Research Article

# Effect of Different Diet Dilutions on Growth and Production Performance of Broiler Breeders

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**Abstract** | The current study was conducted at a commercial parent stock farm to check the effect of different diet dilutions on growth and production performance of broiler breeders. A total of 6,400 parent stock female birds (Ross 308 strain) were randomly selected at the age of day-old-chick as per capacity of a poultry house. Birds were distributed in 16 replicates (4 replicates per treatment) following completely randomized design for applying 4 dietary treatments namely control diet (CON) or 0% dilution (2800ME+14%CP); less diluted diet (LES) or 5% dilution (2660ME+13%CP); medium diluted diet (MED) or 10% dilution (2520 ME+12% CP); extra diluted diet (EXT) or 15% dilution (2380ME+11%CP). Each replicate was allocated 400 birds randomly. Birds were offered (diluted) grower diet from 4 to 19 weeks. The impact of said treatments were checked through growth and production parameters along with economic appraisal of diet formulation. The findings revealed that MED diet produced maximum body weight uniformity, peak egg production and total eggs per hen-housed, while poor performance was observed in EXT treatment. The CON and LES treatments produced comparable results. Although diluted diets were comparatively economical than CON commercial diet, however more feed scale was offered to birds in diluted treatments which neutralized the benefits of low cost diluted diets. To sum up, 10% dilution is viable in commercial rearing while less than 10% dilution produce non-significant results. Furthermore, it is difficult to balance nutrients for higher than 10% diet dilution which produce some unwanted side effects regarding growth and egg production.

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## Introduction

Diet dilution is generally considered an alternative to feed restriction which is usually applied during rearing phase of broiler breeders to control their superior growth potential. So far, the growth potential of broiler breeder (also termed as parent stock or PS) has increased to manifolds compared to previous generations (Mens *et al*., 2022; Sweeney *et al*., 2022). The concept of feed restriction is currently the only option available to poultry farm managers to control the growth of PS birds. While BW uniformity is one of the fundamental goals in PS rearing, such feed restrictions also aid in achieving optimum BW uniformity during this phase of life (Brandt, 2024; Aranibar, 2018). Correct feeding patterns and BW uniformity during rearing phase is often linked to uniform frame size, body composition and sexual synchronization of broiler PS. Resultantly, higher uniformity and sexual synchronization together produce high peak production (Brandt, 2024; Pishnamazi *et al*., 2014). Another advantage of uniform flock is to manage the day-to-day activities at mass level rather than individual level. In uniform flocks, PS farm managers can adjust feed allocations more easily compared to non-uniform flocks. For example, feed can be allocated on flock basis rather than individual bird's need (Sweeney at al., 2022). Overall, high uniformity of PS birds is not a choice but a necessity which is achieved at the cost of manual weight grading. After vaccination of PS, frequent manual weight grading is considered the most laborious task of PS farm during rearing phase. In commercial operations, all the birds are individually weighed and divided into three groups based on their BWs namely under-weight, medium weight and over-weight. These group of birds are then offered feed scale as per their need. For example, under-weight group is given more feed compared to the medium group while over-weight group is given less feed scale compared to the medium group. This way, all the birds are brought back within desired uniformity range within next 4-6 weeks (Asensio *et al*., 2020a).

The added advantages of feed restrictions are usually the improvement of health and reproductive performance of PS birds (Nascimento *et al*., 2021; Riber *et al*., 2021; Aranibar, 2018). However, severe feed restrictions are usually applied to achieve these benefits. That is, the feed can be restricted up to 50% of ad libitum intake in broiler PS during rearing phase, especially in early and mid-phase (Arrazola *et al*., 2019b). Unlike the advantages of feed restriction, the practice has some inherit disadvantages as well. Feed restriction usually results in less feed allowance per bird during early and mid-rearing phase. Such small feed scales create a difficulty to evenly distribute feed among all birds within a pen (Zuidhof *et al*., 2015, 2017). Consequently, the competition develops among birds for feeding which ultimately disturbs the flock uniformity. Because, in this competition, small and less active birds often do not find equal feeding opportunity. These less active birds end up underweight and more active birds become overweight upsetting whole flock uniformity. To rectify this uniformity, manual weight grading is rigorously performed at PS farms globally (Aviagen, 2023; Asensio *et al*., 2020a).

However, an alternative to feed restrictions and manual grading is considered diet dilution. Diluting the diet in terms of nutrients usually decrease the bulk density of feed but increase the feed allowance per bird (Van Emous *et al*., 2021). The plus point of this higher feed allowance is feed higher feed clean-up time (Asensio *et al*., 2020b). Feed clean-up time is usually the time from start of feeding till the end of feed is completely finished in feeder (feed is cleaned up). The more the feeding time, the more the opportunity of getting feed for less active birds which eventually leads to improvement in BW uniformity of PS birds (Aranibar, 2018). Furthermore, this uniformity ends up in better peak and post peak production of PS birds. Indirectly, the diluted feed may produce efficient production without resorting to severe feed restriction (Arrazola *et al*., 2019a, b).

Diet dilution is practiced through several methods. Usually, diet dilution is practiced by reducing the nutrient levels per kilogram of feed proportionately. That is, low energy ingredients (wheat bran, wheat middling, oat hulls etc.) are added during feed formulation. In other words, diluted diet will contain less amount of energy, protein and other nutrients per kilogram compared to the standard diet. This diet dilution method simply decreases the bulk density of diet (Van Emous *et al*., 2024; Mens *et al*., 2022; Asensio *et al*., 2020b; Tahamtani *et al*., 2020; Arrazola *et al*., 2019a, b). Another method is to dilute the diet by adding certain chemicals e.g., by adding appetite suppressants (calcium propionate). Use of such chemicals suppress the appetite and reduce feed intake even when feed is present (Nielsen *et al*., 2011). However, chemical method of diet dilution produces some unwanted health issues during rearing and is usually not recommended in commercial PS farming (Hocking, 1993).

Keeping in view the significance of diet dilution, the present study was conducted to investigate the effect of three diluted diets in comparison to control diet on the performance of broiler PS birds. It was


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hypothesized that diluted diets will increase feed clean-up time and BW uniformity of broiler PS birds during rearing phase without the need of manual weight grading. Ultimately, better BW uniformity will produce higher peak egg production and enhance laying rate of hens during production phase. Although a few literatures has been published on the significance of diet dilution yet the study of different levels of dilution at the same time is novel aspect of the current study. In addition to this, the study was conducted in commercial conditions to further testify the viability of such practices. Moreover, comparison of four dietary treatments regarding the economics of diet formulation was also studied at commercial level as a novel aspect of this study.

## Materials and Methods

*Housing and experimental design*

The study consisted of first 40 weeks of broiler PS life, the rearing phase (0-24 weeks) and production phase (25-40 weeks). A commercial broiler PS farm (geographical location 30.9111214, 73.3545485) was chosen for this purpose to conduct the study in purely commercial conditions. The poultry house was environmentally controlled with deep litter system. It was divided into 16 replicates for applying 4 dietary treatments namely control diet (CON), less diluted diet (LES), medium diluted diet (MED) and extra diluted diet (EXT). Each diet was diluted proportionately in terms of nutrients *i.e.*, CON diet (no dilution), LES diet (5% dilution), MED diet (10% dilution) and EXT diet (15% dilution). The CON diet was commercial standard diet and its nutrient profile was taken as a standard for formulating the dilutions in respective diets *i.e.*, energy in LES diet was 5% diluted (2.65 kcal/g) as compared to the energy in CON diet (2.80 kcal/g). Similarly, other nutrients were diluted compared to the CON diet (Table 1).

Each treatment was randomly allocated 4 replicates following completely randomized design (Table 2). A total of 6,400 parent stock female birds were randomly selected based on floor capacity of the house from a commercial flock at the age of day-old chicks. From these birds, 400 chicks were randomly allocated to each of 16 replicates. All the replicates were partitioned using iron nettings. A floor space of maximum 0.23m$^2$ was offered to birds in single replicate (dimension of each replicate was 6.6m long and 13.5m wide).

*Husbandry practices*

Rearing phase consisted of first 24 weeks of age. Brooding of chicks was accomplished as per guidebook of Ross-308 Parent Stock Management Handbook (Aviagen, 2023). A 3-stage rearing program of phase feeding (starter, grower and pre-breeder diet) was followed (Amoozmehr *et al*., 2023). All the birds were fed crumbs starter (commercial undiluted) diet from day one to 4 weeks after which mash (diluted) grower diets were offered to respective treatment replicates. The CON replicates were offered normal commercial grower diet (0% dilution) and LES replicates were offered diluted grower diet (5% dilution). Similarly, MED replicates were offered 10% diluted grower diet and EXT replicates were offered 15% diluted grower diet. Grower diets were offered from 4$^{th}$ week until 18 weeks of age. During next phase, pre-breeder crumbs (undiluted) diet was offered to all replicates until 24 weeks of age. Thereafter, breeder-1 crumbs (undiluted) diet was given to all replicates till the end of study (40 weeks). Because artificial insemination was started from 41$^{st}$ week and the birds were shuffled, the study could not be continued after this age.

For the sake of homogenous management of nutrition aspects, equal amount of daily nutrients were provided to all replicates. That is, the replicates with diluted (grower) diets were offered proportionate percentage of more feed allowance based on recommended feed scales by primary breeder. For example, pullets in LES replicates were offered 5% more feed scales compared to the pullets in CON replicates, while 10% higher feed scales to MED replicates. Similarly, 15% higher feed scales were given to EXT replicates so that each pullet receive same amount of daily nutrient (Van Emous *et al*., 2021). Weekly feed scale recommendations for CON diet were followed as per Ross-308 Performance Objective guide (Aviagen, 2021).

A strict light schedule was followed for the entire duration of study. Dark house was maintained from 2$^{nd}$ week till 21$^{st}$ week after which all the birds were photo-stimulated at 148$^{th}$ day at once. The rest of management practices were kept same for all replicates and followed as per Ross-308 PS Management Handbook (Aviagen, 2023). For medication and vaccination of birds, advice of company's veterinarian was followed.


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**Table 1:** *Ingredient and nutrient profile of four diets used during rearing phase of broiler breeders. The four phase feeding regimens (starter, grower, pre-breeder and breeder-1) have been used during experimental duration.*

| Particulars | Starter (crumble) | Grower (mash) | | | | Pre-breeder (crumble) | Breeder-1 (crumble) |
|---|---|---|---|---|---|---|---|
| | Normal diet | Diluted diet | | | | Normal diet | Normal diet |
| | | CON | LES | MED | EXT | | |
| Age (weeks) | 0-3 | 4-18 | | | | 19-24 | 25-40 |
| **Ingredient composition** | | | | | | | |
| Corn | 50.00 | 47.0 | 53.00 | 47.00 | 40.00 | 58.00 | 62.00 |
| Wheat | 7.00 | 5.00 | 8.00 | 8.00 | 10.00 | 11.00 | 6.00 |
| Barley | - | - | 5.00 | 5.00 | 5.00 | - | - |
| Wheat bran | 3.00 | 10.0 | 8.00 | 16.00 | 20.00 | 8.00 | 7.35 |
| SBM 48% | 21.00 | 11.0 | 9.00 | 6.00 | 4.00 | 11.00 | 15.00 |
| Corn gluten feed | - | - | - | - | - | 6.00 | - |
| Rice tips | 8.00 | 11.0 | - | - | 4.00 | - | - |
| Oat hulls | - | - | 7.00 | 7.00 | 6.00 | - | - |
| Sunflower meal | 5.00 | - | - | - | - | - | - |
| Rice polishing | - | 11.0 | 4.50 | 5.00 | 5.00 | - | - |
| DCP | 1.00 | - | 0.80 | 0.50 | 1.00 | 1.50 | - |
| Molasses | 1.50 | - | - | - | - | 1.00 | 1.00 |
| Limestone | 1.00 | 1.00 | 0.50 | 0.50 | 0.50 | 2.00 | 2.40 |
| Defluor. Phosphate | 1.00 | 1.00 | 1.00 | 1.00 | 0.50 | - | 1.40 |
| Soft rock phosphate | - | 1.00 | 1.00 | 1.00 | 1.00 | - | - |
| Common salt | 0.50 | 0.40 | 0.50 | 0.30 | 0.40 | 0.50 | 0.30 |
| Vitamin premix | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| Mineral premix | 0.10 | 0.50 | 0.20 | 0.30 | 0.50 | 0.16 | 0.15 |
| DL-Methionine | 0.15 | 0.15 | 0.15 | 0.10 | 0.10 | 0.09 | 0.15 |
| L-Lysine HCl | 0.10 | 0.10 | 0.30 | 0.30 | 0.30 | - | - |
| Choline Cl -70% | 0.40 | 0.60 | 0.80 | 1.75 | 1.45 | 0.50 | - |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **Nutrient profile** | | | | | | | |
| Dry Matter | 85.5 | 85.6 | 84.9 | 84.5 | 84.6 | 84.9 | 81.8 |
| ME (Kcal/g) | 2.81 | 2.79 | 2.64 | 2.48 | 2.42 | 2.75 | 2.73 |
| Crude protein | 19.09 | 14.0 | 13.16 | 12.39 | 11.93 | 14.51 | 14.78 |
| Calcium % | 1.05 | 0.94 | 0.92 | 0.86 | 0.80 | 1.22 | 2.99 |
| Avail. Phos. | 0.47 | 0.42 | 0.40 | 0.42 | 0.34 | 0.37 | 0.40 |
| Potassium | 0.76 | 0.66 | 0.59 | 0.61 | 0.61 | 0.60 | 0.66 |
| Chloride | 0.41 | 0.32 | 0.42 | 0.31 | 0.37 | 0.39 | 0.25 |
| Sodium | 0.28 | 0.24 | 0.28 | 0.20 | 0.22 | 0.24 | 0.22 |
| Choline (mg/kg) | 1468 | 1350 | 1159 | 1049 | 824 | 1619 | 1429 |
| Lysine | 0.95 | 0.69 | 0.76 | 0.71 | 0.67 | 0.61 | 0.67 |
| Methionine | 0.45 | 0.37 | 0.36 | 0.29 | 0.29 | 0.33 | 0.39 |

*SBM: soybean meal; DCP: di-calcium phosphate; ME: metabolize-able energy; CON: controlled diet (0% dilution); LES: less diluted diet (5% dilution); MED: medium diluted diet (10% dilution); EXT: extra diluted diet (15% dilution). All entries are in ratio accept wherever is mentioned.*

**Table 2:** *Design of experiment. Three dietary dilution levels were used.*

| S. No. | Treatments | Dilution | Replicates |
|---|---|---|---|
| 1 | Control diet (CON) | 0% | Feeding sources= 4<br>Replicate of each feeding source= 4<br>Birds per replicate= 400<br>Total birds = 4 × 4 × 400= 6400 |
| 2 | Less diluted (LES) | 5% | |
| 3 | Medium diluted (MED) | 10% | |
| 4 | Extra diluted (EXT) | 15% | |

The study was conducted taking care of all the necessary welfare and ethical aspects under the supervision of company's veterinarian. Furthermore, institutional guidelines of Ethical Review Committee of University of Veterinary and Animals Sciences, Lahore (Pakistan), were also followed.

*Rearing parameters*

**Body weight and BW uniformity:** Body weight of 2% birds was randomly noted from each replicate on weekly basis 5 hours after feeding (Van Emous *et al*., 2024; Asensio *et al*., 2020a). The mean weight was calculated using arithmetic mean formula. BW uniformity was the number of birds within 10% variation of mean body weight (Aviagen, 2023).

**Feed intake and feed clean-up time:** Feed intake was noted on daily basis and cumulative intake per bird (in kg) was recorded. Feed clean-up time (in minute) was noted form 3rd week on weekly basis. The clean-up time was recorded from the start of feeding till the end of feed in feeders (Amoozmehr *et al*., 2023).

**Livability:** Culling and mortality of birds were noted on daily basis and cumulative depletion ratio was calculated for each replicate. This depletion ratio was subtracted from 100 to get livability ratio for each replicate.

**Economics of diluted diet:** For the economics of diet dilutions during rearing phase, cumulative feed intake per bird from each replicate was recorded. The cost per kilogram feed was then multiplied by the amount of feed consumed per bird to obtain the rearing feed cost per bird.

*Production parameters*

**Egg production:** Eggs were collected on daily basis and cumulative number of eggs were recorded for each week. Number of eggs were divided with number of birds on 4th day multiplied by 100 to get hen-week production %. Ross-308 PS birds normally reach peak production at 31st week of age. This week production will be noted as peak egg production for each replicate (Aviagen, 2021).

**Age at 5% production:** The day at which daily egg production reached 5% was noted for each replicate.

**Total eggs per hen-housed (TEH) and hatching eggs per hen-housed (HEH):** These parameters were noted as per guide book of Aviagen (2023). The cumulative number of eggs were noted from each replicate till the end of trial. Total eggs were divided by the number of hen-housed to get TEH. Similarly, cumulative number of hatching eggs were noted for each replicate till the end of trial and were divided by the number of hen-housed to obtain HEH.

*Statistical analysis*

The data were analyzed using platform of IBM SPSS version 26. Data were tested for the assumption of normality and homogeneity of variance. Wherever needed data were transformed to approach normality with studentized model residuals plotted for visual inspection of homoscedasticity. To check the effect of four dietary treatments, one-way analysis of variance (ANOVA) was applied on rearing and egg production parameters keeping the significance level at 95%. For further comparison among treatments, Duncan test was applied as post hoc variant (Duncan, 1955). Following model was adopted for this study:

$$Y_i = \mu + t_i + \varepsilon_i$$

$Y_i$=growth and production performance of broiler PS birds; μ= population means; $t_i$ = effect of ith treatment groups (i=1, 2, 3, 4; CON, LES, MED, EXT); $\varepsilon_i$= residual effect associated with treatment groups.

## Results and Discussion

*Rearing parameters*

**Body weight and BW uniformity:** These are the most important growth parameters in any PS rearing and directly affect the egg production. When treatments were applied, all the pullets showed significant BWs for the effect of diet dilutions (P=0.047). In general, BW did not vary too much between CON, LES and MED treatments (P=0.087) while BW was significantly (P<0.05) lagging behind in EXT treatment compared to the CON (Table 3). Similarly, BW uniformity was found better (P<0.05) in MED treatments compared to the rest of dietary treatments. Conversely, LES and EXT treatments did not produced a significant effect on pullet uniformity compared to the CON diet (P=0.175).

**Feed intake and clean-up time:** Feed intake was taken as parameter to know the effect of palatability of diet dilutions whether the intake increases or decreases after diluting the diets. When treatments



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**Table 3:** *Effect of 4 diet dilutions on growth performance of broiler PS pullets during rearing phase (0-24 weeks).*

| Parameters | P-value | Treatments | | | |
|---|---|---|---|---|---|
| | | CON | LES | MED | EXT |
| BW (g) | 0.047 | 1399.84±83.51[a] | 1401.78±83.96[a] | 1203.10±71.47[ab] | 1162.99±69.68[b] |
| Uniformity % | 0.001 | 72.52±0.61[b] | 73.72±0.55[b] | 75.73±0.59[a] | 73.46±0.60[b] |
| Livability % | 0.685 | 92.87±0.70 | 93.11±0.51 | 92.94±0.68 | 93.81±0.50 |
| FCT (minutes) | <0.001 | 10.82±0.70[c] | 11.85±0.71[c] | 15.98±0.73[b] | 18.18±0.65[a] |
| Feed intake (kg) | 0.123 | 11.75±0.49[c] | 12.35±0.55[ab] | 12.93±0.52[ab] | 13.72±0.62[a] |
| Feed cost/bird (USD) | 0.814 | 5.92±0.25 | 5.91±0.26 | 5.89±0.24 | 5.63±0.25 |

*BW: body weight; FCT: feed clean-up time.*

**Table 4:** *Effect of 4 diet dilutions on production performance of broiler PS hens.*

| Production Parameters | P-value | Treatments | | | |
|---|---|---|---|---|---|
| | | CON | LES | MED | EXT |
| A5P (days) | 0.349 | 169.00±2.27 | 170.25±2.69 | 171.75±2.25 | 174.75±1.70 |
| Peak production % | 0.002 | 80.38±0.19[b] | 81.70±0.72[b] | 87.50±1.65[a] | 82.10±0.89[b] |
| HWP % | 0.491 | 68.19±2.69 | 69.53±2.75 | 73.02±2.98 | 68.10±2.86 |
| Egg weight (g) | 0.818 | 58.51±0.64 | 58.69±0.65 | 59.24±0.66 | 59.17±0.63 |
| TEH | 0.016 | 76.15±1.21[b] | 75.40±0.98[b] | 79.68±0.23[a] | 75.90±0.68[b] |
| HEH | 0.049 | 75.35±1.13[b] | 74.75±0.97[b] | 78.15±0.32[a] | 75.20±0.64[b] |

*A5P: age at 5% production; HWP: hen-week production; TEH: total eggs per hen house; HEH; hatching eggs per hen-housed.*

were applied, all the pullets showed non-significant feed intake for the effect of diet dilutions (P=0.123). However, post hoc test showed that pullets in EXT treatment consumed more feed (P<0.05) compared to CON treatment. While feed intake in CON, LES and MED replicates were found comparable (P=0.174) (Table 3). Contrariwise, pullets showed highly significant feed clean up time for the effect of diet dilutions (P<0.001). Furthermore, feed clean up time was highest (P<0.05) in EXT treatment followed by MED treatment compared to the LES and CON. However, feed clean up time did not vary too much between CON and LES treatments (P=0.300).

**Livability:** Livability is a multifactorial parameter. However, in this study, it was noted to check any side effect of diet dilution on health of pullets. The data for livability is shown in Table 3. No trend of livability of pullets was found for the effect of diet dilutions (P=0.685). In addition to this, post hoc test also showed that livability was comparable among different treatments (P=0.326) (Table 3).

**Economics of diet dilution:** The novelty of this study was to analyze the economic viability of dietary dilutions on commercial scale. In general, diluted diets were relatively cheaper than commercial standard grower diet yet the cost of feed per bird among four treatments were found non-significant (CON: 5.92±0.24 USD; LES: 5.91±0.53 USD; MED: 5.89±0.24 USD; EXT: 5.63±0.25 USD; ($F_{(3,12)}$=0.315; P=0.814; $\eta^2$=0.073), with post hoc test showing comparable cost among treatments (Table 3).

*Production parameters*

**Age at 5% production and egg weight:** Age at 5% production is generally regarded as an indicator to check if there were delay in production. The data regarding production parameters are in Table 4. No significant trend of age at 5% production was found for the effect of diet dilutions (CON: 169.00±2.27days; LES: 170.25±2.69 days; MED: 171.75±2.25 days; EXT: 174.75±1.70 days; $F_{(3,12)}$=1.207; P=0.349; $\eta^2$=0.232), with post hoc test showing comparable findings for diluted diets compared to the control diet (P=0.120). Similarly, egg weight was also found non-significant (P=0.818) among different dietary treatments.

**Hen-week production and peak egg production:** The egg production is the first output of any PS farm rearing management. In general, egg production is related with optimum BW and BW uniformity at the time of photo-stimulation. Although no trend of hen-week production (P=0.574) was found for the effect of diet dilutions (Table 4), yet a trend of increased peak egg production for the effect of diet dilution relative to control diet was observed (P=0.002). Specifically, highest peak production (P<0.05) was found in MED treatment compared to other treatments (Figure 1). Conversely, peak egg production did not vary significantly (P= 0.267) among CON, LES and EXT treatments.

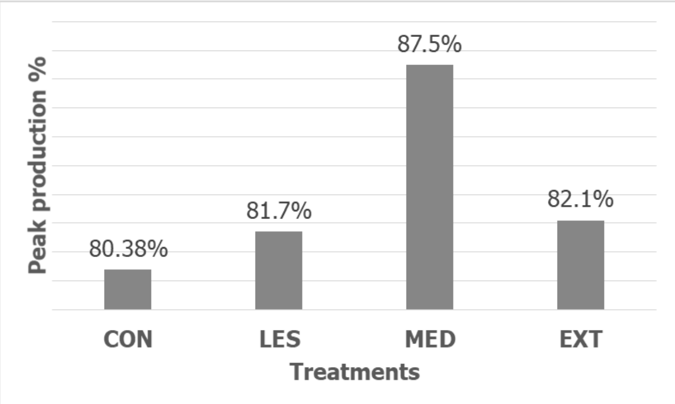


**Figure 1:** *Effect of 4 diet dilutions on peak egg production of broiler breeders. MED diet produced the highest peak egg production.*

**Total eggs per hen-housed (TEH) and hatching eggs per hen-housed (HEH):** These two parameters are an indicator of flock overall performance while considering the mortality and culling of poultry birds. Higher number is generally linked with better performance irrespective of higher or lower mortality. A trend of increased TEH was found for the effect of diet dilutions compared to the control diet (P=0.016), with post hoc showing highest TEHH in MED treatment compared to the other treatments (P<0.05). While TEH was found comparable among CON, LES and EXT treatments (P=0.567). Similarly, a significant trend of HEH was also found (P=0.049). Furthermore, highest HEH were recorded in MED treatment compared to other diets (P<0.05), while CON, LES and EXT were found comparable for HEH (P=0.634).

The study was conducted to investigate whether diluted diets increase BW uniformity of broiler breeders without resorting to manual weight grading during rearing phase. In addition to this, the effect of diet dilution on production performance of broiler breeders and economics of diet dilutions were also investigated. As expected, growth and egg production was much better up to 10% dilution (MED diet) while it decreased unexpectedly when dilution percentage increased to 15% (EXT diet).

The main focus of diet dilution was to achieve weekly target BWs and optimum uniformity during rearing phase. For that, higher feed scales were given to replicates treated with higher amount of diet dilution but the total amount of daily nutrients remained the same for all birds *i.e.*, 5% more feed scale was given to birds in LES replicates (5% diet dilution) compared to the CON groups (Van Emous *et al.*, 2024). The direct effect of this diet dilution was to employing the concept of longer feed clean-up time which was achieved at the cost of more feed allowance in diluted diet treatments (Van Emous *et al.*, 2021; Van Krimpen *et al.*, 2007; de Jong *et al.*, 2005). Owing to this longer clean-up time and less feed competition, less active birds had an opportunity to have a larger meal than what could have been possible during standard diet (Asensio *et al.*, 2020b; Arrazola *et al.*, 2019b; de Jong *et al.*, 2005). Similarly, the positive chain effect of diet dilution continued *i.e.*, higher feed allowance produced longer clean-up time which ultimately increased BW uniformity in diluted (MED) treatment compared to the control (CON) treatment. Certainly, there exists a positive correlation among the amount of diet dilution, feed clean-up time and BW uniformity (Arrazola *et al.*, 2019a, b; Zuidhof *et al.*, 1995). The inverse may be true for less uniformity in CON and LES treatments. Because, high feed restrictions during rearing phase decrease the feed allowance per bird and resultantly increase the competition for feeding among birds. Resultantly, shorter feed clean-up time and higher competition among birds for feeding disturb the flock uniformity (Zuidhof *et al.*, 2015).

Conversely, the studies (Kittelsen *et al.*, 2023; Zuidhof *et al.*, 2015; Morrissey *et al.*, 2014; Sandilands *et al.*, 2005, 2006) which have reported non-significant findings of BW uniformity for the effect of diet dilutions have particular reasons. For example, rather than nutrient dilution (as used in present study), some of these scientists have used different types of qualitative dilutions which do not increase feed clean-up time e.g., appetite suppressant (calcium propionate) or addition of low nutrient ingredients with the commercial diet rather than diluting the whole diet (Kittelsen *et al.*, 2023; Morrissey *et al.*, 2014; Sandilands *et al.*, 2005, 2006). Another reason for lack of improvement in BW uniformity reported by de los Mozos *et al.* (2017), can be attributed to


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the use of crumble feed rather than mash feed. That is, feed structure (whether crumbs or mash) produce a direct impact on uniformity of birds (Van Emous *et al*., 2024). As in present scenario, mash feed was used which further lengthen the feed clean-up time compared to crumble feed (Aviagen, 2023). Therefore, diluted diet can affect BW uniformity in a number of ways e.g., the type of method and amount of diet dilution, dietary ingredients, feed restriction level, extra feed allotment or feed scale etc. (Arrazola *et al*., 2019a, b; Savory *et al*., 1996). However, the linear trend of BW uniformity with that of dilution level could not be established and pullets in EXT treatment was less uniform. The plausible answer of this slump of uniformity for higher dilution can be found in the concept of gut motility because of high fiber in diet. Owing to high flow rate of the gut contents in the presence of fiber, the loss of essential amino acids can be possible in highly diluted (EXT) treatment which can ultimately produce weight loss in some pullets (Asensio *et al*., 2020b; Kluth and Rodehutscord, 2009).

Overall, BWs of birds within 10% variation are considered average or medium BW *i.e.*, neither overweight nor underweight (Aviagen, 2023). However, BW of pullets were slightly lagging behind target in diluted treatments as predicted by previous studies (Riber *et al*., 2021; Arrazola *et al*., 2019a, b; Enting *et al*., 2007). Normally, severe diet dilution has some inherit disadvantages as the loss of essential amino acids and other nutrients. This loss of nutrients could have resulted in loose BW in diluted treatments owing to high fiber (Asensio *et al*., 2020b; Kluth and Rodehutscord, 2009; Leterme et al., 1998; Parsons et al., 1983). In addition to weight difference, loss of essential amino acids in EXT treatment produced an unexpected and extraordinary observation. During visits at the terminal phase of rearing, it was noticed in EXT treatment that birds had developed lose breast muscles and looked bulky compared to birds in other treatments. This effect was also reported in previous studies (Asensio *et al*., 2020b; de los Mozos *et al*., 2017). On the other hand, improved BWs in LES and MED treatment could be due to proper absorption of amino acids and plus feed scale to compensate for daily energy and protein needs of the birds (Sandilands *et al*., 2006). Conversely, the comparable BWs between CON and LES treatments were perhaps because of minor differences in energy dilutions in these two diets (van Krimpen *et al*., 2009). Moreover, non-significant livability rates of pullets validate the fact that nothing is wrong practicing diet dilution at commercial scale PS farming (Tahamtani *et al*., 2020; Asensio *et al*., 2020b; Arrazola *et al*., 2019a; de los Mozos *et al*., 2017; Hudson *et al*., 2001; Zuidhof *et al*., 1995).

The age at 5% production was taken as a parameter to examine the effect of diet dilution on sexual maturity of female birds. Because previous study of Morrissey *et al*., (2014) had reported delayed production for the effect of diet dilution. In current scenario, BW targets were not too far from weekly targets at the time of photo-stimulation and the transition of phase feeding to layer-diet was rapid, so the delay of production was non-significant (Arrazola *et al*., 2019a; Sandilands *et al*., 2005). It was expected that egg weight would be less in diluted diet treatments due to loss of essential nutrients. Conversely, despite the fact that hens in EXT and MED treatments were lagging target BWs yet comparable egg weights were observed (Morrissey *et al*., 2014). This is due to the fact that hens fed diluted diets did not lag in laying and such observation is also obvious from the non-significant age at 5% production reported above. Higher egg weight could have possible in case of delayed laying which normally results in slightly higher than expected egg weight (Enting *et al*., 2007; Hocking, 1996; Bruggeman *et al*., 1999). However, such was not the case in our study.

Although, non-significant hen-day production was found among treatments (Tolkamp *et al*., 2005), yet significantly highest peak production was found in diluted treatment (MED diet) compared to CON diet (Moradi *et al*., 2013; Zuidhof *et al*., 1995). Such peak production output is directly linked to improved rearing uniformity (especially sexual synchronization) at the time of photo-stimulation (Pishnamazi *et al*., 2008; Hudson *et al*., 2001). However, a linear trend of peak production could not be found for the effect of proportionate increase in diet dilutions i.e., peak production decreased in EXT treatment. The plausible answer of this trend could be found in body weight uniformity during rearing phase as well. Because pullets in MED treatment had highest uniformity while pullets in EXT treatment had lowest. Overall, weight uniformity is a major requirement to achieve uniform sexual maturity for better peak egg production (Pishnamazi *et al*., 2014; Lewis *et al*., 2007; Hudson *et al*., 2001; Hocking *et al*., 2004). Following the pattern of peak production, higher number of total eggs per hen-housed (TEH) and hatching eggs per hen-housed (HEH) in diluted (MED) treatment is completely in line with Moradi *et al.* (2013). The higher number of eggs is an obvious effect of better rate of lay (Enting *et al.*, 2007) and consistent production in diluted (MED) diet. This consistency for diluted diet has been reported by previous studies as well (Arrazola *et al.*, 2019a; Hocking *et al.*, 2002) and is considered to be linked with lean mass of breast muscles, more abdominal fat (Asensio *et al.*, 2020b), better weight and sexual uniformity during rearing phase. Conversely, rate of lay decrease faster in pullets fed undiluted diets compared to the diluted diet (Arrazola *et al.*, 2019a).

In general, the economics of diet dilution is considered of no benefit because qualitative diet dilution is often a cost prohibitive method of diet formulation on small scale (Kittelsen *et al.*, 2023). However, on commercial scale it seemed economical option as for current study, the feed became progressively inexpensive based on the amount of dilution *i.e.*, cost per bag of CON diet was 25.20 United States dollars (USD), while for LES, MED and EXT were 23.93, 22.80 and 20.5 USD, respectively. That is, feed cost per bag was comparatively economical for respective diet dilutions compared to controlled diet. Although, more weekly feed scales were offered to birds in diluted diet treatments compared to the CON yet the higher egg laying rate in MED treatment produced the ultimate valuable economic effect. Eventually more number of eggs per hen-housed results in higher number of chicks per hen-housed and profitability. The added benefit of such diet dilution is less frequent manual weight grading as well which is usually laborious task during rearing phase.

## Conclusions and Recommendation

Growth and reproductive performance increased linearly up to 10% dilution (MED treatment) after which the performance decreased drastically for 15% dilution (EXT treatment). That is, growth and egg production performance was better in MED treatment while poor in EXT treatment. However, performance did not vary too much between CON and LES treatments. In addition, the positive linear correlation between diet dilution and egg production performance could be proved up to 10% dilution level (MED diet), while after which it produced negative correlation. Although diluted diets are more economical than commercial diet yet more diluted diet is required which neutralize the effect of cheap formulation. However, higher number of eggs per hen-housed in MED diet produced ultimate economic benefit. In conclusion, farmers may use diet dilution up to 10% while minimizing the frequency of manual weight grading and improving reproductive performance of PS birds. Furthermore, less than 10% dilution may not be supportive regarding feed clean-up time and uniformity at commercial level during rearing phase.

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## Novelty Statement

During this study, effect of different diet dilutions on performance of broiler PS were studied at a time on commercial scale including their comparative economics.

## Author's Contribution

The data was collected by Muhammad Waqas while Dr. Shahid Mehmood helped in design of experiment, analysis of data and compilation of results. The manuscript was edited and reviewed by Dr. Saeed Ahmed. Furthermore, Dr. Muhammad Shabir Shaheen being company's consultant and certified veterinarian supervised the whole management of flock and study.

### *Data availability statement*
Derived data supporting the findings of this study are available via online repository at Zenodo platform: https://doi.org/10.6084/m9.figshare.27291633.v1.

### *Conflict of interest*
The authors have declared no conflict of interest.

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