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Effect of Feeding Potato Peels and Sugar Beet Pulp With or Without Enzyme on Nutrient Digestibility, Intestinal Morphology, and Meat Quality of Broiler Chickens

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Abstract

This study was conducted to evaluate the effects of sugar beet pulp and potato peels, as agro-industrial byproducts, with and without enzyme supplementation on nutrient digestibility, gut morphology, and meat quality of broiler chickens. Broiler chicks (n= 150) were randomly divided into five groups, each with 30 birds. Chicks in the first group were fed on the control diet. Birds in second and third groups were given diets containing potato peels and sugar beet pulp at a level of 15.0% and 7.5%, respectively, while those in the fourth and fifth groups were offered the same diets but with adding an enzyme mixture. Diets containing potato peels or sugar beet pulp did not *($P > 0.05$)* affect the digestibility of ether extract, crude fiber, or crude protein. Feeding of potato peels did not *($P > 0.05$)* affect the intestinal morphology during the starter or grower period. However, sugar beet pulp reduced *($P < 0.05$)* the villus height and villus height/crypt depth ratio during the starter period, but without any effect at the grower period. Generally, feeding of potato peels or sugar beet pulp did not *($P > 0.05$)* affect the physicochemical and sensory characteristics of the breast or thigh muscles. Supplementation of the enzyme to the diets increased *($P < 0.05$)* digestibility of nutrients and improve the development of the small intestine. Also, the dietary enzyme inclusion increased *($P < 0.05$)* the crude protein content and reducing the ether extract of the meat as well as increasing its water holding capacity with a reduction of the cooking loss rate. In conclusion, adding the enzyme to the diets containing potato peels or sugar beet pulp can enhance the digestion and absorption of nutrients as well as improve the meat quality of the broilers' carcass. Also, the tested byproducts can help in solving the problem of low availability and rising costs of traditional poultry feeds.

Introduction

The demand for animal products has steadily increased during the last years, which has a direct effect on the availability and price of feeds (Alagwany *et al.,* 2018). The cost of traditional ingredients used for poultry feeding is in a continuous increase. This has necessitated more research into the potential use of locally available, less competed and cheaper ingredients as feedstuffs. Among these alternatives are the wastes produced from the processing of agro-industrial products. Sugar beet pulp and potato peels are one of the most low-cost available agro-industrial byproducts, which are produced in large quantities during the processing of potatoes or sugar beet for food and industrial uses, and pose disposal problems in most producing regions (Diarra *et al.,* 2012). One way of utilizing these products efficiently could be as poultry feed ingredients. Poultry does not have fiber degrading enzyme for the digestion of complex carbohydrates like cellulose, hemicellulose, and xylose that are found in sugar beet pulp or potato peels (Annison, 1993). Also, birds cannot resist anti-nutritional substances that present in potato peels, such as raw starch and trypsin inhibitors (Fugui *et al.,* 2012). So, as to incorporate these materials in poultry feed

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without negative results on their production and nutrients digestibility, suitable exogenous enzymes supplementation can be utilized (Michard, 2011). The use of enzymes could improve the usefulness of these ingredients in poultry diets (Bedford and Partridge 2010).

High fiber content, low nutrient density, and likely presence of anti-nutritional substances limit the efficient utilization of the agro-industrial byproducts by poultry. Many studies indicated that the addition of moderate amounts of fiber in the diets of broilers increased secretion of HCl, bile acids, and digestive enzymes (Sacranie *et al.,* 2012), intestinal morphology of poultry (Jimenez-Moreno *et al.,* 2013) as well as nutrient digestibility (Mateos *et al.,* 2012). In this respect, the inclusion of fibrous feeds such as sugar beet pulp or potato peels in broiler diets maybe have a beneficial effect on nutrient digestibility and gut morphology. Also, treatment of the agro-industrial byproducts with exogenous enzymes may improve digestion and gut health, by removing anti-nutritional factors, or by digestion of fiber components that would otherwise pass undigested throughout the gastrointestinal tract (Bedford 1996). Moreover, diet composition and enzyme supplementation can change the nutritional status of broiler chickens and alter meat quality (Dalólio *et al.,* 2015).

The information regarding the effects of agro-industrial materials and enzyme supplementation on the gastrointestinal tract and meat quality is very scanty. Also, in a recently published study (Abdel-Hafeez *et al.,* 2018), potato peels and sugar beet pulp can be used in poultry diets at high levels after treating them with enzymes, but the mechanisms of action need to be explained and also the effects of these ingredients on meat features have not been tested. Therefore, the present study was conducted to evaluate the effects of sugar beet pulp and potato peels, as agro-industrial byproducts, with and without enzyme supplementation on nutrient digestibility, gut morphology, and meat quality of broiler chickens.

Materials and Methods

Birds, management, and feeding

One hundred and fifty, one-day-old, broiler chicks (Ross-308) were taken from a commercial hatchery with a mean body weight of about 46 g. These chicks were individually weighed, identified by using plastic rings in different colors, and randomly divided into five groups with 30 birds per group. The birds in the first group were offered a control diet which consisted of the conventional feeds without any enzyme supplement. The chicks in the second and third groups were given diets including potato peels and sugar beet pulp meals at a level of 15% and 7.5%, respectively, while those in the fourth and fifth groups were provided the same diets but with the inclusion of an enzyme mixture (Enziver®) at a rate of 250g / ton. The experiment lasted for 42 days. The broilers were fed a starter diet from the beginning of the experiment up to 21 days of age, and then changed to a grower diet till the experimental end at 42 days. The diets were offered to the chickens in a form of mash. The diets were formulated to meet the nutrient requirements of broilers according to NRC (1994). The different experimental diets were formulated to be isocaloric and isonitrogenous. The diets were analyzed for dry matter (DM), ash, crude protein (CP), crude fiber (CF), and ether extract (EE) according to AOAC (2005) procedures, while the other nutrients were calculated by using the feed composition tables of NRC (1994), and that of Egyptian Central Laboratory for Food and Feed (2001) especially for sugar beet pulp and potato peels. The physical and chemical compositions of the diets are shown in Tables 1 and 2.

The tested agro-industrial byproducts were potato peels and sugar beet pulp which were ground to powders and chemically analyzed before addition to diets. It was found that the potato peels contained about 90.5% DM, 11.4% CP, 1.05 % EE, 5.45% CF, 11.1% ash, and 2690 kcal ME/kg, whereas the sugar beet pulp had 90.5% DM, 9.63 % CP, 1.45% EE, 19.0% CF, 5.51% ash, and 646 kcal ME/kg. The raw potato peels were obtained from a native restaurant in the form of flakes. It was exposed to the sun for 72 h with turning twice daily to make it dry and to avoid microbial spoilage and then ground in a hammer mill to be easily mixed with other dietary ingredients. The dried sugar beet pulp was obtained from a local sugar factory, where it was in pellets form. These pellets were also ground into powder before mixing with other feed ingredients.

The enzyme mixture (Enziver®) was included in the diets at a level of 250g / ton, based on the recommendation of the produced company, substituting equal amounts of yellow corn. This enzyme is produced by Zoetis Company (Mumbai, Maharashtra, India). Each gram of the enzyme comprises 5000 IU xylanase, 10000 IU cellulase, 800 IU β- glucanase, and 900 IU pectinase, 7500 IU amylase, 5500 IU protease, and 1000 phytase units (FTU). The enzyme mixture was selected to destroy all the anti-nutritional factors found in the tested unconventional feeds, such as non-starch polysaccharides (NSPs) in both ingredients, and trypsin inhibitors with raw starch in potato peel only. The broilers were housed in floor pens which littered with wheat straw. A lightning period of 23 h /day was used throughout the experiment. The ambient temperature was about 33°C at the start of the experiment and decreased gradually 2°C per week until reaching about 20°C at the end of the

experiment. The birds had free access to freshwater and feed throughout the experimental period.
The experiment design and procedures were approved by the Animal Ethics Committee at Faculty of Veterinary Medicine, Beni-Suef University, Egypt, and the trials were performed following the internationally accepted standard ethical guidelines for animal use and care.

Table 1. Physical and chemical composition (%) of the starter diets (as fed)

Composition	Diet				
	Control	Potato peels	Sugar beet pulp	Potato peels + Enzyme	Sugar beet pulp+ Enzyme
Dietary ingredients					
Yellow corn, ground	47.57	33.45	39.08	33.425	39.055
Soybean meal, 44% CP	33.39	30.00	28.01	30.00	28.01
Corn gluten meal	8.00	9.50	11.81	9.50	11.81
Potato peels, ground	-	15.00	-	15.00	-
Sugar beet pulp, ground	-	-	7.50	-	7.50
Vegetable oil	6.94	8.01	9.50	8.01	9.50
Limestone	1.40	1.30	1.32	1.30	1.32
Dicalcium phosphate	1.77	1.78	1.80	1.78	1.80
Common salt	0.48	0.47	0.44	0.47	0.44
DL-Methionine	0.10	0.10	0.09	0.10	0.09
L- Lysine HCl	0.05	0.09	0.15	0.09	0.15
Mineral and vitamin premix [a]	0.30	0.30	0.30	0.30	0.30
Enzyme mixture	-	-	-	0.025	0.025
Chemical composition					
A- Analyzed:					
Dry matter	90.22	89.72	90.00	89.89	89.10
Crude protein	22.81	22.96	23.00	22.78	22.81
Ether extract	9.21	9.86	10.52	9.96	10.81
Crude fiber	3.50	3.71	4.22	3.66	4.36
Ash	6.50	7.22	6.36	7.30	6.41
B- Calculated:					
Metabolizable energy, kcal/kg	3204	3203	3200	3202	3200
Methionine	0.51	0.51	0.51	0.51	0.51
Methionine + Cystine	0.92	0.91	0.91	0.91	0.91
Lysine	1.14	1.15	1.14	1.15	1.14
Calcium	1.00	1.02	1.02	1.02	1.02
Phosphorus, available	0.46	0.46	0.45	0.46	0.45

[a] Poultry mineral and vitamin premix "Avimix, Agri – Vet company, Egypt": each 3 kg contains Vit. A, 12,000,000 IU; Vit. D3, 2,000,000 IU; Vit. E, 10,000 mg; Vit. K_3, 2000 mg; Vit. B_1, 1000 mg, Vit. B_2, 5000 mg; Vit. B_6, 1500 mg; Vit. B_{12}, 10 mg; biotin, 50 mg; pantothenic acid, 10000 mg; nicotinic acid, 30000 mg; folic acid,1000 mg, choline chloride, 250000 mg; Mn, 60000 mg; Zn, 50000 mg; Fe, 30000 mg; Cu, 10000 mg; I, 1000 mg; Se, 100 mg; Co, 100 mg; and calcium carbonate up to 3kg.

Digestibility trial

The trial was conducted during the final five days of the experimental period by selecting five chickens from each group. The average body weight of the separated birds was almost identical to the average weight of the remaining chickens in each treatment. The chickens were fed *ad libitum* on experimental diets and housed individually in metabolism cages to determine the individual feed consumption and to collect the excreta samples of each bird. Fresh excreta, free from feathers and feed particles, were collected daily then weighed and frozen for storage until analyzed chemically. In a chemical analysis, the collected excreta of each bird were pooled and thoroughly mixed. Then, the samples of excreta were analyzed, as they feed, for DM, ash, EE, CP, and CF according to AOAC (2005) methods. Also, organic matter (OM) of the feed or excreta was calculated by taking the difference between the DM and ash content. Subsequently, the apparent digestibility of the measured nutrients or OM was calculated using the following formula: (nutrient or OM intake - nutrient or OM excreted) x 100/nutrient or OM intake.

pH values of gastrointestinal digesta

At the end of starter and grower periods, five birds from each treatment were sacrificed and the digesta of the crop, gizzard, proventriculus, small intestine, and caecum were individually collected in tubes. The separated digesta samples were diluted with water at the level of 1:5 and then mixed thoroughly (Youssef *et al.,* 2012). Afterward, the pH values in these diluted samples were determined using a pH meter.

Table 2. Physical and chemical composition (%) of the grower diets (as fed)

Composition	Diet				
	Control	Potato peels	Sugar beet pulp	Potato peels + Enzyme	Sugar beet pulp+ Enzyme
Dietary ingredients					
Yellow corn, ground	56.19	41.43	48.84	41.405	48.815
Soybean meal, 44% CP	30.50	28.09	23.14	28.09	23.14
Corn gluten meal	4.00	4.88	8.98	4.88	8.98
Potato peels, ground	-	15.00	-	15.00	-
Sugar beet pulp, ground	-	-	7.50	-	7.50
Vegetable oil	5.95	7.29	8.08	7.29	8.08
Limestone	1.41	1.34	1.32	1.34	1.32
Dicalcium phosphate	1.21	1.23	1.30	1.23	1.30
Common salt	0.34	0.34	0.32	0.34	0.32
DL-Methionine	0.05	0.05	0.03	0.05	0.03
L- Lysine HCl	0.05	0.05	0.19	0.05	0.19
Mineral and vitamin premix	0.30	0.30	0.30	0.30	0.30
Enzyme mixture	-	-	-	0.025	0.025
Chemical composition					
A- Analyzed:					
Dry matter	90.00	90.62	90.06	90.91	90.86
Crude protein	19.89	19.76	19.68	19.96	19.80
Ether extract	8.01	9.17	9.84	9.22	9.91
Crude fiber	3.47	3.54	4.09	3.77	4.22
Ash	5.58	7.00	5.29	6.98	5.61
B- Calculated:					
Metabolizable energy, kcal /kg	3200	3200	3200	3200	3200
Methionine	0.40	0.40	0.40	0.40	0.40
Methionine +Cystine	0.76	0.75	0.75	0.75	0.75
Lysine	1.05	1.04	1.04	1.04	1.04
Calcium	0.90	0.91	0.90	0.91	0.90
Phosphorus, available	0.35	0.35	0.35	0.35	0.35

Intestinal morphology

At the end of the experiment, five birds from each group were euthanized by cervical dislocation and the jejunum was removed for assessment of intestinal morphology. The selected birds were used for measuring the pH values, as previously described, and also for intestinal morphology determination. The tissue samples were taken from the middle part of the jejunum by collecting 2-cm-long pieces according to Maiorka *et al.,* (2000) technique. The tissue fragments were fixated in a boom, subjected to alcohol series for dehydration, clarified in xylol, and implicated in blocks of paraffin, then cut in sections of 5- µm length and used to glass slides. These slides were stained with hematoxylin and eosin, and glass coverslips were included. Afterward, the prepared slides were examined under a light microscope using an image analyzer. The intestinal villus height, crypt depth, and length of villus surface and the corresponding length of the lamina muscularis mucosae in this area were measured. Only parts of the intestinal sections were measured, as villi were cut completely from tip to bottom and most crypts were also cut vertically. About 50 villi and crypts per sample were measured and the average values were taken for further calculations. The enlargement factor was estimated according to Wiese *et al.,* (2003), where the length of the villus surface was put concerning the length of the corresponding lamina muscularis mucosae.

Meat quality

At the end of the experiment, five birds from each treatment were sacrificed, and the physio-chemical and sensory characteristics of broiler cuts (breast and thigh muscles) were determined as follow:

pH values

The pH of the muscles was measured at 2 and 24 hours post mortem according to Balamatsia *et al.,* (2007) method. Broiler cuts samples were homogenized for about 2 minutes with distilled water (1:10) by a food blender. The pH was determined using a pH meter previously calibrated with standard buffers at 4.0, 7.0, and 9.0.

Water holding capacity

The water holding capacity was evaluated according to Hamm (1960). About 0.50 g of meat samples were put between two filter papers and two glass plates. Afterward, a weight of 10 kg was placed on the top glass plate for 5 minutes. The water loss was represented by the difference in the weight of breast or thigh muscles before and after the procedure application. The obtained results were expressed as a percentage of exuded water concerning the starting sample weight.

Cooking loss

Broiler cuts samples were weighed, and then an oven cooked at 170ºC until well done. Thereafter, the samples were cooled at room temperature and re-weighed. The cooking loss was calculated as follows: (sample weight before cooking minus sample weight after cooking) × 100 / sample weight before cooking.

Chemical composition

Five broiler chickens, with a body weight close to the overall mean, from each treatment, were selected. The birds were weighed after being subjected to 24 h.-feed fastings with free access to water and sacrificed by neck dislocation. The chickens were scalded, de-feathered, and eviscerated after the elimination of head, neck, and legs. The breast and thigh muscles of each bird were separated from the carcass, dissected into small pieces, and then dried in a hot air oven at 70 °C for 48 h by putting them, individually, in trays with aluminum foil. After reaching a constant weight, the muscles were weighed and its DM was calculated. Thereafter, the meat muscles were ground by using an electrical grinder, homogenized, and representative samples were obtained for the chemical analysis. Then, the meat samples were analyzed for CP, EE, and ash according to AOAC (2005) procedures.

Sensory analysis

Sensory characteristics of 20 samples from each raw broiler cut were carried out immediately after slaughtering. Acceptability as a composite of color, texture, and aroma was estimated using a nine-point hedonic scale (Economou *et al.*, 2009). The points of used scale were: excellent, 9; very good, 8; good, 7; acceptable, 6; poor (first off odor and off-taste development), <6; and a score of 6 was used as the lower limit of acceptability.

Statistical analyses

The results were analyzed statistically by using the SPSS statistical program (IBM, version 22, Chicago, USA 2013). A one-way ANOVA test was used to analyze data, which was accompanied by Duncan's multiple range tests to determine the differences between the treatment means. The sensory characteristics score of meat was analyzed by using non-parametric tests; therefore, Kruskal-Wallis-test was used to examine the significant differences between the means. The results were presented as means ± SE. Probability of less than 0.05 *($P < 0.05$)* was considered significant values.

Results

Feeding of potato peels or sugar beet pulp to broilers did not affect *($P > 0.05$)* the digestibility of DM, CP, EE, CF, and ash of the diets compared to the control, but slightly reduced *($P < 0.05$)* the digestibility of OM (Table 3). However, adding the enzyme to these ingredients increased *($P < 0.05$)* the digestibility of the measured dietary nutrients, but without any effect on the ash digestibility. Moreover, it was noticed that the effect of the enzyme on the digestibility rates was significantly *($P < 0.05$)* higher with sugar beet pulp than with potato peels, especially in the digestibility of EE and CF.

Table 3. Apparent digestibility (%) of different nutrients in broiler chickens at the end of the experiment (Mean ± SE)

Item	Group					*P*-value
	Control	Potato peels	Sugar beet pulp	Potato peels + Enzyme	Sugar beet pulp + Enzyme	
Dry matter	73.81±1.55^{ab}	68.15±0.59^{b}	68.00± 1.51^{b}	74.00±1.63^{a}	74.55±1.19^{a}	0.011
Organic matter	73.14±0.39^{b}	70.78±0.44^{c}	69.85± 1.07^{c}	76.77±0.96^{a}	78.02±0.64^{a}	0.034
Crude protein	67.20±1.24^{b}	65.33±1.03^{b}	64.14±1.50^{b}	71.82±0.85^{a}	73.06±0.99^{a}	0.005
Ether extract	73.13± 1.90^{c}	72.49±0.37^{c}	74.44±0.89^{c}	79.32±0.62^{b}	83.89±0.56^{a}	0.001
Crude fiber	19.44±1.46^{c}	14.93±1.14^{c}	15.48±2.88^{c}	23.24±1.29^{b}	31.42±2.33^{a}	0.006
Ash	44.72±1.87	44.04± 1.07	44.18±1.48	45.09±0.94	45.66±1.03	0.967

$^{a, b}$Means within the same row with different superscripts are significantly different ($P < 0.05$).

The pH values of the digesta in gastrointestinal organs/segments of broilers are shown in Table 4. Mostly, there was no significant *($P > 0.05$)* difference between potato peels or sugar beet pulp and the control either at the starter or grower period, except the pH of the gizzard, at the starter period, showed a lower value. Moreover, the pH of gizzard at the starter phase and that of the crop at the grower one in the beet pulp group were lower *($P < 0.05$)* than that of potato peels. Nevertheless, during the starter period, the addition of the enzyme reduced the pH values in the crop, stomach, and small intestine, but not in the caecum. The reducing effect of the enzyme on the pH was greater *($P < 0.05$)* in the beet pulp group, especially the pH of proventriculus and duodenum, than that of potato peels. During the grower period, the enzyme also reduced significantly *($P < 0.05$)* the pH of crop and gizzard only, but with a numerical decreasing effect on the pH of the proventriculus and small intestine segments, and did not affect the pH of the caecum.

Table 4. pH values of gastrointestinal digesta in broiler chickens fed different experimental diets, at the end of starter and grower periods (Mean ± SE)

Item	Group					*P*-value
	Control	Potato peels	Sugar beet pulp	Potato peels + Enzyme	Sugar beet pulp + Enzyme	
Starter Period						
Crop	5.37±0.03[a]	5.36±0.02 [a]	5.36± 0.01[a]	5.22±0.06[b]	5.21±0.03[b]	0.016
Gizzard	3.59±0.04[a]	3.44± 0.03[b]	3.28±0.05 [c]	3.03±0.05 [d]	3.07±0.03[d]	< 0.001
Proventriculus	4.58± 0.08 [a]	4.58±0.12 [a]	4.63±0.05 [a]	4.48±0.04 [a]	4.23±0.08[b]	0.028
Duodenum	6.34±0.03[a]	6.29±0.02[ab]	6.15±0.09[b]	6.11±0.06[b]	5.39±0.05[c]	< 0.001
Jejunum	6.26±0.02[a]	6.15±0.03[ab]	6.17±0.03[ab]	6.10±0.06[b]	6.05±0.04[b]	0.033
Ileum	6.56±0.08[ab]	6.48±0.0[abc]	6.73±0.06[a]	6.42±0.04[bc]	6.27±0.14[c]	0.023
Caecum	6.74±0.01	6.65±0.06	6.63±0.08	6.53±0.12	6.43±0.14	0.161
Grower period						
Crop	5.84±0.09[a]	5.47±0.33[a]	4.95± 0.38[b]	4.72±0.17[c]	4.42±0.48[c]	0.005
Gizzard	3.71±0.51[a]	3.45± 0.46[ab]	3.22±0.08[abc]	3.05±0.03[bc]	2.72±0.92[c]	0.008
Proventriculus	5.09± 0.38	5.09±0.53	4.80±0.27	4.77±0.81	4.31±0.26	0.070
Duodenum	6.13±0.48	6.03±0.30	5.98±0.26	5.98±0.17	5.83±0.18	0.723
Jejunum	6.22±0.06	6.14±0.31	6.12±0.21	5.92±0.28	5.75±0.23	0.076
Ileum	5.39±0.12	6.05±0.57	6.05±1.03	5.99±0.61	5.90±0.08	0.328
Caecum	6.55±0.30	6.56±0.30	6.87±0.12	6.50±0.39	6.42±0.44	0.533

[a, b] Means within the same row with different superscripts are significantly different ($P < 0.05$).

Comparing to the control, feeding of 15.0% potato peels did not *(P > 0.05)* affect the intestinal morphology during the starter or grower period (Table 5). However, dietary inclusion of 7.5% sugar beet pulp reduced *(P < 0.05)* the villus height, villus height/crypt depth ratio, and enlargement factor during the starter period, whereas at the grower phase the effect of beet pulp on intestinal morphology was similar *(P > 0.05)* to that of control and potato peels. Supplying the potato peels or beet pulp diets with enzymes increased the villus height, villus height/crypt depth ratio, and enlargement factor either at starter or grower period. The effect of the enzyme was higher *(P < 0.05)* with sugar beet pulp than with potato peels, especially during the grower period.

Table 5. Intestinal morphology of broiler chickens fed different experimental diets, at the end of starter and grower periods (Mean ± SE)

Item	Group					*P*-value
	Control	Potato peels	Sugar beet pulp	Potato peels + Enzyme	Sugar beet pulp + Enzyme	
Starter period						
Villus height, µm	728.70±28.49[bc]	660.69±26.62[c]	569.22±22.59[d]	767.19±24.38[ba]	832.38±27.12[a]	<0.001
Crypt depth, µm	138.46±4.55	149.70±4.44	141.14±6.18	135.99±4.13	137.26±4.34	0.075
Villus height/crypt depth ratio	5.26±0.32[bc]	4.41±0.45[cd]	4.03±0.27[d]	5.64±0.28[ab]	6.06±0.27[a]	0.003
Enlargement factor	7.76±0.52[b]	6.74±0.48[cb]	5.74±0.37[c]	9.52±0.70[a]	9.87±0.56[a]	0.001
Grower period						
Villus height, µm	893.00±39.85[b]	912.67±17.88[b]	858.56±18.17[b]	915.69±17.09[b]	1328.96±29.04[a]	<0.001
Crypt depth, µm	217.55±8.82	220.23±4.15	225.42±7.59	210.44±4.63	218.87±5.10	0.186
Villus height/crypt depth ratio	4.10±0.49[b]	4.14±0.55[b]	3.81±0.31[b]	4.35±0.59[b]	6.07±0.51[a]	<0.001
Enlargement factor	7.50±0.46[b]	7.66±0.40[b]	7.74±0.36[b]	9.32±0.42[a]	13.68±0.66[a]	0.001

[a, b] Means within the same row with different superscripts are significantly different ($P < 0.05$).

Concerning the meat quality of broilers, the effect of different treatments on the breast (Table 6) and thigh (Table 7) muscles was nearly identical. Generally, feeding of potato peels or sugar beet pulp did not *(P > 0.05)* affect the physicochemical and sensory characteristics of these muscles, except increasing the ash content. Sugar beet pulp was able to decrease the EE percentage of the thigh cuts only compared to the control. The pH values of meat, at 2h or 24 h, were not affected *(P > 0.05)* by different treatments. However, dietary supplementation of the enzyme had significant *(P < 0.05)* effects in increasing the CP content and reducing the EE of the breast and thigh meat. Moreover, adding the enzyme significantly *(P < 0.05)* increased the water holding capacity, but reduced the cooking loss. Nevertheless, the enzyme did not affect *(P > 0.05)* the sensory characteristics of the breast or thigh meat.

Table 6. Physiochemical and sensory characteristics of raw broiler breast muscles in different experimental groups at the end of the experiment (Mean ± SE)

Item	Group					*P*-value
	Control	Potato peels	Sugar beet pulp	Potato peels + Enzyme	Sugar beet pulp + Enzyme	
Chemical composition						
Moisture, %	74.21±0.39	73.88± 0.53	74.15±0.60	75.22±0.93	75.76±0.26	0.379
Crude protein, %	83.78± 0.49[b]	83.36±1.73[b]	84.16±1.86[b]	87.67±0.97[a]	87.58±0.40[a]	0.009
Ether extract, %	9.86±0.78[a]	8.98±1.52[a]	7.73±1.84[a]	5.51±1.04[b]	5.66±0.47[b]	0.005
Ash, %	2.48±0.43[b]	3.78±0.24[a]	4.23±0.14[a]	2.94±0.13[b]	2.88±0.07[b]	0.009
Physical characteristics						
pH at 2h	6.23±0.17	6.20±0.14	6.20±0.11	6.19±0.10	6.08±0.11	0.902
pH at 24h	5.69±0.08	5.62±0.05	5.62±0.01	5.69±0.11	5.70±0.13	0.052
Water holding capacity, %	83.09±0.02[b]	80.47±0.05[b]	77.49±0.01[b]	90.07±0.01[a]	86.39±0.02[a]	0.018
Cooking loss, %	39.72±3.66[a]	37.99±2.46[a]	42.66±3.29[a]	32.93±2.53[b]	33.01±1.49[b]	0.012
Sensory properties						
Color	8.67±0.21	8.67±0.14	8.17±0.11	8.83±0.17	8.83±0.11	0.101
Texture /Touch	8.33±0.17	8.33±0.21	8.33±0.52	8.67±0.21	8.50±0.22	0.745
Chicken aroma	8.17±0.17	8.50±0.50	8.66±0.33	8.50±0.23	8.50±0.51	0.335

[a, b] Means within the same row with different superscripts are significantly different ($P < 0.05$).

Table 7. Physiochemical and sensory characteristics of raw broiler thigh muscles in different experimental groups at the end of the experiment (Mean ± SE)

Item	Group					*P*-value
	Control	Potato peels	Sugar beet pulp	Potato peels + Enzyme	Sugar beet pulp + Enzyme	
Chemical composition						
Moisture, %	73.21±1.33	72.97± 0.95	74.90±0.43	75.01±0.40	75.06±1.15	0.762
Crude protein, %	76.93± 1.44[b]	75.04±0.51[b]	77.79±3.77[b]	79.85±1.69[a]	82.59±1.97[a]	0.009
Ether extract, %	16.38±0.48[a]	17.33±0.30[a]	13.56±0.26[b]	13.86±0.17[b]	10.91±0.18[c]	0.013
Ash, %	2.96±0.11[c]	3.90±0.17 [b]	4.92±0.40 [a]	2.56±0.19 [c]	2.77±0.19 [c]	0.004
Physical characteristics						
pH at 2h	6.03±0.28	6.08±0.31	6.07±0.28	5.81±0.28	5.76±0.29	0.890
pH at 24h	5.59±0.11	5.57±0.03	5.61±0.13	5.55±0.04	5.59±0.15	0.218
Water holding capacity, %	84.25±0.02[b]	80.89±0.02[b]	80.95±0.01[b]	90.08±0.01[a]	86.87±0.04[a]	0.001
Cooking loss, %	37.89±1.75[a]	37.50±0.82[a]	37.90±3.35[a]	32.56±2.56[b]	33.91±2.33[b]	0.005
Sensory properties						
Color	8.50±0.29	8.67±0.33	8.00±0.01	8.67±0.30	8.68±0.30	0.488
Texture /Touch	8.00±0.01	8.67±0.50	8.67±0.33	8.77±0.33	8.67±0.22	0.076
Chicken aroma	8.50±0.17	8.67±0.21	8.66±0.33	8.67±0.30	9.00±0.01	0.801

[a, b] Means within the same row with different superscripts are significantly different ($P < 0.05$).

Discussion

There is an increasing interest to evaluate the feeding value of alternative cheaper feeds for poultry and reducing the feed competition. The growing production of potato peels and sugar beet pulp and their moderate nutrient contents make them potential ingredients in poultry diets. The high fiber content and the presence of anti-nutritional factors are the major factors limiting the efficient utilization of peels and beet pulp by poultry. Using enzymes to reduce the anti-nutrients in these by-products can enhance their utilization by poultry. The maximum levels of potato peels (15.0%) and sugar beet pulp (7.50%), which could start to affect the broiler performance (Jiménez-Moreno *et al.,* 2011; Diarra *et al.,* 2012), were tested in this study. The potato peels and sugar beet pulp were found to contain about 2690 and 646 ME kcal/kg, respectively (Egyptian Central Laboratory for Food and Feed, 2001) as well as 5.45% and 19.0% CF, in respective order. Moreover, both ingredients contain about 10.5% of CP.

Nutrients digestibility

In this study, the potato peels and sugar beet pulp diets reduced only the digestibility of OM, but without any negative effect on the DM, ash, EE, CF, and CP digestibility. The reduction in OM digestibility could be due to the decrease in the digestibility of starch (Fugui *et al.,* 2012). Usually, it has been known that dietary fiber decreased nutrient digestibility and metabolizable energy in poultry diets (Jørgensen *et al.,* 1996). Also, dietary fiber has been recognized as a diluent and an anti-nutritional factor in poultry diets due to its adverse effects on energy intake and digestibility of dietary nutrients (Rougière and Carré, 2010). Solubility, water-holding ability, bulk, viscosity, fermentative activity, and other Physico-chemical properties of fiber-rich ingredients affect the development and pH of the gastrointestinal tract and consequently, they may have nutritional impacts on the poultry industry (Jiménez-Moreno *et al.,* 2009). It was found that the digestibility of DM, OM, nitrogen, and energy was found to be lower with sugar beet pulp than with oat hull inclusion (Gonzalez-Alvarado *et al.,* 2010). Moreover, the addition of sugar beet pulp reduced the digestibility of OM compared to the control diet. A reduction in the digestibility of OM was also detected in broilers by Pettersson and Razdan (1993) when the dietary rate of sugar beet pulp was raised from 2.3 to 9.2%.

Supplementation of the enzyme to the diets increased the digestibility of DM, OM, EE, CF, and CP. The effect of the enzyme with beet pulp was higher than potato peels, especially for EE and CF digestibility. Enzymes break down the NSPs and other anti-nutritional factors found in these ingredients, reducing intestinal viscosity and improving the gut performance, and consequently increased nutrients digestibility (Amerah, 2015). Also, enzymes cause the breakdown of the plant cell wall and subsequently release the nutrients encapsulated by the cell wall (Ravindran, 2013). Higher rates of apparent digestibility of DM, OM, CP, and EE were observed for broiler chicks fed enzyme-supplemented diets when compared to the control group (Khan *et al.,* 2006). Moreover, the use of commercial enzymes in poultry diets containing sunflower meals can enhance the digestion of fiber and decrease its deleterious effects (Alagawany *et al.,* 2017). The obtained results of the enzyme on nutrients digestibility in this study explaining the improvement in the performance of broilers fed high levels of potato peels and sugar beet pulp with enzymes in the research of Abdel-Hafeez *et al.,* (2018).

pH values of gastrointestinal digesta

Feeding of potato peels or sugar beet pulp reduced significantly the pH of gizzard at the starter period. Dietary fiber was reported to reduce the pH in gizzard which aids pepsin activation and the solubility of the minerals sources (Guinotte *et al.,* 1995). Moreover, the inclusion of moderate amounts of fiber in broiler diets can improve HCl, bile acids, and enzyme production (Sacranie *et al.,* 2012), and subsequently can affect the digesta pH. The reducing effect of sugar beet pulp on the pH of gizzard (at starter period) and crop (at the grower one) was higher than that of potato peels could be due to the greater solubility of its fiber (Jimenez-Moreno *et al.,* 2009). Enzyme supplementation reduced significantly the pH of crop and gizzard, with a numerical diminishing effect on pH in most other segments, but without any effect on the pH of the caecum. It was noticed that the concentrations of short-chain fatty acids and lactic acid as well as the pH values of the gastrointestinal tract digesta were closely related to the density and activity of the resident microflora (Engberg *et al.,* 2002; Ricke, 2003). Changes in the fermentation end products at the different segments of the digestive tract can indicate that bacterial populations are affected by enzyme supplementation. Therefore, it is assumed that one of the enzyme functions in the broiler diets could be the modification of the resident microflora. The decreasing effect in digesta pH by an enzyme with sugar beet pulp was more significant than with potato peels, which could be attributed to the fibers of sugar beet pulp were more digestible. This finding is supported by the obtained results of CF digestibility in the present study.

Intestinal morphology

The small intestine development can be evaluated through the measuring of villus height, crypt depth, and surface area to determine the available area for digestion and absorption (Franco *et al.,* 2006). Feeding of 15.0% potato peels did not affect the intestinal morphology, whereas 7.50% sugar beet pulp decreased the villus height at the starter period but without any effect during the grower one. The impact of beet pulp could be due to increasing the digesta viscosity in the gut with thin mucosa at younger ages. Supplying of enzymes to the diets increased the height and area of the villus in the intestine. The measurement of the intestinal villus area was highly correlated with the total number of epithelial cells in the villus (Hasan and Ferguson 1981). Therefore, it seems that enzyme supplementation could lead to an increase in digestion and absorption of the dietary nutrients in the small intestine. Moreover, enzymes can increase the ratio of villus height to crypt depth. A higher villus height to crypt depth ratio resulted in a reduced turnover of the intestinal mucosa, resulting in higher growth efficiency of the animals (Van *et al.,* 2005). Thus, an increase in villus height or villus height to crypt depth ratio was accompanied by an enhancement in the digestion and absorption of dietary nutrients (Hou *et al.,* 2013).

Meat quality

The pH, texture, color, water holding capacity, cooking loss, and chemical compositions are considered the main parameters of meat quality measurement (Mendes *et al.,* 2003). The pH measured at 2, 24 hours post-mortem is critical for meat quality, as it is directly related to proteins and meat pigments. Therefore, the stability of the pH values affects the characteristics of color, cooking weight loss, water-holding capacity, juiciness, and softness (Qiao *et al.,* 2001). In the present study, no differences were observed in pH values of breast and thigh muscle, at 2h or 24 h after slaughter among the treatments. These results are inconsistent with that reported by previous studies (Zakaria *et al.,* 2010; Dalólio *et al.,* 2015). The addition of enzyme to potato peels and sugar beet pulp significantly improved the water holding capacity of broiler breast and thigh muscles. The higher water holding capacity of such groups was accompanied by low cooking loss and better meat quality due to the low loss of protein into the water during cooking (Bowker and Zhuang, 2013). The cooking loss is a liquid and soluble matter lost from the meat during cooking. This water loss is of economic impacts as it reduces the meat nutritional value due to the loss of some nutrients, resulting in less tender bad flavor meat (Lee *et al.,* 2012; Suo *et al.,* 2015). In this respect, Oko *et al.,* (2012) reported that meat with low cook loss had higher quality and protein content. Our results showed that a higher protein percentage in both breast and thigh muscles of chicken fed diets supplemented with enzymes, besides, these groups were accompanied by a higher water holding capacity. Muscle protein can hold many water particles on its surface, a relationship that has been found in previous research (Bowker and Zhuang, 2013; Lee *et al.,* 2017).

Feeding of potato peels with enzyme and sugar beet pulp with or without enzyme to broiler chicken diets was associated with a decrease in fat contents of broiler breast and thigh muscles when compared to the control group. This could be attributed to an increase in the protein content of carcasses (Waldroup *et al.,* 2001) and the high fiber content of sugar beet pulp (Pettersson and Razdan, 1993). Regarding the ash content, it was significantly higher in the potato peels and sugar beet pulp group than in control and other experimental groups. This could be attributed to their high ash content in these products (Abdel-Hafeez *et al.,* 2018). In this respect, Pettersson and Razdan (1993) mentioned that the ash content in broiler chicken carcasses was significantly affected by the type of diet and increasing sugar beet pulp inclusion in the diets.

No differences were found in color, texture, and aroma among experimental groups. However, other studies found that feeding of potato peels or sugar beet pulp had a positive impact on the sensory characteristics, as breast and thigh muscles were scored better in comparison to control (AbouSekken *et al.,* 2013; Beckford and Bartlett 2015). This high acceptability highlighting that potato peels and sugar beet pulp with or without enzyme could be used for broiler feeding without any adverse effect on the sensory characteristic of poultry meat.

Conclusion

Feeding of 15.0% potato peels or 7.5% sugar beet pulp to broiler chickens did not affect the digestibility of CP, EE, or CF, but slightly reduced the digestibility of OM of the diets. Adding the enzyme to the diets containing these ingredients can improve the digestion and absorption of nutrients through its effects in increasing the digestibility rates of nutrients and enhancing the development of the small intestine. Moreover, the tested ingredients did not influence the chemical composition or quality of broilers' meat. Nevertheless, supplementation of the enzyme to the diets could increase the CP content and reduce the EE of carcass meat. Also, the dietary enzyme inclusion can improve the meat quality of broilers via enhancing the water holding capacity of meat with diminishing the cooking loss rate. Therefore, potato peels up to 15% and sugar beet pulp up to 7.5% can be included in the broiler diets after supplying them with enzymes. Moreover, these ingredients can help in solving the problem of low availability and rising costs of traditional poultry feeds.

Conflict of interest: The authors declare that there is no conflict of interest.

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