chloride	0.08	0.08	0.08	0.08	0.08	0.08
Premix [1]	1.00	1.00	1.00	1.00	1.00	1.00
Calculated composition, %						
ME, MJ/kg	12.70	12.70	12.70	13.33	13.32	13.32
Crude protein	22.0	22.0	22.0	19.5	19.5	19.5
Lysine, total	1.33	1.33	1.33	1.16	1.16	1.16
Lysine, digestible	1.20	1.21	1.21	1.05	1.12	1.10
TSAA	0.99	0.99	0.99	0.91	0.91	0.91
TSAA, digestible	0.90	0.90	0.91	0.83	0.83	0.83
Calcium	0.90	0.91	0.91	0.79	0.79	0.79
Av. phosphorous	0.45	0.45	0.45	0.40	0.40	0.40
Crude fat	4.92	4.84	4.99	5.63	6.27	6.54
Crude fiber	2.80	2.86	2.86	2.61	2.56	2.51
Analyzed composition, %						
Dry matter	89.77	90.10	90.08	89.82	90.05	90.02
Crude protein	22.09	22.04	22.02	19.52	19.55	19.53
Crude fat	4.94	4.90	5.09	5.72	6.50	6.58
Crude fibre	3.05	2.91	3.11	2.67	2.77	2.61

Abbreviation: ME, metabolizable energy; TSAA, total sulfur amino acids.
[1]Supplied per kg diet: 12000 IU vitamin A, 5000 IU vitamin D3, 75 mg vitamin E, 3 mg vitamin K_3, 3 mg vitamin B_1, 8 mg vitamin B_2, 5 mg vitamin B_6, 0.016 mg vitamin B_{12}, 13 mg pantothenic acid, 55 mg nicotinic acid, 2 mg folic acid, 0.2 mg biotin, 120 mg Mn, 100 mg Zn, 40 mg Fe, 16 mg Cu, 1.25 mg I and 0.3 mg Se, 70 mg Monteban G100, 0.2 g Axtra PHY 5,000 L (1,000 FTU).

At the end of the trial (d 42), six birds from each treatment (one per replicate pen with BW close to the average) were slaughtered and eviscerated, following a 12-h fast. The relative weights of the breast, legs, abdominal fat, heart, liver, gizzard, spleen, thymus, and bursa of Fabricius as well as the gastrointestinal tract (GIT) were estimated as a percentage of the eviscerated carcass. The length of the GIT (duodenum, jejunum, ileum, and ceca) was also measured and recorded.

Meat quality parameters (pH_{24}, and color) were assessed on the Pectoralis major on the right breast, while the left breast muscle was frozen at -20°C until further analysis, such as instrumental texture profile analysis (TPA) and proximate chemical composition (i.e., crude protein, fat, collagen, and moisture content). After 24 h cold storage at 4°C, breast meat pH value was measured in triplicate using a Hanna portable pH-meter (model HI 99163, Hanna Instruments, Romania), fitted with a spear-type electrode (FC 099 stainless steel blade tip) and an automatic temperature compensation probe. Muscle cross-section colour were determined using a portable colorimeter (model CR 410, Konica Minolta Co., Ltd.., Osaka, Japan). The colour was classified according to the Commission Internationale de l'Éclairage (CIE lab system, 2007) determining L* (lightness), a* (redness), and b* (yellowness), with the following measurement parameters: light source D65; observer 2°; measuring head slot 8 mm; and calibration on the white tile L* = 97.83, a* = -0.43, and b* = 1.98. Three measurements were performed at different spots of each meat sample. The pH_{24}, and colour of the liver were also measured and recorded.

TPA attributes of breast muscle samples were analyzed individually by a double cycle compression using a texture analyzer (Model CT3 BROOKFIELD Engineering Laboratories, Inc. MA, USA). For TPA analysis, each sample was cut into 3-cylinder shapes with a diameter of 20 mm and a height of 15 mm. For an increased accuracy of the parameters reading, there were avoided any large areas of fat. The texture analyzer was equipped with a 50 kg load cell, a cylinder probe of 76.2 × 10 mm to compress the samples, and a fixture base table. The probe moved towards the sample at a constant speed of 2.0 mm s^{-1} (pre-test), 1.0 mm s^{-1} (test), and 2.0 mm s^{-1} (post-test). The data was collected using Texture Pro CT Software.

Thereafter, the remaining part of the meat samples was cut, homogenized in a blender, and used to perform NIR (near-infrared reflectance) spectroscopy analysis. NIR data were acquired using a DA6200 meat analyzer (PerkinElmer, Inc. MA, USA), with transmission spectroscopy that uses diode array detectors in the wavelength range of 850 to 1,050 nm. Homogeneous samples were loaded into a magnetically coupled plastic sample dish of 14 mm in height and a volume of 170mL and analyzed for moisture, protein, fat, and collagen contents. To minimize sampling error, we set two duplicates, and each duplicate was measured twice. The averaged spectrum was then used in subsequent analysis.

For bacteria enumeration, both ceca (6 birds per treatment) were aseptically removed, separated into sterile bags, and homogenized with 7 mL of Brain Heart Infusion broth (Oxoid Basingstoke, Hampshire, UK) supplemented with 2mL of glycerol and frozen at - 20°C until the analysis. After defrosting, decimal dilutions in phosphate-buffered saline (Dulbecco A; Oxoid Livingstone Ltd., London, England) were done. The samples were assessed for the total number of lactic acid bacteria (LAB) in Man Rogosa and Sharpe agar (MRS, Oxoid CM0361); coliforms in MacConkey agar (Oxoid CM0007); and *Clostridium* spp. in Reinforced Clostridial Agar (Oxoid CM0151) as described by Ciurescu et al., 2020. *Escherichia coli* (*E. coli*; biotype β-hemolytic) was analyzed, as reported by Dumitru et al. (2018). *Salmonella* spp. were enumerated on *Salmonella–Shigella* agar (Oxoid CM0099). Each sample had three replicates. The microflora level was expressed as log10 CFU g^{-1} cecum content.

Statistical Analysis

The pen (replicate) was the experimental unit for the performance parameters evaluation. For microflora and carcass measurements, and meat quality, each broiler was the experimental unit. The effect of dietary treatments in the present study was analyzed with one-way ANOVA using SPSS 25.0 (BM SPSS Statistics for Windows, Version 25.0. Armonk, NY, USA: IBM Corp.). The dietary treatment groups were included as fixed factors in the statistical model. Post-hoc comparisons between treatments were investigated by Tukey's test. The average values including the standard error of the mean were calculated for every examined parameter. The chart for microflora evaluation from cecum content was generated using SigmaPlot V.11 software (San Jose, CA, USA) and data are represented as means ± standard deviation of means. The level of significance was set at $P < 0.05$.

RESULTS AND DISCUSSION

Nutrient composition of Rye

The basic nutrients and fiber fractions of the Suceveana rye variety used for this study are shown in Table 2. The content of crude protein amounted to 133.3 g kg^{-1} DM and was higher than that (116.69 g kg^{-1} DM) determined by Milczarek et al. (2020). The level of crude fat in the evaluated grain was low (12.7 g kg^{-1} DM) and in line with the findings of Alijošius et al. (2016) who reported a lower mean content of this component. The content of crude fiber in hybrid rye amounted to 39.7 g kg^{-1} DM and was higher than that (28.17 g kg^{-1} DM) determined by Milczarek et al. (2020). The energy level of about 14.2 MJ/ME kg^{-1} DM is only slightly lower than in wheat (14.7 MJ/ME kg^{-1} DM).

Rye also is a good source of phosphorus (4.8 g kg^{-1} DM; Table 1) similar to wheat.

Table 2. Chemical composition of hybrid rye

Nutrients content (g/kg^{-1} DM)	Rye, Suceveana *var.*
Dry matter	887.3 ±0.9
Crude protein	133.3 ±4.3
Crude fat	12.7 ±0.6
Ash	20.3 ±1.1
Crude fiber	39.7 ±3.2
NFE	794.0 ±0.3
ME, MJ	14.2 ±0.7
Fiber fractions	
NDF	304.1 ±0.9
ADF	68.9 ±0.7
ADL	13.2 ±0.2
CEL = ADF - ADL	55.7 ±0.2
HCEL = NDF - ADF	235.1 ±0.4
Calcium	0.9 ±0.1
Phosphorus	4.8 ±0.8

Abreviation: NFE, nitrogen-free extract; ME, metabolizable energy; NDF, neutral detergent fibre; ADF, acid detergent fibre; ADL, acid detergent lignin; CEL, cellulose; HCEL, hemicellulose.

Fiber components are one of the most important nutritional and technological factors of cereal grain. The determined content of NDF fractions fell within the range of 220.1 – 461.0 g kg⁻1 DM, as reported by Žilić et al. (2011). The ADF fraction (68.9 g kg^{-1} DM) contains cellulose and lignin. Less than 29.4–47 g kg^{-1} DM of ADF was found by Žilić et al. (2011). Milczarek et al. (2020) found as many as 53.92 g kg^{-1} DM of ADF in rye. In the present study, the level of ADL fractions was measured as 13.2 g kg^{-1} DM and fell within the range of 6 – 13.8 g kg^{-1} DM, as determined by Žilić et al. (2011). The content of cellulose and hemicellulose in the evaluated rye was a resultant of the above-mentioned fractions. Alijošius et al. (2016) found that some rye cultivars had a statistically significant effect on the content of fiber fractions.

Productive performance

The results on performance parameters at the starter-grower (1–24 d) and finisher phases (25–42 d), as well as the overall (1–42 d) study period, is reported in Table 3. The results show that BWG, FI, and FCR of broiler chickens were not affected ($P > 0.05$) by the levels of the rye hybrid inclusion. Over the 42 d rearing period of the trial, the best BWG and FCR ($P > 0.05$) values were observed for chickens fed at a level of 50% replacement of corn compared to those that were offered 100% corn-based diets (CON). As the content of rye increased, a linear improvement could be observed in the production performance of birds.

Table 3. Effects of dietary treatments on performance variables (mean values1) of broiler chickens[2]

Parameter	Dietary treatment			SEM[3]	P-value
	CON	RYE 25	RYE 50		
BWG, g					
1–24 d	1,059	1,057	1,050	19.602	0.979
25–42 d	1,617	1,641	1,664	43.142	0.910
1–42 d	2,676	2,698	2,714	38.308	0.922
Feed intake, g					
1–24 d	1,539	1,531	1,522	9.443	0.767
25–42 d	3,044	3,047	3,080	11.855	0.534
1–42 d	4,583	4,578	4,602	14.951	0.778
FCR, g					
1–24 d	1.45	1.45	1.45	0.009	0.998
25–42 d	1.88	1.86	1.85	0.016	0.577
1–42 d	1.71	1.70	1.70	0.007	0.752

Abbreviation: BWG, bodyweight gain; FCR, feed conversion ratio.
[1]Data are means of 6 replicate pens with 20 birds per pen. [2]Survival rate =100%.
[3]SEM, standard error of the mean.

Similarly, Milczarek et al. (2020), evaluating broilers over a 42-day rearing period, found better performances when the birds were fed a diet containing the highest percentage of hybrid rye (15% in starter and 30% in grower and finisher), as a partial substitute of corn. In contrast, Arczewska-Wlosek et al. (2019) noticed that in the starter rearing period of chickens, the inclusion of modern hybrid rye (Brasetto variety, without xylanase addition) into the diet, even at the lowest dietary level (5%), significantly negatively affected BWG and did not affect the FCR. In older chickens (22–42 d of age), none of the dietary levels of rye (5%, 10%, 15%, or 20%) affected growth performance indices. Similarly, no significant effect of increasing the dietary level of rye was found for the overall rearing period (1–42 d of age).

Findings of other authors (Lazaro et al. 2004; Józefiak et al., 2007; Mourão and Pinheiro, 2009; van Krimpen et al., 2015; van Krimpen et al., 2017) regarding the effects of rye inclusion in the diet on broiler performance are consistent and frequently show a negative influence of high, i.e., 20% or more, dietary levels of rye on BWG and/or FCR.

In our study, the good performances of chickens could be connected with the rye variety because the magnitude of such adverse effects is not always the same, and this mainly depends on the chemical composition of the rye variety used. For instance, conventional rye typically contains more alkylresorcinols (Schwarz et al., 2015). Older broilers, i.e., aged 22–42 days, were not as susceptible to the presence of anti-nutrients, such as alkylresorcinols, in the diet, so we did not find any negative effects of rye on performance during the grower-finisher rearing period.

Carcass traits

The inclusion of the Suceveana rye variety in diets did not affect the carcass, breast, and legs' yield of birds, at 42 d, but it altered the share of abdominal fat in the carcass (*P* = 0.008; Table 4).

Table 4. Effects of dietary treatments on results of slaughter analysis (mean values[1]) of broiler chickens

Parameter	**Dietary treatment**			**SEM[2]**	**P-value**
	CON	**RYE 25**	**RYE 50**		
Carcass[3]	76.04	76.38	76.40	0.512	0.233
Breast[4]	38.97	39.44	39.78	0.346	0.577
Leg[4]	26.82	27.55	27.47	0.292	0.340
Abdominal fat[4]	1.07^{a}	0.85^{ab}	0.61^{b}	0.051	0.008
Gizzard[4]	1.88	1.93	1.87	0.055	0.890
Liver[4]	2.79	2.87	2.74	0.034	0.345
Heart[4]	0.59	0.57	0.60	0.023	0.780
Lymphoid organs[4]					
Spleen	0.13	0.12	0.13	0.006	0.367
Thymus	0.22	0.24	0.22	0.003	0.936
Bursa of Fabricius	0.24	0.22	0.24	0.008	0.810
GITW[4]					
Duodenum	0.75	0.64	0.72	0.028	0.261
Jejunum	1.38	1.29	1.36	0.053	0.745
Ileum	1.24	1.17	1.06	0.068	0.564
Ceca	0.31	0.32	0.32	0.017	0.979
GITL[5]					
Duodenum	1.74	1.70	1.79	0.042	0.588
Jejunum	4.29	4.52	4.53	0.093	0.156
Ileum	4.25	4.37	4.39	0.085	0.619
Ceca	1.84	1.67	1.70	0.071	0.233

Abbreviation: GITW, gastrointestinal tract weights; GITL, gastrointestinal tract length.
[1]Data are means of 6 broilers per dietary treatment. [2]SEM, standard error of the mean.
[3]Represents as weight (g) of without head, neck, feet, and viscera carcass as 100 g of live body weight.
[4, 5]Calculated as weight or length (g and cm) of organs as 100 g of carcass weight.

No effects of diet inclusion of rye on relative gizzard, liver, and heart weights, as well as lymphoid organs, i.e., spleen, thymus, and bursa as a percentage of carcass at slaughter, were found. In contrast, Mourão and Pinheiro (2009) claimed that birds fed on rye diets (53% rye) for 31 d showed the worst dressing percentage when compared with birds fed the control diet

(71.6% vs. 74.4%), although the weights of the liver were not affected by the feed in their study. Recently, Arczewska-Wlosek et al. (2019) did not find significant effects of the different levels of rye (0%, 5%, 10%, 15%, 20%) fed to chickens on their dressing percentage, breast meat share, abdominal fat, as well as the relative weight of the liver and gizzard. In addition, Van Krimpen et al. (2015) also suggested that the relative liver weight was also not affected by the cereal type.

In the current study, it was observed that an increase in rye level resulted in a decrease in the share of abdominal fat (up to 40%). This fact could be attributed to improved BWG and FCR (Arczewska-Wlosek et al., 2019; Milczarek et al., 2020). Previous studies have shown that the pattern of fat deposition can be modified by dietary energy-protein sources. For example, Cherian et al. (2002) found less accumulation of abdominal fat in broiler chickens fed diets containing high levels of sorghum. The reduction of abdominal fat in chickens fed alternative protein sources was accompanied by a reduction in muscle fat contents (Ciurescu et al., 2019). These changes in fat deposition most likely resulted from changes in lipid metabolism.

Results also showed that the diets replacing corn at 25% or 50% respectively did not affect the weight and length of the GIT (i.e., duodenum, jejunum, ileum, and ceca). To the best of our knowledge, there is no comparative information on the influence of rye grains differing in chemical characteristics on the development of the GIT. Chicks might require a minimal amount of fiber in the diet to stimulate the development of the upper GIT.

Meat Quality

Consumers consider the safety and high quality of products to be essential aspects of poultry consumption. Diet, is an environmental factor that directly influences meat quality. Meat quality is characterized by such parameters as pH, color, and texture attributes. The meat's chemical composition (crude protein percentage, fat, and water content) is one of the major features that translates to meat value. The effect of diets on the physicochemical composition of breast muscles (*pectoralis major*) and liver of broiler chickens are presented in Table 5.

There were no differences in fundamental components (i.e., protein, fat, moisture) of breast muscles due to dietary treatment. The source of variability in diets influenced total collagen amounts. Muscles collected from broilers under the rye treatment (RYE 25 or RYE 50) registered a higher total collagen content ($P < 0.0001$) than the CON group. The variables related to pH 24 h after slaughter was not influenced by the dietary treatment, indicating an acidification process of meat in agreement with that described in the literature (Mourão et al., 2008).

Table 5. Effects of dietary treatments on physicochemical parameters (mean values1) of broiler chickens

Parameter	Dietary treatment			SEM[2]	P-value
	CON	RYE 25	RYE 50		
Breast muscles					
Moisture, %	76.60	76.22	76.35	0.27	0.609
Protein, %	21.18	20.60	21.22	0.34	0.382
Fat, %	1.46	1.49	1.51	0.12	0.965
Collagen, %	0.69^{b}	0.85^{a}	0.72^{b}	0.02	0.000
pH_{24}	6.08	6.10	6.07	0.02	0.354
L*	55.44^{b}	62.74^{a}	60.45^{a}	0.74	0.000
a*	10.87^{b}	12.19^{b}	14.44^{a}	0.48	0.000
b*	12.27^{b}	14.96^{a}	13.48^{ab}	0.44	0.001
Liver					
pH_{24}	6.47	6.43	6.42	0.03	0.486
L*	29.87^{b}	37.27^{a}	37.26^{a}	0.56	0.000
a*	15.39^{b}	18.00^{a}	17.95^{a}	0.36	0.000
b*	6.16^{b}	7.94^{a}	8.45^{a}	0.35	0.000

Abbreviation: pH_{24}, pH 24 h after slaughter; L*, lightness; a*, redness; b*, yellowness. [1]Data are means of 6 broilers per dietary treatment. [2]SEM, standard error of the mean; [a,b] Means in the same row without the same superscript differ significantly (P < 0.05).

Since it is directly perceived by the consumer, color is an essential quality parameter. In our study, the change of energy source in the diet significantly influenced the color of breast muscle. Breast muscles of chickens fed with the highest share of rye were characterized by a significantly higher (P < 0.0001) concentration of hydrogen ions or the L*, as well as a* and b* saturation (P < 0.0001 and P < 0.001 respectively) in comparison to the muscle of birds in CON treatment. Likewise, a trend toward higher a* of breast muscles was also reported by Milczarek et al. (2020) who investigated the effect of a rye-based diet (15% in starter and 30% in grower and finisher rations). In our study, even if breast muscles of RYE groups showed a higher lightness, the pH value was in the range for normal meat.

The liver is an important organ for the metabolism and storage of glycogen. In our study liver pH values, estimated 24 h after slaughter, were of similar magnitude for all broilers and ranged from 6.47 to 6.42. However, the liver of birds fed rye-based diets was characterized by a significantly higher L* (P < 0.0001) as well as a* and b* (P < 0.0001) saturation in comparison to the liver of birds in CON treatment. The lighter colour of liver in rye treatment (RYE 25 or RYE 50) indicates a lower liver fat content.

The dietary inclusion of hybrid rye into broilers' diets modified the TPA attributes, i.e., hardness, adhesiveness, resilience, cohesiveness, springiness, gumminess, and chewiness of breast muscles (Table 6). Thus, hardness, as well as gumminess, significantly increased (P < 0.001 and P = 0.042, respectively), whereas resilience values significantly decreased (P = 0.042), particularly at higher levels used (RYE 50).

Table 6. Effects of dietary treatments on textural properties of breast muscle (mean values[1]) of broiler chickens

Parameter	Dietary treatment			SEM[2]	P-value
	CON	RYE 25	RYE 50		
Hardness, g	4626.61[ab]	3642.60[b]	5538.70[a]	326.71	0.001
Adhesiveness, mJ	0.28	0.29	0.29	0.03	0.920
Resilience	0.19[a]	0.17[ab]	0.15[b]	0.011	0.042
Cohesiveness	0.26	0.26	0.24	0.019	0.751
Springiness, mm	2.08	2.14	2.27	0.19	0.753
Gumminess, g	756.89[ab]	595.36[b]	837.41[a]	65.10	0.042
Chewiness, mJ	15.81	13.10	19.38	2.13	0.138

[1]Data are means of 6 broilers per dietary treatment. [2]SEM, standard error of the mean; [a,b] Means in the same row without the same superscript differ significantly (P < 0.05).

However, no significant effects were observed on adhesiveness, cohesiveness, springiness, and chewiness between samples of all treatments. Lyon et al. (2004) also reported that breast fillets from wheat-fed birds required more force to shear compared with breasts from corn-fed birds. On the other hand, Grashorn (2006) found that nutrient levels did not impact the texture of the breast.

Microflora of cecal digesta

Replacing corn with rye at different inclusion levels in diets for broiler chickens affected the microflora composition from cecum digesta at d 42.

The microflora composition from caecal digesta of chickens fed with diets containing rye had the highest score for LAB populations (p > 0.05) than the birds receiving diets with 100% corn-based diets, without rye. Moreover, as regards microflora evaluation assay, those chickens from the RYE treatments scored lowest, with a statistically confirmed difference recorded for *Clostridium spp*., and *E. coli* bacteria only (Figure 1).

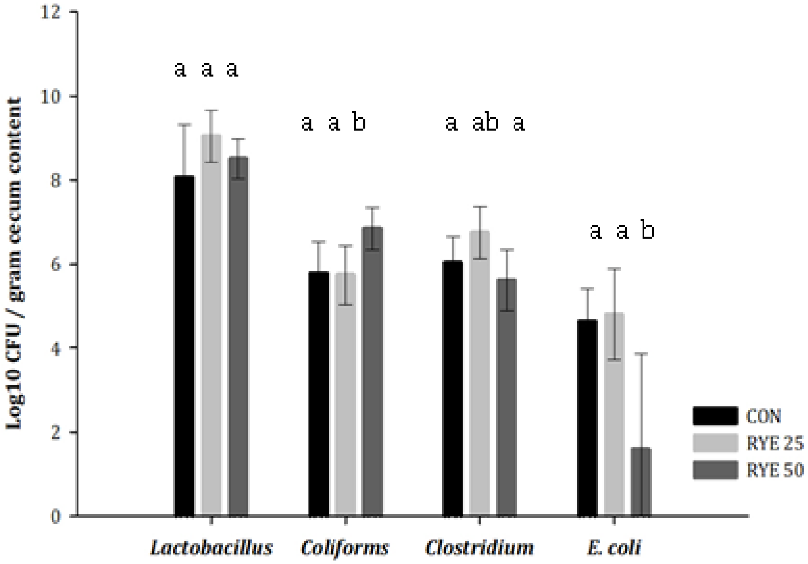

Figure 1. Microflora evaluation of cecal digesta.
[a,b] Means with different superscripts within a row are significantly different at P < 0.05.

A significant increase in the numbers of total lactic acid bacteria was detected in the duodenum, ileum, and ceca of young broilers fed a diet containing 58% rye compared to the broilers fed a corn-rich diet (Tellez et al., 2014). In addition, the total number of coliforms in the duodenum and ileum increased as well, whereas, an increase in the total number of anaerobes was observed only in the duodenum (Tellez et al., 2014). Although the changes in microbiota composition differed among the mentioned rye studies, the general trend is an increase in the numbers of microbiota because of feeding rye-based diets to broilers. Furthermore, some reports (Gani et al., 2012; Rosén et al., 2011) indicated that rye, due to its valuable chemical composition, has health-promoting properties. In addition, some reports (Rezaei et al. 2011) have noted the positive effects of dietary insoluble fiber on growth performance, gizzard activity, gut health (preventing the adhesion of certain pathogen bacterial populations to the epithelial mucosa), and gastrointestinal tract reflux, as which might promote nutrient digestibility and utilization. In the current experiment, the share of *Lactobacillus spp* increased with higher dietary rye inclusion levels in birds that were fed these diets for 42 d.

CONCLUSION

Our results indicated that hybrid rye can be incorporated into up to 30% of the diet (replacing 50% of corn), without any detrimental effects on the growth performance of younger chickens from 1-24 days of age, as well as the overall (1–42 d) study period. Furthermore, providing rye-rich diets did not affect the carcass, breast, and legs' yield as well as organ size and meat quality of birds, at 42 d. It can, therefore, be concluded that local hybrid rye, the Suceveana variety, could be an alternative energy source for corn-based diets.

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