Effects of potato peels inclusion with exogenous enzymes in broiler diet on growth performance, nutrients digestibility and carcass characteristics

Muhammad Aziz ur Rahman1, Usama Jamal1, Urooj Anwar1, Muhammad Qamar Bilal1, Muhammad Riaz1, Mubasher Hussain1 and Sibtain Ahmad1,2
1Institute of Animal and Dairy Sciences, University of Agriculture, Faisalabad, Punjab, Pakistan
2University of Agriculture, Faisalabad Sub Campus Depalpur Okara, Faisalabad, Punjab, Pakistan

Abstract
The purpose of the research was to investigate the effects of including potato peels (PP) in broilers diet with exogenous enzymes supplementation on feed intake (FI), body weight gain (BWG), nutrient digestibility and carcass parameters. For this purpose, five iso-caloric and iso-nitrogenous rations were formulated with different levels of PP (0, 5, 10, 15 and 20%). Experimental diets were supplemented with a blend of exogenous enzymes (Xylanase, Mannanase, Protease, Cellulase). A total of four hundred male broiler chicks (day old) of 38 ± 3 gram were randomly distributed into 5 experimental groups in such a way that each group had 8 replicates and each replicate had 10 birds. Results revealed that the inclusion of PP @ 5% with exogenous enzymes had similar FI, BWG, nutrient digestibility and carcass parameters. However, the inclusion of P @ of 10, 15, and 20% with exogenous enzymes in the broiler diet adversely affected the BWG, feed conversion ratio and nutrient digestibility (p < 0.05). Results of carcass parameters were not affected (p > 0.05) by dietary treatments. Based on findings, it is concluded that 5% addition of PP with exogenous enzymes could be practiced in broiler diet without any adverse effect on the performance of commercial broilers.

Corresponding author:
Muhammad Aziz ur Rahman, Institute of Animal and Dairy Sciences, University of Agriculture, Faisalabad, Punjab, Pakistan.
Email: drazizurrhanman@uaf.edu.pk

Creative Commons Non Commercial CC BY-NC: This article is distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 License (https://creativecommons.org/licenses/by-nc/4.0/) which permits non-commercial use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access page (https://us.sagepub.com/en-us/nam/open-access-at-sage).
Keywords
Broiler, carcass characteristics, exogenous enzyme, growth performance, potato peels

Introduction
In poultry industry, 65% of total feed cost comprises of the ingredients serving as energy sources. Animal nutritionists are using agro-industrial by-products to reduce the rising costs of conventional feed ingredients. Abundantly available agricultural by-products like potato peels (PP), sweet PP, citrus pulp, Yucca schidigera, soybean hulls, and pulp of sugar beet are being used in the poultry industry.

Potato peels are one of the agro-industrial by-products having a good nutrition profile i.e. 2690 (kcal/kg) metabolizable energy (ME), and 11.38% crude protein (CP). However, the use of PP as a feed ingredient is restricted to ruminant feed and not commonly practiced in the poultry feed due to its higher contents of non-starch polysaccharides (NSPs). Potato peel’s NSP’s are cellulose, hemicellulose, xylose and lignin. Moreover, in the insoluble fibrous cell walls, some nutrients like starch and protein are also trapped, which could be available to poultry birds by exogenous enzymes supplementation after digestion of fiber inside the insoluble fibrous cell walls.

Exogenous enzymes which can degrade fiber are non-starch polysaccharidase (NSPase). It has been reported that NSPase reduces the negative effects of NSPs in the diets of poultry. Non-starch polysaccharidase enzymes (cellulase, hemicellulase, xylanase, b-glucanase and pectinase) are being used in the poultry diets to improve the digestibility of NSP’s contents of feed. Non-starch polysaccharidases also improve the apparent digestion, trapped protein and starch inside NSP’s observed that NSPase enzymes supplementation in wheat-barley based diets (high NSPases and fiber) of broilers improved the performance of broilers. Furthermore, Walters et al. and Attia et al. reported that NSPase improved the caloric value of low energy diets as well as reducing the anti-nutritive factors linked with NSP’s.

In a recent study of Abdel-Hafeez et al., PP in combination with exogenous enzymes were added up to 15% in broilers’ diet without compromising the performance of broiler. Therefore, PP along with exogenous enzymes has the potential to be used to a higher extent in the feed of broilers. To date, no study has reported the impacts of adding PP more than 15% with exogenous enzymes in the diet of broilers on FI, BWG, feed efficiency, nutrient digestibility, and carcass characteristics of broilers. Therefore, the current research was planned to investigate the effect of inclusion of graded levels of PP (5, 10, 15 and 20%) with a blend of dietary enzymes on total FI, BWG, FCR, carcass parameters and digestibility of nutrients in growing broilers.

Materials and methods
Birds and management
The current study was carried out at Raaja Mohammad Akram Animal Nutrition Research Center, University of Agriculture, Faisalabad, Pakistan. In the present study, four hundred (n = 400) day-old male broiler chicks were procured from the local broiler breeder hatchery.
On the very first day of the experiment, all the chicks were weighed individually and randomly distributed into five experimental treatment groups. Each experimental treatment group had eight replicates and each replicate had ten chicks. At the arrival of the birds, the initial weight of chicks was 38 ± 3 grams. Each replicate was reared in a separate pen of dimension 4′′ × 3′′ × 2.5′′. Rice husk was used as a bedding material in each pen. The light duration of twenty-four hours per day was maintained throughout the experimental trial. At the start of the experiment, 33°C brooding temperature was ensured and decreased regularly 2°C per week. The room temperature was reached approximately 20°C at the termination of the trial. Ad-libitum feed in the form of pellet crumbs was offered to chicks throughout the experiment.

**Experimental design and diets**

In the current study, the chicks in treatment one were reared on a feed that contained traditional feed ingredients without any exogenous enzymes supplement. The chicks in treatment 2, 3, 4, and 5 were reared on rations contained PP @ 5%, 10%, 15% and 20%, respectively. The duration of the experiment was of 5 weeks. All the experimental diets were in the form of pellet crumbs.

Proximate analysis of conventional feed ingredients was carried out by using the standard methods according to AOAC. Analyzed feed was used to formulate an experimental ration by following the recommendation of NRC for broiler. It was ensured that all experimental diets were isocaloric and isonitrogenous. The ingredients inclusion level and nutrient composition of the experimental rations are presented in Table 1. PP was the tested unconventional feed ingredient in combination with the exogenous enzyme. PP was prepared into meal and subjected to chemical analysis before inclusion in the experimental rations. The raw PP was collected from the Pepsi-Co Processing plant situated in Sunder Industrial Estate, Lahore-Pakistan. Potato peels were sun-dried until the moisture level was reduced to 12%. Dried PP was ground in hammer mills before addition into experimental diets.

The blend of exogenous enzymes (Avizyme®) was supplemented in the experimental ration containing PP, @ 0.250 kg/ton following the instruction of the supplier. Avizyme® is an enzyme product of Chinese Company (Shandong, China), obtained from Polaris, Pakistan. Each gram contains 7400 IU Xylanase, 10,000 IU Cellulase, 5000 IU Protease, 5000 IU Xylanase, and 900 IU Mannanase. The reason for selecting a blend of exogenous enzymes was to reduce antinutritional factors quantity by the breakdown of antinutritional factors found in the PP.

**Data collection**

*Feed intake and growth performance.* The rations were fed to the birds under trial on daily basis. The weekly data of total FI was obtained by the difference method. In the difference method, the difference between the amount of experimental ration offered and the refused was calculated. For average weekly FI per broiler, the intake of feed per week per pen was divided by the total number of broilers in every replicate. The weekly FI was corrected with mortality to avoid any chance of error. The experimental birds were weighed individually on the first day of the experiment, and after that weekly
body weight (BW) was measured per pen. The weekly BWG was determined as the difference between the initial BW of birds at the start of the week and the final BW at the end of the week. The number of total mortalities was recorded daily in each experimental treatment throughout the experimental period. The feed conversion ratio was measured by dividing the quantity of experimental feed consumed per bird in a given duration by the weight gain per bird at the same duration.

**Nutrient digestibility trial.** Nutrient digestibility was determined on the 35th day of the experiment by using the marker method. The marker used for nutrient digestibility was acid insoluble ash (AIA). On day 31 of the experimental trial, celite® was mixed in experimental rations. Feeding of Celite® mixed rations continued till the end of the trial.

### Table 1. Ingredient and nutrient composition of diets.

| Ingredients (%) | 0 PP | 5 PP | 10 PP | 15 PP | 20 PP |
|-----------------|------|------|-------|-------|-------|
| Corn            | 60   | 55   | 50    | 45    | 40    |
| Rice polish     | 2    | 2.45 | 4.05  | 5     | 4.86  |
| Soybean meal    | 25.57| 22   | 23    | 22.41 | 22.13 |
| Potato peel meal| 0    | 5    | 10    | 15    | 20    |
| Sunflower meal  | 3.31 | 3.78 | 1.44  | 0     | 0     |
| Fish meal       | 2.3  | 4    | 3     | 4     | 3.5   |
| Poultry by product meal | 2.5 | 3.37 | 4     | 3.5   | 3.8   |
| Vegetable oil   | 2    | 2    | 2     | 2.5   | 3     |
| NaCl            | 0.25 | 0.25 | 0.25  | 0.25  | 0.25  |
| DCP             | 1.1  | 1.1  | 1.1   | 1.1   | 1.1   |
| DL-Methionine, 99% (0.03) | 0.2 | 0.23 | 0.25  | 0.29  | 0.31  |
| L-Lysine sulphate 55% (0.07) | 0.49 | 0.54 | 0.63  | 0.68  | 0.74  |
| Vitalink®<sup>a</sup> | 0.25 | 0.25 | 0.25  | 0.25  | 0.25  |
| Nutrimin®<sup>b</sup> | 0.03 | 0.03 | 0.03  | 0.03  | 0.03  |
| Total           | 100  | 100  | 100   | 100   | 100   |
| Nutrient composition (%) | | | | | |
| CP              | 19.98| 19.93| 20.01 | 19.92 | 19.99 |
| ME (Kcal/kg)    | 2988 | 3005 | 2993  | 2999  | 3010  |
| CF              | 3.37 | 3.87 | 4.01  | 4.13  | 4.23  |
| Ca              | 0.80 | 0.89 | 0.92  | 0.94  | 0.96  |
| P               | 0.36 | 0.39 | 0.42  | 0.40  | 0.41  |
| Dig. Lys.       | 1.14 | 1.14 | 1.14  | 1.14  | 1.14  |
| Dig. Met.       | 0.47 | 0.47 | 0.47  | 0.47  | 0.47  |
| Sodium          | 0.17 | 0.18 | 0.17  | 0.18  | 0.18  |
| Potassium       | 0.74 | 0.69 | 0.68  | 0.66  | 0.63  |

<sup>a</sup>Every kg of Vitalink® provided: 20,000 KIU of vitamin A; 5400 KIU of vitamin D3; 48,000 mg of vitamin E; 4000 mg vitamin K3; 4000 mg vitamin B1; 9000 mg vitamin B2; 7600 mg vitamin B6; 20 mg vitamin B12; 60,000 mg niacin; 20,000 mg pantothenic acid; 1600 mg folic acid; 200 mg biotin.

<sup>b</sup>Every kg of Nutrimin® provided: 10,000 mg of iron; 120,000 mg of zinc; 140,000 mg of manganese; 12,000 mg of copper; 1800 mg of iodine; 400 mg of cobalt; 360 mg of selenium.
trial. On day 35, polythene sheets were placed under each pen to collect droppings twice a day. The particles like feathers, feed, or dust were removed from the feces carefully. The collected fecal samples were transferred to a plastic bag. A plastic bag containing fecal samples was transferred into the freezer to freeze samples at $-20^\circ$C.

**Carcass characteristics.** Three birds from each replicate, with nearly similar live body weight, were chosen at the end of the trial. Experimental broilers were weighed individually, subjected to a day feed withdrawal time. During the feed withdrawal time, it was ensured that all birds had free access to water. After the withdrawal period, all the birds were weighed again. Weighed birds were slaughtered for determination of carcass and internal organs weight. The carcass without internal organs (giblets) was weighed. Weighed giblets were expressed as a percentage of their live BW and measured as the carcass yield. Moreover, the weight of the thigh, breast, gizzard, liver (without gall bladder), spleen, and heart were recorded and its relation to the live BW of the birds, in percentages, was calculated.

**Chemical analyses.** Experimental feeds and fecal samples within the replicate were pooled into a single sample in such a way that each treatment had eight composite samples of feed and feces. Pooled samples were dried by using the hot air oven at 65°C. The dried feeds and fecal samples were ground and passed through a 0.5 mm sieve. These ground samples were stored at $-20^\circ$C. The experimental diets were further analyzed for dry matter, CP, ether extract as described in previous studies by using standard methods.4,5,23,24 For the determination of CP, the nitrogen content was determined by the Kjeldahl procedure and CP was further calculated as nitrogen contents $\times 6.25$. For determination of fat contents in the feed and fecal sample, Soxhlet apparatus was used. The fecal samples were analyzed for nitrogen by using Kjeldahl apparatus and AIA was determined in the ash samples of diet and feces.

**Calculations and statistical analysis.** The apparent nutrients digestibility coefficient25 was calculated as followed:

$$\text{Digestibility coefficient (\%) } = 100 - \left( 100 \times \frac{\% \text{ marker in feed}}{\% \text{ marker in feces}} \times \frac{\% \text{ nutrient in feces}}{\% \text{ nutrient in feed}} \right)$$

The current study was carried out in a completely randomized design. The mean of each replicate (pen) was considered an experimental unit. The effect of PP on intake, performance, nutrient digestibility and carcass parameters was determined by GLM by using MINITAB 15.26 The level of significance was set at 0.05 unless and otherwise stated. In case of significance, Tukey’s test was used to detect the differences in means.

**Results**

**Growth performance**

Data on weekly FI and live BW, and performance are shown in Table 2. In the starter period (0–21 days), the FI of birds fed experimental rations containing various levels of PP was similar to the control. Similarly, at the grower phase (22–35 days), the FI of
Table 2. Effect of dietary potato peel and exogenous enzymes supplementation on growth performance in broiler chickens during starter phase (0–5 weeks).

| Parameters | T1     | T2     | T3     | T4     | T5     | SEM  | P-value |
|------------|--------|--------|--------|--------|--------|------|---------|
| Week-1     |        |        |        |        |        |      |         |
| BWG (g)    | 141.66 | 138.31 | 119.34 | 111.59 | 105.53 | 3.00 | **      |
| Fl (g)     | 173.81 | 181.53 | 176.16 | 165.75 | 162.13 | 5.43 | NS      |
| FCR        | 1.23   | 1.31   | 1.48   | 1.49   | 1.53   | 0.03 | **      |
| Week-2     |        |        |        |        |        |      |         |
| BWG (g)    | 240.75 | 231.72 | 206.84 | 207.09 | 180.59 | 5.14 | **      |
| Fl (g)     | 409.34 | 420.16 | 415.09 | 406.69 | 409.63 | 9.04 | NS      |
| FCR        | 1.71   | 1.82   | 2.02   | 1.97   | 2.28   | 0.06 | **      |
| Week-3     |        |        |        |        |        |      |         |
| BWG (g)    | 546.06 | 504.22 | 452.00 | 434.94 | 419.97 | 14.12 | **      |
| Fl (g)     | 761.50 | 811.25 | 806.44 | 824.56 | 803.09 | 24.61 | NS      |
| FCR        | 1.40   | 1.61   | 1.79   | 1.91   | 1.92   | 0.06 | **      |
| 0–3 Weeks  |        |        |        |        |        |      |         |
| BWG (g)    | 928.47 | 874.25 | 778.19 | 753.63 | 706.09 | 18.13 | **      |
| Fl (g)     | 1344.70| 1412.90| 1397.70| 1374.80| 1374.80| 33.61 | NS      |
| FCR        | 1.45   | 1.61   | 1.79   | 1.86   | 1.95   | 0.05 | **      |
| Week-4     |        |        |        |        |        |      |         |
| BWG (g)    | 668.59 | 62.38  | 597.91 | 554.38 | 530.47 | 15.86 | **      |
| Fl (g)     | 989.70 | 980.80 | 975.10 | 980.20 | 986.60 | 23.89 | NS      |
| FCR        | 1.48   | 1.52   | 1.68   | 1.76   | 1.86   | 0.04 | **      |
| Week-5     |        |        |        |        |        |      |         |
| BWG (g)    | 359.00 | 378.30 | 395.83 | 422.91 | 416.94 | 18.34 | NS      |
| Fl (g)     | 799.94 | 847.98 | 879.52 | 894.00 | 865.94 | 26.12 | NS      |
| FCR        | 2.23   | 2.25   | 2.26   | 2.12   | 2.08   | 0.07 | NS      |
| 4–5 Weeks  |        |        |        |        |        |      |         |
| BWG (g)    | 1027.60| 1040.70| 993.70 | 977.30 | 947.40 | 29.18 | NS      |
| Fl (g)     | 1789.70| 1850.80| 1885.60| 1874.20| 1851.50| 41.7  | NS      |
| FCR        | 1.74   | 1.78   | 1.90   | 1.91   | 1.96   | 0.03 | **      |
| 0–5 Weeks  |        |        |        |        |        |      |         |
| BWG (g)    | 1956.10| 1944.90| 1771.90| 1730.90| 653.50 | 36.33 | **      |
| Fl (g)     | 3134.30| 3263.70| 3283.30| 3271.20| 3226.40| 60.36 | NS      |
| FCR        | 1.60   | 1.70   | 1.85   | 1.89   | 1.95   | 0.03 | **      |

NS, Non significant (P > 0.05), **: Significant (P < 0.05). Values which are not followed by common superscript with in a row differ significantly.

T1: Diet without any supplementation (basal diet); T2: Diet with supplementation of Enzyme @0.250 kg/ton + potato peels 5%; T3: Diet with supplementation of Enzyme @0.250 kg/ton + potato peels 10%; T4: Diet with supplementation of Enzyme @0.250 kg/ton + potato peels 15%; T5: Diet with supplementation of Enzyme @0.250 kg/ton + potato peels 20%.

diets contained various levels of PP was similar to that of the control. Overall, the experimental duration (0–35), FI in experimental treatments were statistically similar to the control.

The BW of broilers fed experimental rations contained PP @ 10, 15 and 20% respectively was lower (p < 0.05) than the control and experimental feed containing PP @ 5%
during week 1st, 2nd and 3rd, respectively. Similarly, during the starter phase (0–21 days), BW of birds fed experimental feeds contained PP @ 10, 15 and 20% respectively was less \((p < 0.05)\) than the experimental feed without PP and experimental feeds containing PP @ 5%. Similarly, the results of BW on 4th week represent that BW of broilers fed experimental diets contained PP @ 10, 15 and 20% respectively was less \((p < 0.05)\) than the birds fed rations without PP and experimental feed contained PP @ 5%. However, 5th week BW result showed that experimental rations did not influence BW of birds. In overall phase (0–35 d), BW of fed experimental rations contained PP @ 10, 15 and 20% respectively was lower \((p < 0.05)\) than the control and experimental ration contained PP @ 5%.

Similarly, during week 1st, 2nd and 3rd, the FCR of broilers fed experimental rations having PP @ 10, 15 and 20% respectively was more \((p < 0.05)\) than the control and diet containing PP @ 5%. Likewise, during starter phase (0–21 days), broilers fed experimental ration with PP @ 10, 15 and 20% respectively showed poorest FCR \((p < 0.05)\) than the control and diet contained PP @ 5%. The results of FCR on the 4th week showed that PP @ 10, 15 and 20% respectively performed poorly \((p < 0.05)\) than the control and 5% PP diet. However, 5th week there was no effect of diets on FCR. In overall phase (0–35 d), FCR of birds fed experimental ration contained PP @ 10, 15 and 20% respectively was poor \((p < 0.05)\) than the control and 5% PP diet.

**Nutrient digestibility**

The digestibility results of nutrients are presented in Table 3. Nutrient digestibility results revealed that DM, crude fiber, and CP digestibility was higher as in the control diet compared to experimental diets containing PP \((p < 0.05)\). Dry matter and CP digestibility were significantly reduced in birds fed a diet containing 20% PP as compared to other control diets \((p < 0.05)\). However, crude fiber digestibility was reduced in birds fed diets containing 15% and 20% PP. Results further showed that ether extract digestibility was not affected \((p > 0.05)\) by dietary treatments.

**Carcass traits**

The results of carcass characteristics are shown in Table 4. It was observed that total carcass yield, thigh weight and breast weight had no statistical differences among experimental treatments \((p > 0.05)\). Furthermore, gizzard, liver, spleen, and heart weight were similar \((p > 0.05)\) among the experimental treatments. The visible abdominal fat is also not affected by dietary treatments \((p > 0.05)\). However, a numerical difference was observed between control and diets containing unconventional PP in the rations. Abdominal fat was lower in the PP diets compared to the control.

**Discussion**

In this study, an attempt was made to get benefit from the use of cheap unconventional feed ingredients *i.e.* PP with exogenous enzymes. Four feeds were formulated to optimize the level of PP in the broiler diet. The rates of inclusion of PP levels were selected on the
maximum level used in the previous study.\textsuperscript{11} The upper inclusion level of PP was 5% more than the previous study\textsuperscript{11} where PP maximum inclusion level of 15% did not affect the performance of broilers.

Dry matter FI of chicks fed various levels of PP was similar to the control at the starter period as well as finisher period. This may be a sign of the capability of broilers to utilize the PP. The results of the current experiment are similar to the findings of a previous study\textsuperscript{27} that found that moderate fiber levels in the feed of growing broiler birds had

| Nutrient’s digestibility (%) | T1    | T2    | T3    | T4    | T5    | SEM  | P-value |
|------------------------------|-------|-------|-------|-------|-------|------|---------|
| Dry matter digestibility     | 96.88 | 96.83 | 96.76 | 95.84 | 95.24 | 0.19 | **      |
| Crude protein digestibility  | 81.58 | 78.75 | 81.07 | 73.13 | 81.25 | 0.91 | **      |
| Ether extract digestibility  | 89.26 | 87.92 | 90.11 | 89.45 | 88.39 | 0.43 | NS      |
| Fiber digestibility          | 78.61 | 71.99 | 68.50 | 65.87 | 62.90 | 1.44 | **      |

NS: Non-significant (P > 0.05), **: Significant (P < 0.05). Value which are not followed by common superscript within a row differ significantly.

T1: Diet without any supplementation (basal diet); T2: Diet with supplementation of Enzyme @0.250 kg/ton + potato peels 5%; T3: Diet with supplementation of Enzyme @0.250 kg/ton + potato peels 10%; T4: Diet with supplementation of Enzyme @0.250 kg/ton + potato peels 15%; T5: Diet with supplementation of Enzyme @0.250 kg/ton + potato peels 20%.

Table 4. Effect of dietary potato peel and exogenous enzymes supplementation on the carcass parameters in broiler chickens.

| Variables         | T1     | T2     | T3     | T4     | T5     | SEM  | P-value |
|-------------------|--------|--------|--------|--------|--------|------|---------|
| Carcass yield (%) | 61.96  | 63.21  | 61.26  | 59.75  | 59.96  | 0.95 | NS      |
| Breast meat (%)   | 35.94  | 35.35  | 35.57  | 33.86  | 34.13  | 0.93 | NS      |
| Thigh meat (%)    | 25.94  | 28.16  | 25.94  | 25.52  | 25.83  | 0.75 | NS      |
| Gizzard (%)       | 1.90   | 1.78   | 1.87   | 2.10   | 1.81   | 0.11 | NS      |
| Heart (%)         | 0.43   | 0.43   | 0.47   | 0.46   | 0.49   | 0.02 | NS      |
| Liver (%)         | 2.63   | 2.65   | 2.68   | 2.79   | 2.67   | 0.11 | NS      |
| Abdominal fat (%) | 0.42   | 0.33   | 0.25   | 0.20   | 0.22   | 0.03 | NS      |
| Spleen (%)        | 0.14   | 0.13   | 0.18   | 0.16   | 0.17   | 0.02 | NS      |

NS: Non-significant (P > 0.05), **: Significant (P < 0.05). Value which are not followed by common superscript within a row differ significantly.

T1: Diet without any supplementation (basal diet); T2: Diet with supplementation of Enzyme @0.250 kg/ton + potato peels 5%; T3: Diet with supplementation of Enzyme @0.250 kg/ton + potato peels 10%; T4: Diet with supplementation of Enzyme @0.250 kg/ton + potato peels 15%; T5: Diet with supplementation of Enzyme @0.250 kg/ton + potato peels 20%.
no effect on FI. However, in the recent study, an adverse effect of PP inclusion on FI of broiler was observed in the finisher phase. The harmful results of PP inclusion on broilers were due to the absence of exogenous enzymes in this study. However, reported that the adverse results of the unconventional feeds ingredients on FI could be minimized by supplementation of enzyme in the rations of broilers. Therefore, it could be assumed that the similar FI between treatments was due to supplementation of exogenous enzymes that started from the very first week of the current study. It has also been reported that exogenous enzymes have the ability to break the NSPs present in PP and improve nutrient digestibility and nutritive value of PP.

Nevertheless, in the present experiment, the digestibility of dry matter, CP and crude fiber were reduced when PP was supplemented @ 20% in the diet with exogenous enzymes supplementation. These results showed that the supplementation of exogenous enzymes was not sufficient to reduce the PP poor palatability and antinutritional factors at 20% inclusion of PP in broilers diet.

Weekly data of body weight gain in the current experiment explored that supplementation of PP in the diet of more than 5% had a negative effect on the body weight gain of broilers during the first four weeks. Better weight gain in birds fed 5% PP based feed in the first four weeks could be attributed to the prominent effect of exogenous enzymes on PP. It has been reported that the impact of the enzyme is attributed to its activity in breaking the polymeric chains of NSPs found in feeds, so improving the digestibility rates, and performance. Therefore, it could be speculated that exogenous enzymes used in the current study were unable to break the polymeric chains of NSPs found in feed that contained more than 5% PP in the first four weeks and hence reduced the body weight gain in birds fed more than 5% PP based diet during this period. However, bodyweight gain was similar in all experimental treatments at the 5th week. It is well established that enzymes secretion organs are underdeveloped in birds during the early age of life which results in less secretion of endogenous enzymes that leads to reduced digestion and absorption of nutrients and growth. Similar body weight gain in all experimental treatment at 5th week of age in the current experiment could be supported by the complete development of enzymes secreting organs that supported exogenous enzymes to break the polymeric chains of NSPs and antinutritional factors found in feed contained more than 5% PP and results in better body weight gain. Therefore, based on weekly data of body weight gain, it could be suggested that PP could be included in the diet of broiler at later stages of life in broilers.

In the current experiment, the final BW of the birds fed the rations without PP was similar to that of previous researchers. The significant reduction in BW of broilers in the starter and finisher phase fed the PP inclusion level 15% and 20% may be due to the higher level of indigestible dietary fiber with the increasing levels of PP. The decrease in BW of birds fed on rations contained PP at the inclusion level of 15% and 20% in the current study is accredited to its higher matter of raw starch and trypsin inhibitors. Results of BW in the current study with PP inclusion level 15% and 20% are similar to the findings of Muhammad et al. Similarly, other researchers including Maphosa et al., Ayuk and Muhammad et al. also reported similar results. However, Abdel-Hafeez et al. stated that unconventional feed ingredient PP could effectively be included @ 15% in the diet of broilers during the finisher phase without compromising
the performance of the birds. The improved BW in PP fed broiler @ 5% inclusion rate with exogenous enzymes supplementation in the current experiment may indicate that the supplementation of exogenous enzymes is important for the utilization of high fiber unconventional feeds ingredients. Findings from the current study revealed that supplementation of exogenous enzymes in feed contained high fibrous feed ingredients (PP) at certain levels, elevates the adverse impact of NSP contents, for example, negative influence on BWG.

It has been reported that use of unconventional feed ingredients without the addition of exogenous enzymes in broiler rations had a harmful effect on FCR.\textsuperscript{11} It has also been reported that the decrease in the FCR in broilers fed the diets with unconventional feed ingredients without exogenous enzymes supplementation is due to a higher passage rate and lower nutrient digestibility.\textsuperscript{36} Furthermore, it has also been reported that supplementation of exogenous enzymes in feed improved the FCR and reduced the cost of feed.\textsuperscript{37} The improved FCR by supplementation of the exogenous enzyme with unconventional feed ingredients was probably due to the breakdown of nutrients that were in bound form.\textsuperscript{38} This availability of nutrients from unconventional sources resulted in better digestibility and improved FCR. In the current study, FCR of diets containing PP @ 5% with supplementation of the enzyme was similar to the control. Therefore, it could be assumed that the exogenous enzymes started improving FCR in broilers diets containing PP @ 5% from the very first week and thereafter in the grower and finisher phases. However, exogenous enzyme addition in the diet was not enough to cope with the deleterious effects of PP antinutritional factor on FCR when PP inclusion level was higher than 5% in the diet of broilers. However, further research may improve FCR of broilers fed a higher level of PP in the diet by further supplementation of exogenous enzymes.

In the current study, carcass yield, relative thigh, and breast weight were similar in all experimental treatments. Similarly, the relative weight of liver, spleen and heart was also similar among all experimental treatments. Similar results have been reported in the recent studies of Abdel-Hafeez et al.\textsuperscript{11} and Attia et al.\textsuperscript{20} In the current experiment, the dressing percentage was also similar in all experimental treatments. The visible abdominal fat was numerically lower in birds fed the diet without PP. The lower abdominal fat in the birds fed the diet without PP could be explained by the fiber contents of the diet. It has been reported that birds fed diet with higher fiber levels fulfill birds only energy necessities for maintenance and spare no energy for fat deposition in the abdominal part of the broilers.\textsuperscript{11} The findings of the current study are analogous with the results of Sarikhan et al.\textsuperscript{39} who stated that fat of the abdomen in the broilers is reduced by increasing the level of fiber in the feed of growing broilers. The findings of the current study explored that the PP could be used at a rate of 5% with exogenous enzymes supplementation in the rations of growing broilers without any harmful impact on the growth performance. However, PP inclusion rate higher than 5% with exogenous enzymes supplementation in the diet of broilers negatively influence intake, performance, resulting in reduced weight gain, poor nutrient digestibility and higher FCR compared to the conventional diets.

Based on current study results, it is recommended that unconventional feed ingredients like PP (up to 5%) should be included in the diets of broiler with exogenous enzymes. The
addition of PP will not only solve the problem of shortage of conventional feed ingredients but will also reduce the rising costs of conventional feed ingredients.

**Author's contribution**

Conceptualization, methodology and supervision of the research project were done by Aziz ur Rahman and Sibtain Ahmad. Usama Jamal conducted the research trial, data curation and lab analysis. Resources for analysis were managed by Aziz ur Rahman. Urooj Anwar helped during lab analysis and statistical analysis. Aziz ur Rahman prepared the original draft of manuscript. Manuscript was reviewed and checked by all authors and finalized by Sibtain Ahmad. All authors approved the final version of the manuscript.

**Availability of data and material**

We accept the transparency; therefore, raw data and statistical data will be available for everyone.

**Code availability**

Not applicable.

**Consent to participate**

We hereby declare that this research did not involve human subjects. Therefore, Consent to Participate is not applicable

**Consent for publication**

We hereby declare that this research did not involve human subjects. Therefore, Consent to publish is not applicable

**Declaration of conflicting interests**

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

**Funding**

The author(s) received no financial support for the research, authorship and/or publication of this article.

**Ethical approval**

Birds were managed according to the principles and specific guidelines of Institute of Animal and Dairy Sciences, University of Agriculture, Faisalabad, Pakistan. The experimental procedure was approved by the ethical and synopsis committee of Institute of Animal and Dairy Sciences, and Director Graduate Studies, University of Agriculture, Faisalabad, Pakistan (Permit Number: IADS2018-04-212)

**ORCID iD**

Muhammad Aziz ur Rahman [https:orcid.org/0000-0002-6894-1128](https:orcid.org/0000-0002-6894-1128)
References

1. Walters HG, Brown B, Augspurger N, et al. Evaluation of NSPase inclusion in diets manufactured with high- and low-quality corn on male broilers. J Appl Poult Res 2018; 27: 228–239.

2. Lysenko Y, Andrei Koshchayev A, Luneva A, et al. Organic meat production of broiler chickens hubbard redbro cross. Int J Vet Sci 2021; 10: 25–30.

3. Xia C, Liang Y, Bai S, et al. Effects of harvest time and added molasses on nutritional content, ensiling characteristics and in vitro degradation of whole crop wheat. Asian-Australasian J Anim Sci 2018; 31: 354–362. 2017/10/24.

4. Xia CQ, Muhammad AUR, Niu WJ, et al. Effects of dietary forage to concentrate ratio and wildrye length on nutrient intake, digestibility, plasma metabolites, ruminal fermentation and fecal microflora of male Chinese Holstein calves. J Integr Agric 2018; 17: 415–427.

5. Aziz ur Rahman M, Xia C, Ji L, et al. Nutrient intake, feeding patterns, and abnormal behavior of growing bulls fed different concentrate levels and a single fiber source (corn stover silage). J Vet Behav 2019; 33: 46–53.

6. Hafez HM and Attia YA. Challenges to the poultry industry: current perspectives and strategic future after the COVID-19 outbreak. Front Vet Sci 2020; 7: 516. Review. DOI: 10.3389/fvets.2020.00516.

7. Al-saffar AE, Attia YA, Mahmoud MB, et al. Productive and reproductive performance and egg quality of laying hens fed diets containing different levels of date pits with enzyme supplementations. Trop Anim Health Prod 2012; 45: 327–334.

8. Nurfeta A. Feed intake, digestibility, nitrogen utilization, and body weight change of sheep consuming wheat straw supplemented with local agricultural and agro-industrial by-products. Trop Anim Health Prod 2010; 42: 815–824. 2009/11/03.

9. Apata DF and Babalola TOJJJoFS and Engineering N. The use of cassava, sweet potato and cocoyam, and their by-products by non-ruminants. Int J Food Sci Nutr Eng 2012; 2: 54–62.

10. Diarra S, Igwebuike J, Kwari I, et al. Evaluation of yam – sweet potato peels mixture as source of energy in broiler chickens diets. Am J Agric Biol Sci 2012; 7: 497–502.

11. Abdel-Hafeez HM, Saleh ESE, Tawfeek SS, et al. Utilization of potato peels and sugar beet pulp with and without enzyme supplementation in broiler chicken diets: effects on performance, serum biochemical indices and carcass traits. J Anim Physiol Anim Nutr (Berl) 2018; 102: 56–66. 2017/03/18.

12. Khaskheli A, Khaskheli M and Khaskheli AJIJoVS. Dietary influence of Yucca schidigera on broilers and layers: a review. Int J Vet Sci 2020; 9: 458–461.

13. Cowieson AJ, Toghyani M, Kheravii SK, et al. A mono-component microbial protease improves performance, net energy, and digestibility of amino acids and starch, and upregulates jejunal expression of genes responsible for peptide transport in broilers fed corn/wheat-based diets supplemented with xylanase and phytase. Poult Sci 2019; 98: 1321–1332. 2018/10/06.

14. Alshamiri MMA, Ali SAM, Abdalla HO, et al. The effect of supplementing different levels of phytase enzyme on performance, some carcass properties and economics of broiler chickens. Agrobiol Records 2021; 4: 14–22.

15. Ge Y, Li Y, Chen L, et al. Basic analysis of glycolysis in cardiac tissue in broiler chickens presenting with ascites syndrome. Pak Vet J 2020; 40: 365–369.

16. Gul ST, Ahamd I, Saleemi MK, et al. Toxico-pathological effects of thiamethoxam on hematobiochemical and productive performance of commercial laying hens. Pak Vet J 2020; 40: 181–185.

17. Saeed M, Ayaşan T, Alagawany M, et al. The role of β-mannanase (hemicell) in improving poultry productivity. Health and environment. Braz J Poult Sci 2019; 21: 1–8. DOI: 10.1590/1806-9061-2019-1001.
18. Horvatovic M, Glamocic D, Zikic D, et al. Performance and some intestinal functions of broilers fed diets with different inclusion levels of sunflower meal and supplemented or not with enzymes. *Braz J Poult Sci* 2015; 17: 25–30.

19. Hashemi M, Seidavi A, Javandel F, et al. Influence of non-starch polysaccharide-degrading enzymes on growth performance, blood parameters, and carcass quality of broilers fed corn or wheat/barley-based diets. *Colombian J Livest Sci* 2017; 30: 286–298.

20. Attia YA, El-Tahawy WS, El-hamid A, et al. Effect of feed form, pellet diameter and enzymes supplementation on growth performance and nutrient digestibility of broiler during days 21–37 of age. *Arch Anim Breed* 2014; 57: 1–11.

21. The Association of Official Analytical Chemists (AOAC). *Official methods of analysis*. MD: AOAC International Gaitherburg, 2005.

22. National Research Council (NRC). *Nutrient requirements of poultry*. 9th Rev. Washington, DC: National Academy Press, 1994.

23. Su H, Wang Y, Zhang Q, et al. Responses of energy balance, physiology, and production for transition dairy cows fed with a low-energy prepartum diet during hot season. *Trop Anim Health Prod* 2013; 45: 1495–1503. 2013/04/16.

24. Hussain M, Mahmud A, Hussain J, et al. Effect of dietary amino acid regimens on growth performance and bodyconformation and immune responses in Aseel chicken. *Indian J Anim Res* 2020; 54: 53–58.

25. Sharif M, Shoaib M, Rahman MAU, et al. Effect of distillery yeast sludge on growth performance, nutrient digestibility and slaughter parameters in Japanese quails. *Sci Rep* 2018; 8: 1–6.

26. Software MS. *Computer software*. State College, PA: Minitab, Inc, 2007.

27. Alvarado D, Klein DE and Lemmon MA. Structural basis for negative cooperativity in growth factor binding to an EGF receptor. *Cell* 2010; 142: 568–579. 2010/08/21.

28. González-Alvarado J, Jiménez-Moreno E, González-Sánchez D, et al. Effect of inclusion of oat hulls and sugar beet pulp in the diet on productive performance and digestive traits of broilers from 1 to 42 days of age. *Fuel and Energy Abstracts* 2010; 162: 37–46.

29. Elwakeel E, Titgemeyer E, Johnson B, et al. Fibrolytic enzymes to increase the nutritive value of dairy feedstuffs. *J Dairy Sci* 2007; 90: 5226–5236.

30. Giraldos L, Tejido M, Ranilla M, et al. Influence of direct-fed fibrolytic enzymes on diet digestibility and ruminal activity in sheep fed a grass hay-based diet. *J Anim Sci* 2008; 86: 1617–1623.

31. Shahid I, Anwar U, Swar SO, et al. Effect of emulsifier (lysophospholipid) supplementation in broilers during different phases on growth performance, blood profile, digestibility, economics and meat quality. *Pakistan J Agric Sci* 2021; 58: 1033–1040. DOI: 10.21162/PAKJAS/21.972.

32. Yin F, Wang J, Ruan Z, et al. The in vitro digestion rate and in vivo digestibility of raw starches from selected cereals and tubers. *J Food Agric and Environ* 2012; 10: 577–581.

33. Muhammad A, Adeduwura A and Olayiwola O. Growth performance of broiler chickens fed diets containing partially cooked sweet potato meal. *J Nat Sci Res* 2012; 2: 50–59.

34. Maphosa T, Gunduza K, Kusina J, et al. Evaluation of sweet potato tuber (*Ipomoea batatas* L.) as a feed ingredient in broiler chicken diets. *Livest Res Rural Dev* 2003; 15: 13–17.

35. Ayuk A. The effect of the inclusion of different levels of sweet potato meal on the feed consumption rate of broiler chicks. *Journal of Agriculture. For Soc Sci* 2004; 2: 80–83.

36. Agwunobi LN. Performance of broiler chickens fed sweet potato meal (*Ipomoea batatas* L.) diets. *Trop Anim Health Prod* 1999; 31: 383–389. 1999/12/22.

37. Bedford MR and Partridge GG. Enzymes in farm animal nutrition. Wallingford, United Kingdom: CAB International, 2010.

38. Al-Harthi M, Attia Y and Elgandy M. The effect of pelleting and enzyme supplementation on performance, carcass and blood parameters of broilers fed on different concentrations of olive cake. *European Poult Sci* 2019; 83: 1–13.
39. Sarikhan M, Shahryar HA, Gholizadeh B, et al. Effects of insoluble fiber on growth performance, carcass traits and ileum morphological parameters on broiler chick males. *Int J Agric Biol* 2010; 12: 531–536.

**Author biographies**

**Muhammad Aziz ur Rahman** is an assistant professor in the Institute of Animal and Dairy Science, University of Agriculture, Faisalabad-Pakistan. He published more than 43 research articles in different national and international peer reviewed journals with more than 500 citations, and H-index 15.

**Usama Jamal** has recently completed his MSc (Hons.) in Animal Nutrition under the supervision of Dr. Muhammad Aziz ur Rahman.

**Urooj Anwar** is a PhD scholar and published more than 5 research articles.

**Muhammad Qamar Bilal** is a professor in the Institute of Animal and Dairy Science. He published more than 50 research articles in different national and international peer reviewed journals.

**Muhammad Riaz** is a professor in the Institute of Animal and Dairy Science. He published more than 50 research articles in different national and international peer reviewed journals.

**Mubasher Hussain** has completed his PhD and published more than 5 research articles.

**Sibtain Ahmad** is an assistant professor in the Institute of Animal and Dairy Science, University of Agriculture, Faisalabad-Pakistan. He published more than 15 research articles in different national and international peer reviewed journals.