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# Effects of feeding incremental levels of *Spirulina platensis* on feed intake and growth performance of Boschveld and Potchefstroom Koekoek chicken breeds

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**Abstract**
Spirulina is increasingly being used in feed manufacturing because of its high nutritional value, especially proteins, for humans and animals. This study examined the feed intake and growth performance of Boschveld and Potchefstroom Koekoek chicken breeds when soybean meal was substituted with incremental levels of *Spirulina platensis*. The experimental design was a 2 × 4 factorial with repeated measures over a 12-week period, with breed and diet as factors. The experimental unit was a cage holding 3 birds, with 3 cages allocated to each breed-diet combination, hence 36 birds per breed. The diets were: 0%, 5%, 10% and 15% using dried *Spirulina platensis* powder to replace soybean meal per 100 kg of feed. Chickens fed control diet consumed more ($P < 0.05$) feed than those fed Spirulina-containing diets. Diet affected ($P < 0.0001$) final weights (g) of the birds which were 1093.2, 921.6, 762.8 and 771.2 for 0%, 5%, 10% and 15% inclusion levels of *Spirulina platensis*, respectively. Boschveld chickens had better average daily gain compared to Potchefstroom Koekoek at week 15–16. Averaged over the 12 weeks, the control diet gave better ($P < 0.0001$) average daily gain (9.42 g/d) than the Spirulina-containing diets. Over the 12 weeks, the control diet had a more desirable (7.79 vs. 8.17, $P = 0.01$) feed conversion ratio than the Spirulina-containing diets Spirulina at a level of 5–10% can be used as a protein supplement in indigenous chicken feeds because it resulted in growth performance close to control diets.

**Keywords** Spirulina powder · Indigenous chickens · Grower diet · Growth performance

## 1 Introduction

In rural communities, indigenous chickens play an important economic and social role [1]. Population growth, urbanization, and rising incomes have resulted in a surge in animal protein demand. Emerging farmers are converting to poultry farming, mainly indigenous chicken farming, but feeds remain a big challenge. Soybean is the leading conventional protein source for animal feeding, but the current allocation of soybean is unsustainable due to unsuitable climate for soya production in many regions of Southern Africa [2]. In addition, food competition between humans and animals, especially monogastric animals, has resulted in an increase in the cost of feeding chickens for maximum growth performance. As a result, indigenous chickens contribute very little to food security as production of indigenous chickens on a

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larger scale has yet to materialize [3]. This is primarily related to their relatively low productive performances attributed to their slow growth [4].

Many households in rural areas raise indigenous chickens due to their adaptability [5] and low feed consumption compared to exotic breeds [6]. The nutritional requirements of indigenous chickens differ from that of exotic strains, which require feed of high nutritional value which is mostly used as human food [3]. Additionally, indigenous chickens are preferred in rural areas because they can be kept as scavengers with low costs on a subsistence production system [7]. Farmers in rural areas depend on hens for hatching chicks and caring for them, which results in long production cycles as they take longer to mature and reach slaughter weight [8]. In order to promote food security, indigenous chicken production should be advanced and promoted [3]. In attempts to improve productivity, an increasing number of farmers utilize better performing dual-purpose breeds for example Boschveld and Potchefstroom Koekoek. The average weight of Boschveld cockerels was 1.78 kg at 16 weeks of age [9–11] reported an average weight of 1.65 kg at 24 months; the average body weight of Potchefstroom Koekoek at 14 weeks of age was 0.88 kg [11]. To optimize the performance of these dual-purpose breeds, nutrition needs to be improved by several measures including identifying new feedstuff. The new feedstuffs should be high in nutritional value, be able to utilize land and water efficiently, and ultimately produce a high-quality product that is acceptable to consumers [12].

Biological ingredients can be found in natural environments, for example algae (e.g. *Spirulina platensis*) that can be used as a protein alternative [13, 14]. Microalgae can contribute to the safety of the environment and natural resources, especially land degradation and water scarcity [15]. *Spirulina platensis* is blue-green algae, edible, high in protein and able to survive in harsh environment and has gained popularity as food for both man and animals. Dietary Spirulina has been associated with increased growth performance and feed conversion of chickens [16, 17]. There have been limited studies on how to improve the performance of indigenous chickens under intensive systems while using Spirulina for protein. Therefore, the objective of this study was to determine the effect of dietary inclusion of *Spirulina platensis* as a replacement for soybean meal on the feed intake and growth performance of Potchefstroom Koekoek and Boschveld chickens.

## 2 Materials and methods

### 2.1 Bird management and care

The study was conducted at the University of Namibia, Neudamm campus, which is situated approximately 35 km east of Windhoek. The research was approved by the University of Namibia Research Ethics Committee (Research Approval Number: FANR/004/2019), hence the relevant ethics guidelines and regulations were adhered to. A total of 72 1-day old unsexed indigenous chicks consisting of 36 Boschveld (BV) and 36 Potchefstroom Koekoek (PK) were sourced from a local indigenous poultry producer in Windhoek. The chicks were vaccinated against Gumboro, Infectious Bronchitis (IB) and Newcastle disease at day 1. About 1 week before the arrival of chicks, all facilities and equipment including the brooding area were thoroughly cleaned and disinfected with veterinary disinfectant F10 [Health and Hygiene (Pty) Ltd, South Africa] to eliminate the disease-causing organisms.

The brooder house was pre-heated with infra-red bulbs. The day-old chicks were kept in the brooder for 4 weeks. Bulbs were turned on during the night to encourage eating and to keep the chicks warm. Newspapers beddings were used as insulator throughout the brooding phase. During the brooding period feeds were placed on the feeding trays for chicks. Feeding troughs were used after the brooding period. Waterers were washed daily before replacing the water. The litter materials were replaced every second day during brooding and subsequently every week, until the end of the experiment. For the first 4 weeks, chicks were fed with commercial broiler starter diet alone. Proper sanitation and management were observed during the entire duration of the study.

### 2.2 Experimental design

A complete randomized design (CRD) with a 2 × 4 factorial arrangement was used. Factor one was two chicken breeds of Boschveld and Potchefstroom Koekoek and factor two was the four dietary treatments. The average weight (g) of birds at the beginning of week 5 in the Boschveld was 302.6 ± 7.7 and in the Potchefstroom Koekoek it was 328.3 ± 7.4. From week 5, within each breed, three birds were randomly assigned to each of three cages (of dimension 0.9 m × 0.6 m × 0.6 m) with a single dietary treatment. Hence the experimental unit was a cage (diet) holding three birds and there were three replicates within each breed-diet treatment combination, giving a total of 72 birds.

Excluding the brooding period, the experiment lasted for 12 weeks. Due to repeated measurements on the same experimental unit which introduces correlations among observations, week was factored into the analysis.

### 2.3 Treatment diets formulation and chemical composition analyses

The four grower diets were formulated with graded levels (0%, 5%, 10% and 15%) of dried *Spirulina platensis* (SP) powder as replacement for soybean meal per 100 kg of feed. The *Spirulina platensis* used in this experiment was sourced from Germany (Brandenburg University of Technology). The four final diets were fed as mash. The proportion of ingredients used to formulate the grower diets are shown in Table 1.

The samples of the *Spirulina platensis*, soybean meal and of the four diets were dried and milled through a 1 mm screen before laboratory analyses. The dry matter (DM), ash, crude protein (CP), crude fat extract (CF) content and concentration of macro and micro elements of feeds was determined as per Official Methods of AOAC international [18]. The neutral detergent fiber (NDF) and acid detergent fiber (ADF) was determined as per procedure described by Van Soest et al. [19]. Table 2 shows the nutritional and mineral composition of the Spirulina, soybean meal, commercial starter and the formulated grower diets.

The total phenols (TP), total non-tannins (NTP), total tannins (TT), condensed tannins (CT) and hydrolysable tannins (HT) were determined according to a modified method of Makkar [20] and the results are given in Table 3.

### 2.4 Performance parameters measurements

Feed and water were provided ad libitum during the 12-week experimental period. Average daily feed intake per bird (FI) was calculated from 5 to 16 weeks of age by subtracting the weight of the feed refusals from that of the feed offered per day and dividing the difference by the total number of birds in a cage. The weight of individual birds at week 4 was used as initial weight in this experiment. Individual body weights of the birds in a cage were measured weekly until slaughter. The final weight (FW) was the individual bird weight at the end of the trial. The average body weight (ABW) is the least squares mean after fitting the individual body weights over the 12-week trial period. The data for daily feed intake and live body weight was used to calculate the feed intake, average daily gain (ADG), feed conversion ratio (FCR), crude protein intake (PI) and protein efficiency ratio (PER). Average daily gain was estimated by subtracting weight of each bird in each week from the previous week divided by 7. Feed conversion ratio (FCR) was estimated by dividing FI by ADG. Protein intake (PI) was obtained by multiplying FI by crude protein (CP) percentage in the diet. Protein efficiency ratio (PER) was estimated by dividing ADG by PI. The number of chickens that died during the experiment was recorded on a daily basis.

**Table 1** Proportion of ingredients used for the formulation of grower diets

| Items | Diets | | | |
|---|---|---|---|---|
| | 0% SP | 5% SP | 10% SP | 15% SP |
| Ingredients % | | | | |
| Yellow maize | 59 | 59 | 59 | 59 |
| Wheat bran | 21 | 21 | 21 | 21 |
| Soybean meal | 19.4 | 14.4 | 9.4 | 4.4 |
| *Spirulina platensis* | 0 | 5 | 10 | 15 |
| Vit. & Min premix[1] | 0.3 | 0.3 | 0.3 | 0.3 |
| Sodium chloride | 0.2 | 0.2 | 0.2 | 0.2 |
| Sunflower oil | 0.1 | 0.1 | 0.1 | 0.1 |

[1]Vitamin and mineral premix contains: protein 169 g/kg; *moisture 12 g/kg; fat 25 g/kg; fibre 15 mg/kg; Vitamin A 12 000 IU/kg; Vitamin D 4000 IU/kg; Vitamin E 50 IU/kg; Vitamin K 4 IU/kg; Vitamin B2 9 IU/kg; Niacin 60 mg/kg; calcium 8.4 mg/kg; phosphorous 6.4 mg/kg; iron 60 mg/kg; *sodium 1.8 mg/kg; *chlorine 120 mg/kg; *copper 15 mg/kg; *manganese 80 mg/kg; *zinc 50 mg/kg; *selenium 0.2 mg/kg; *iodine 1 mg/kg; *cobalt g/kg

[*] maximum values as indicated by manufacturer, the rest of the components in the Vitamin premix are indicated as minimum values

Table 2 Nutritional and mineral composition of the soybean meal, *Spirulina platensis,* commercial starter[#] and experimental grower diets (g/kg DM)

| Parameters | *Spirulina platensis* | Soybean meal | Diets | | | |
|---|---|---|---|---|---|---|
| | | | 0% SP | 5% SP | 10% SP | 15% SP |
| Dry matter | 928.7 | 934.50 | 905.75 | 908.20 | 910.50 | 909.55 |
| Ash | 771.50 | 60.35 | 41.90 | 42.15 | 41.60 | 44.50 |
| Ether extract | 2.80 | 23.25 | 71.70 | 68.80 | 73.35 | 73.10 |
| Crude protein | 712.00 | 499.00 | 181.00 | 207.00 | 204.50 | 216.00 |
| NDF | 85.50 | 121.35 | 410.25 | 461.10 | 463.55 | 448.65 |
| ADF | 143.00 | 58.20 | 53.90 | 62.35 | 67.05 | 56.05 |
| Metabolizable Energy (Kcal/kg) | 3467.97 | 3704.59 | 3959.13 | 3945.98 | 3979.45 | 3971.08 |
| K | 12.40 | 18.65 | 91.00 | 9.35 | 8.65 | 8.40 |
| Mg | 2.20 | 2.20 | 2.35 | 2.15 | 2.30 | 2.25 |
| Na | 1.00 | 0.04 | 0.97 | 0.99 | 1.82 | 2.36 |
| Ca | 0.70 | 2.31 | 1.00 | 0.96 | 0.88 | 0.82 |
| Cu | 0.01 | 0.01 | 0.03 | 0.02 | 0.02 | 0.02 |
| Fe | 0.44 | 0.10 | 0.14 | 0.14 | 0.17 | 0.24 |
| Mn | 0.02 | 0.04 | 0.12 | 0.11 | 0.12 | 0.13 |
| Zn | 0.02 | 0.05 | 0.14 | 0.11 | 0.10 | 0.12 |

[#]Commercial starter diet contains: protein 200 g/kg; *moisture 12 g/kg; fat 25 g/kg; *fibre 50 mg/kg; Vitamin A 12 000 IU/kg; Vitamin D 5000 IU/kg; Vitamin E 60 IU/kg; Vitamin K 3.5 IU/kg; Vitamin B2 7.5 IU/kg; Vitamin B6 4 mg/kg; Vitamin B12 20 mg/kg; Niacin 80 mg/kg; D-Pantothenic 5 mg/kg; Biotin 0.2 mg/kg; Folic acid 2 mg/kg; calcium 8 mg/kg; phosphorous 6 mg/kg; copper 15 mg/kg; iron 50 mg/kg; manganese 100 mg/kg; cobalt 0.5 mg/kg; iodine 2 mg/kg; zinc 60 mg/kg; selenium 0.3 mg/kg

[*] maximum values as indicated by manufacturer, the rest of the components in the Vitamin premix of the commercial starter diet are indicated as minimum values

Table 3 The concentration of phenols and tannins (g/kg DM) in *Spirulina platensis*, soybean meal and experimental diets

| | TP | NTP | TT | CT | HT |
|---|---|---|---|---|---|
| SB | 30.5 | 7.75 | 22.75 | 5.78 | 16.97 |
| SP | 74.2 | 19.4 | 54.8 | 10.07 | 44.73 |
| 0% SP | 32.4 | 7.3 | 25.1 | 4.28 | 20.82 |
| 5% SP | 59.2 | 7.7 | 51.5 | 6.94 | 44.56 |
| 10% SP | 59.15 | 10.85 | 48.3 | 7.01 | 41.29 |
| 15% SP | 60.85 | 15.2 | 45.65 | 7.14 | 38.51 |

*SB* soybean meal; *SP Spirulina platensis*; *0% SP* control diet; *5% SP* 5% Spirulina inclusion; *10% SP* 10% Spirulina inclusion; *15% SP* 15% Spirulina inclusion; *TP* total phenols; *NTP* non-total phenols; *TT* total tannins; *CT* condensed tannins; *HT* hydrolysable tannins

### 2.5 Cost analysis of diets

The cost of the diets was computed based on the prevailing local market prices of ingredients in 2021 when the feeding trial was conducted, Substitution of soybeans by Spirulina did not have substantial effects on other costs of growing indigenous chickens from weeks 5 to 16, hence these were ignored in the computations for costs of feed per unit weight gain.

### 2.6 Statistical analyses

The final weight was analysed using Proc GLM (SAS, 2009) [21]. The data on daily feed intake, CP intake, average body weight, average daily gain, protein efficiency ratio and feed conversion ratio were analyzed using Proc Mixed procedure of SAS (2009) [21], where the initial bird weight was used as a covariate. To account for the correlation among several measurements of the same experimental unit, repeated measures analysis was done and the best covariance structure was selected using the Bayesian Information Criterion (BIC) [22]. Data transformation was carried out to achieve approximate normality, where necessary. Significance level was set at P < 0.05. The model below was fit for the effect of diet, breed, week and their interactions:

$$Y_{ijkl} = \mu + D_i + B_j + W_k + (D \times B)_{ij} + (B \times W)_{jk} + (D \times W)_{ik} + (D \times B \times W)_{ijk} + \alpha S_l + E_{ijkl}$$

where $Y_{ijk}$ is the response of the lth replicate of the ith diet, jth breed, in the kth week; $\mu$ the fixed effect of population mean variable; $D_i$ is the effect of ith treatment diet (i = 0% SP, 5% SP, 10% SP, 15% SP); $B_j$ is the effect of jth chicken breed (j = BV, PK); $W_k$ is the effect of the kth week (k = 1, 2 …12); $(D \times B)_{ij}$ is the interaction effect of the ith diet and jth chicken breed; $(B \times W)_{jk}$ is the interaction effect between jth chicken breed and the kth week; $(D \times W)_{ik}$ is the interaction effect between the ith treatment diet and the kth week; $(D \times B \times W)_{ijk}$ is the interaction effect between the ith diet, jth chicken breed and the kth week; $S_l$ is the Average initial weight of chickens in the lth replicate; α is the regression coefficient on the initial weight; $E_{ijkl}$ is the random error.

## 3 Results

Table 4 shows the effect of the main factors (diet, breed and week) and their interactions on feed intake and growth performance of chickens at different levels of spirulina in the diet. The results of the study showed that 3-way interactions (breed × diet × weeks) did not (P ˃ 0.05) influence feed intake and growth performance parameters, except ADG. The 2-way interactions of diet × breed did not (P ˃ 0.05) affect feed intake, ADG, FCR and PER, but influenced (P < 0.05) protein intake. Treatment diets and week interacted (P < 0.05) to influence almost all the parameters.

Across all treatments, feed intake increased with time (weeks) (Fig. 1). With a few exceptions, all the diets (0% SP, 5% SP, 10% SP and 15% SP) were consumed in similar quantities (P ˃ 0.05) during week 1 to week 3. However, from week 4 to 12, the control diet was consumed in greater quantities (P < 0.05) than 5% SP, 10% SP and 15% SP diets. Intake of Spirulina-containing diets was similar (P > 0.05) in each week across the trial period, with the exceptions of both 5% SP and 10% SP exceeding (P < 0.05) 15% SP at week 1. Averaged over the experimental period, the control diet intake exceeded (P = 0.0002) that of the Spirulina-containing diets. Feed intake of Boschveld chickens was similar (P > 0.05) to that of Potchefstroom except at weeks 10 and 11, where Boschveld had a higher (P < 0.05) intake (Fig. 2). Whereas the Boschveld attained peak feed intake at week 10 (P = 0.06), for the Potchefstroom it was at week 4 (P = 0.26).

The significant breed × diet interaction (P < 0.05) for PI was due to a higher intake by Boschveld at weeks 10 and 11, with similar (P > 0.05) protein intakes at other weeks. Boschveld chickens had higher (P = 0.04) PI than Potchefstroom Koekoek only on the 15% SP (Table 5).

The average body weights in Boschveld under the control diet were similar (P > 0.05) to those from 5% SP, but were heavier (P < 0.05) than those from 10% SP and 15% SP. In the Potchefstroom Koekoek the control diet resulted in heavier (P < 0.0001) body weights than the Spirulina-containing diets. The 5% SP led to better (P < 0.05) ABW than 10% SP and 15% SP in both breeds. While the 10% SP diet resulted in better (P < 0.05) ABW than 15% SP in the Boschveld,

**Table 4** The effect of the main factors (treatment diet, chicken breed and weeks) and their interaction on feed intake and growth performance parameters of chickens at different inclusion levels of Spirulina in the diet

| Parameters | Effect of treatment | | | Interactions | | | |
|---|---|---|---|---|---|---|---|
| | Diet (D) | Breed (B) | Week (W) | D×B | D×W | B×W | D×B×W |
| FI | * | NS | *** | NS | * | *** | NS |
| PI | NS | NS | *** | ** | *** | *** | NS |
| ABW | *** | NS | *** | ** | *** | *** | NS |
| FW | *** | NS | N/A | NS | N/A | N/A | N/A |
| ADG | *** | * | NS | *** | *** | NS | *** |
| FCR | * | NS | *** | NS | ** | *** | NS |
| PER | *** | NS | *** | NS | *** | * | NS |

*D* Treatment diet; *B* Chicken breed; *W* Week; *FI* Feed intake; *PI* Protein intake; *FW* Final weight; *ABW* average body weight; *ADG* average daily gain; *FCR* feed conversion ratio; *PER* protein efficiency ratio; *P < 0.05; **P < 0.001; ***P < 0.0001; *NS* not significant; *N/A* Not applicable

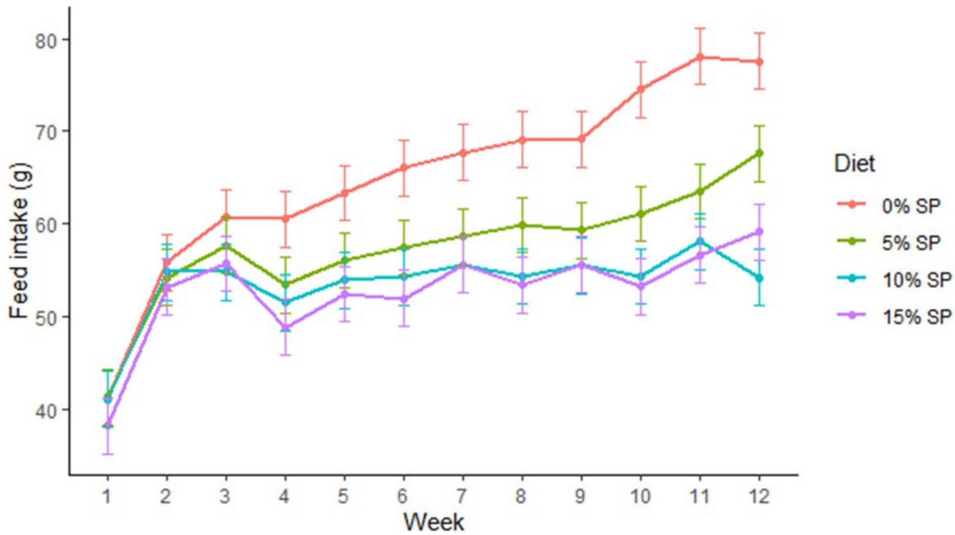


**Fig. 1** Daily feed intake (g) least squares means under varying inclusion levels of Spirulina in grower diets

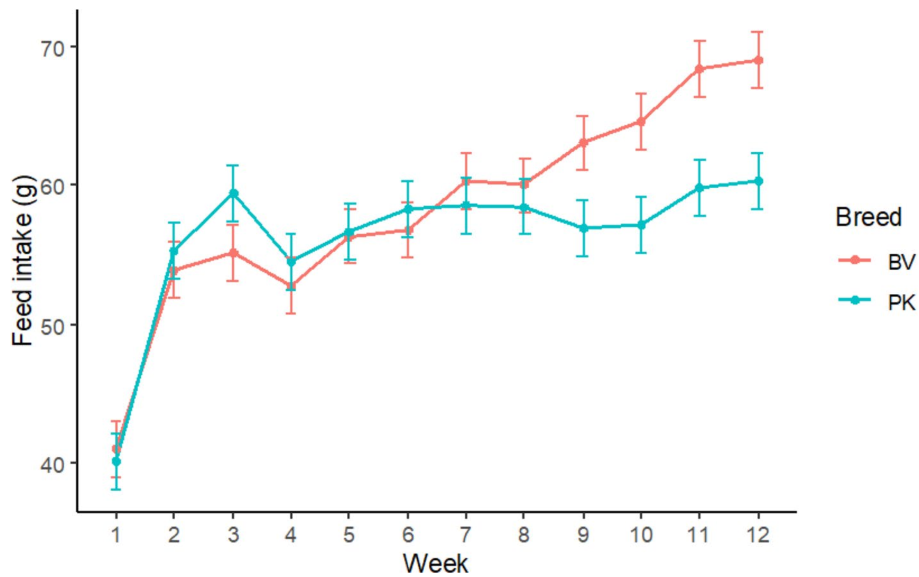


**Fig. 2** Effects of breed × week interactions on feed intake (g) least square means of Boschveld and Potchefstroom Koekoek chickens fed incremental levels of Spirulina. Indicate what BV and PK means here

**Table 5** Effects of diet × breed interactions on least squares means for protein intake (PI) and average body weight (ABW) of Boschveld and Potchefstroom Koekoek chickens

| Breed | Treatments | Parameters | |
|---|---|---|---|
| | Diet | PI (g) | ABW (g) |
| BV | 0% SP | 11.97$^{a}$ | 671.36$^{b}$ |
| | 5% SP | 12.14$^{a}$ | 653.01$^{c}$ |
| | 10% SP | 11.16$^{b}$ | 618.69$^{c}$ |
| | 15% SP | 11.90$^{a}$ | 585.29$^{c}$ |
| PK | 0% SP | 11.62$^{a}$ | 700.43$^{a}$ |
| | 5% SP | 11.69$^{a}$ | 637.40$^{c}$ |
| | 10% SP | 10.79$^{b}$ | 579.17$^{c}$ |
| | 15% SP | 10.96$^{b}$ | 599.56$^{c}$ |
| SEM | | 0.52 | 10.40 |
| P-value | | 0.0010 | 0.0065 |

*BV* Boschveld; *PK* Potchefstroom Koekoek; *0% SP* control diet; *5% SP* 5% Spirulina inclusion; *10% SP* 10% Spirulina inclusion; *15% SP* 15% Spirulina inclusion; $^{abc}$Mean with different superscripts within a column differ (P < 0.05) there was no difference (P > 0.05) in the Potchefstroom Koekoek. The Potchefstroom Koekoek was heavier (P < 0.05) in weeks 2, in weeks 1, and 3–9 the ABW was similar (P > 0.05) for the two breeds and the Boschveld chickens were heavier (P < 0.05) in week 10–12. The Potchefstroom Koekoek attained peak (P = 0.12) ABW at week 10; the Boschveld attained peak (P = 0.30) ABW at week 12.

The ABW of birds on the control diet exceeded that of the Spirulina-containing diets (Fig. 3). The ABW of birds on the control diet was similar (P > 0.05) to those on the 5% SP for weeks 1–7, whereas for weeks 8–12, the control diet led to heavier (P < 0.05) birds. Similarly, the ABW for birds on the 5% SP was similar (P > 0.05) to those on the 10% SP for weeks 1–7, but exceeded (P < 0.05) those on the 10% SP at weeks 8–12. The ABW for 10% SP and 15% SP was similar (P > 0.05).

The ADG (g/d) was influenced (P < 0.05) by breed × diet × week interactions. The ADG declined with increasing week; additionally, the Boschveld generally showed some advantage over the Potchefstroom Koekoek. Averaged over the 12 weeks, the control diet gave better (P < 0.0001) ADG (9.42 g/d) than the Spirulina-containing diets (5% SP = 7.28; 10% SP = 5.12; 15% SP = 5.57 g/d). Inclusion of Spirulina at 5% led to similar ADG as at 10% level, except at weeks 7 and 12 where the former was superior (P < 0.05). Inclusion of Spirulina at 10% and 15% level gave similar (P > 0.05) ADG at all time points. Breed of chickens interacted (P < 0.05) with period of growth (week) to influence ADG. The ADG initially increased in both breeds and then begun to decline in week 6 in Boschveld, while in Potchefstroom Koekoek the decline started earlier at about week 4.

The FCR was similar (P > 0.05) for the two breeds for weeks 2–7, but the Potchefstroom was more (P < 0.05) efficient at weeks 8 and 10–12. The FCR for the control diet was similar (P > 0.05) to that for 5% SP, except at week 2. The 5% SP diet gave a more desirable FCR than 10% SP at weeks 11 and 12; there were no differences (P > 0.05) at other weeks. Similarly, the 10% SP gave a more (P < 0.05) desirable FCR than 15% SP only at week 12; the FCR was similar (P > 0.05) at other weeks. Contrasts showed that 10% SP and 15% SP diets had similar (P > 0.05) FCR to the control, except at weeks 11 and 12 where the control had a more desirable value. Averaged over the 12 weeks, the control diet had a more desirable (7.79 *vs.* 8.17, P = 0.01) FCR than the Spirulina-containing diets. The PER was similar (P > 0.05) for both breeds, except at week 7 where the Boschveld was better (P < 0.05). The PER for the control diet was better (P < 0.05) than 5% SP at weeks 3, 4, 6 and 9; there were no differences (P > 0.05) at other weeks. Diets 5% SP, 10% SP and 15% SP had similar (P > 0.05) PER during the trial. Overall the control diet had better (P < 0.05) PER than the Spirulina-containing diets (0.91 *vs*. 0.62). Table 6 shows the least squares means for the main effects for FI and the growth performance variables. Due to significant interactions (P < 0.05), however, these main effect estimates should be cautiously interpreted.

The variables considered in this study for the cost–benefit analysis of using *Spirulina platensis* to replace soy bean meal as a protein source at varying levels (0%, 5%, 10% and 15%) are presented in Table 7. Feed costs per kg gain increased by 30.6%, 83.9% and 134.5% for 5% SP, 10%SP and 15% SP diets respectively, relative to the control. The largest contributor to the high feed cost was the Spirulina, which was highly priced relative to other ingredients.

**Fig. 3** Effects of diet × week interactions on average body weights (g) least squares means of chickens fed incremental levels of Spirulina

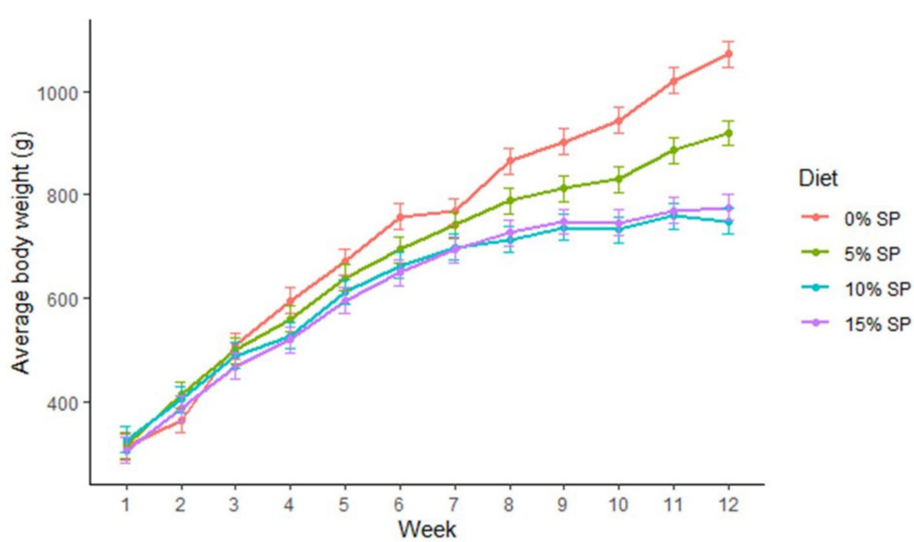

**Table 6** Main effects of diet and breed on least squares means for feed intake and growth parameters of Boschveld and Potchefstroom Koekoek chickens

| | Parameters | | | | | |
|---|---|---|---|---|---|---|
| | FI (g) | FW (g) | ABW (g) | ADG (g/d) | FCR | PER |
| Diet | | | | | | |
| 0% SP | 65.33[a] | 1093.19[a] | 685.74[a] | 9.42[a] | 7.79[b] | 0.91[a] |
| 5% SP | 57.56[b] | 921.61[b] | 645.16[b] | 7.28[b] | 8.66[b] | 0.68[b] |
| 10% SP | 53.60[c] | 762.76[c] | 598.60[c] | 5.12[c] | 10.99[a] | 0.61[c] |
| 15% SP | 52.88[c] | 771.20[c] | 592.35[c] | 5.57[c] | 11.69[a] | 0.57[c] |
| SEM | 2.253 | 47.80 | 7.355 | 0.51 | 2.43 | 0.052 |
| P-value | 0.005 | < 0.0001 | 0.0001 | < 0.0001 | 0.02 | 0.0002 |
| Breed | | | | | | |
| BV | 58.41 | 916.74 | 631.25 | 7.38[a] | 8.78 | 0.67 |
| PK | 56.27 | 857.64 | 627.25 | 6.06[b] | 10.66 | 0.57 |
| SEM | 1.593 | 33.26 | 5.201 | 0.36 | 1.68 | 0.037 |
| P-value | 0.356 | 0.200 | 0.619 | 0.02 | 0.05 | 0.118 |

*FI* Feed intake; *FW* Final weight; *ABW* average body weight; *ADG* average daily gain; *FCR* feed conversion ratio; *PER* protein efficiency ratio; *SP* Spirulina; *0% SP* control diet; *5% SP* 5% Spirulina inclusion; *10% SP* 10% Spirulina inclusion; *15% SP* 15% Spirulina inclusion; *BV* Boschveld; *PK* Potchefstroom Koekoek, [abc-] Means with different superscripts within a column differ ($P < 0.05$)

**Table 7** Feed cost benefit analysis of using *Spirulina platensis* as a replacement of soy bean meal in grower diets of Boschveld and Potchefstroom Koekoek chickens

| Ingredients | Diets | | | |
|---|---|---|---|---|
| | 0% SP | 5% SP | 10% SP | 15% SP |
| Yellow maize (kg) | 59 | 59 | 59 | 59 |
| Wheat Bran (kg) | 21 | 21 | 21 | 21 |
| Soy bean (kg) | 19.4 | 14.4 | 9.4 | 4.4 |
| *Spirulina platensis* (kg) | 0 | 5 | 10 | 15 |
| Vit & Min premix (kg) | 0.3 | 0.3 | 0.3 | 0.3 |
| Salt (kg) | 0.2 | 0.2 | 0.2 | 0.2 |
| Sunflower oil (kg) | 0.1 | 0.1 | 0.1 | 0.1 |
| Cost of 100 kg feed (US$)* | 241.81 | 302.61 | 363.48 | 424.32 |
| Initial weight (g) | 300.11 | 307.89 | 307.33 | 295.22 |
| Final weight (g) | 1086.75 | 971 | 834 | 771 |
| Total feed intake (kg) | 5.49 | 4.83 | 4.50 | 4.44 |
| Feed cost (US$/kg) | 2.42 | 3.03 | 3.63 | 4.24 |
| Total feed cost (US$) | 13.29 | 14.63 | 16.36 | 18.84 |
| Total weight gain (kg) | 0.79 | 0.66 | 0.53 | 0.48 |
| Feed cost per kg gain (US$) | 16.89 | 22.06 | 31.06 | 39.60 |

Calculated based on ingredient prices in 2021; *1 US $ = 14.60 in January 2021

## 4 Discussion

This study investigated the effect of substitution of Spirulina for soybeans at different levels in diets of two slow-growing chicken breeds (Boschveld and Potchefstroom Koekoek). The Spirulina had a CP and fibre content comparable to other studies [23, 24]. Compared to soybeans, Spirulina had higher total phenols and total tannins, which may negatively influence its utilization in these slow-growing chicken breeds. While the feed formulation aimed to have grower diets comparable to those used commercially, the analysed ME levels were higher. The high ME resulted from use of published feed values in feed formulation, which differed from the analysed ME values, which may have been a result of sampling or analytical inaccuracies.

Chickens given Spirulina diets consumed less feed than those fed a control, and this reduction varied with the level of inclusion and week of measurement. The reduced feed intake might be due to the higher phenolic content in Spirulina-containing diets than in control, as well as its weak organoleptic properties. In monogastric animals, tannins can cause antinutritional effects and make the feed taste astringent, which may lead to low palatability and discourage consumption [23–25]. These results agree with those of Zahir et al. [17] and Gongnet et al. [26] who reported reduced feed intake with increasing Spirulina concentration in diets of broilers.

Inclusion of microalgae in poultry diets at levels exceeding 10% has been reported to cause gelation of its indigestible proteins leading to higher digesta viscosity, which restricts enzyme access to substrates and hence reduced performance [15, 27, 28]. We observed a tendency to sort particles when birds were given Spirulina-containing diets, with the Spirulina being eaten last. Additionally, the Spirulina-containing diets had a distinctive odour and tended to stick on the birds' beaks which we surmise may have adversely affected intake. The reduction in feed intake in these slow-growing composite breeds may have some benefit because it could enhance feed utilization efficiency depending on the target slaughter age. Indeed, there were no significant differences between the 10% SP and 15% SP diets on ADG, FCR and PER up to about week 10. Evidently breed differences were detected in performance, with the Boschveld having better utilization of Spirulina at higher inclusion levels (10% SP and 15% SP) than the Potchefstroom Koekoek, as they grew older. These results agree with Fernandes et al. [29] who reported depressed performance at 15% Spirulina inclusion, but in contrast our results show differences in utilization of higher levels of Spirulina among slow-growing breeds.

The current study results contradict those of Pestana et al. [15], Mirzaie et al. [30] and Mullenix et al. [31] who supplemented broiler diet with Spirulina at the inclusion levels similar to this study (10% and 15% Spirulina) and reported no significant difference in the feed intake of broiler chickens. The differences between the results could be related to the breed of chickens used, the age of birds at which inclusion of Spirulina commenced and the duration of the experiments. Feed intake increased with age of bird as expected, that leads to increased nutritional requirements and therefore they eat to satisfy their needs [32]. At the younger ages, feed intake was similar for the two breeds, however, the Boschveld consumed more feed in the terminal part of the experimental period, which may indicate its better adaptation to the Spirulina diet at an older age. This result agrees with the finding of Rondelli [33] who observed that the genetics of a chicken influences its feed consumption at different stages.

The BV chickens consumed more feed and had more protein intake in the terminal weeks of the experimental period, hence there was more energy and nutrients available for growth, which may have contributed to the higher ADG in the BV compared to the PK chickens. Chickens fed the control diet (0% SP) had better average body weights compared to those fed Spirulina-containing diets. This may be attributed to higher feed intake in birds fed control than those fed Spirulina-containing diets because feed intake is positively correlated with the growth performance of meat-type poultry [34]. In agreement with studies conducted by Pestana et al. [15], Gongnet et al. [26], Ross [34] and Fernandes et al. [29] and birds fed Spirulina diets had lower body weights than those fed control diets. In contrast, the results disagree with the findings of Bonos et al. [35], Mariey et al. [36] and Sugiharto et al. [37] who reported a non-significant difference in the body weight between birds fed diet supplemented with Spirulina and the control group.

Despite the FI being similar at most time points among the Spirulina-containing diets, the ABW on 5% SP, was better than on 10% SP and 15% SP, implying that digestion and nutrient utilization were impaired at higher Spirulina inclusion levels. The significant diet × week interactions on ABW imply that optimal Spirulina inclusion levels in these slow-growing breeds will depend on the target slaughter age, because differences among diets emerged at later ages. Clearly the results show there is room for incorporation of Spirulina in diets of these slow-growing breeds, with the Boschveld showing greater versatility in utilizing Spirulina at higher (5%, 10% SP) inclusion levels. These results agree with the findings of Pestana et al. [15], Zahir et al. [17], Gongnet et al. [26] and Mullenix et al. [31] who reported poorer feed conversion ratio in chickens fed diets containing Spirulina than a control group. These results, however, contradict those of Shanmugapriya et al. [38] who reported better feed conversion ratio in birds fed diets supplemented with Spirulina than control groups, possibly because of the age at which feeding of Spirulina-containing diets commenced, the level of inclusion, duration of experiment and genotypes of chickens used.

The high concentration of tannins in Spirulina and gelation of indigestible proteins may have affected protein digestibility and reduced efficiency of protein utilization [15, 39]. The PER increased slightly when the birds were younger and subsequently declined with age because young animals grow faster up to the inflection point of the growth curve at which they attain their maximum growth rate [40]. Overall, significant diet × week and breed × week interactions for most variables studied were observed, but not breed × diet, which indicates age-related changes due to the sigmoid nature of the growth curve, with concomitant changes in nutrient utilization as affected by genetic potential. Hence Spirulina utilization will be dependent on age in these slow-growing breeds. These results need to be confirmed in future studies with a higher number of replicates and with chicks separated by sex prior to random allocation to different treatments. Cost/benefit analyses are also needed as part of the evaluation of the merits of different substitution levels of soybeans with Spirulina.

The feed cost per kg gain shows that incorporation of Spirulina at 5% or more would not be viable at the prevailing market prices, especially in slow-growing indigenous chickens. Thus, although generally unconventional feed ingredients are sought after because they are cheaper [40, 41] and have few alternative uses, Spirulina does not conform to this. Production and processing methods for Spirulina are expensive rendering the final product expensive for incorporation in poultry feeds, however, scaling up or developing new production methods that are locally based may contribute to its viability in the future. These results need to be confirmed in future studies with a higher number of replicates and with chicks separated by sex prior to random allocation to different treatments.

## 5 Conclusion

Substitution of soybeans with Spirulina at levels of 10–15%, in slow-growing breeds may be acceptable as it did not seriously impair ADG, FCR and PER compared to the control up to about 14 weeks of age; however, the optimal inclusion level will depend on the breed and target slaughter weight. Inclusion of Spirulina in poultry diets up to about 10% level may be warranted, particularly in Boschveld chickens raised up to 16 weeks of age.

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**Data availability** Data will be available upon reasonable request.

### Declarations

**Ethics approval and consent to participate** The experiment used chickens, hence University of Namibia ethical standards were followed and the ethical clearance certificate number FANR/004/2019 was obtained from the University Ethics committee before commencement of the experiment. Additionally, the researchers worked hand-in-hand with the veterinarians on campus to guarantee that the animal welfare standards were adhered to.

**Consent for publication** The data in the manuscript have been agreed upon by all of us, and we have submitted our final manuscript to the Journal of Discover Agriculture.

**Competing interests** The authors declare no competing interests.



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