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# Effect of Partial Replacement of Yellow Corn by Mango Seed Kernel on Productive Performance, Egg Quality, and Blood Constituents of Laying Hens

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## ABSTRACT

Corn is the main energy source in most poultry feed. Due to rapid climate change, corn production cannot keep up with the demand for food and industrial applications. This necessitated the search for alternatives, such as agro-industrial by-products like mango seed kernel, which is a good source of carbohydrates and protein and can wholly or partly replace corn. The purpose of this study was to investigate the effect of partial replacement of yellow corn (YC) with soaked mango seed kernel (SMSK) on productive and reproductive performance, egg quality, blood biochemistry, hematological parameters, and antioxidants status of local laying hens. A total of 120 local *Gimmizah* breeds (108 females and 12 males) at 32 weeks of age were randomly assigned to four dietary treatments with three replicates (9 hens + 1 male per replicate). The treatments were YC replaced by SMSK at 0, 10, 15, and 20% levels in the hen diets for 12 weeks. Replacing YC with SMSK increased egg production, weight and number of eggs, and egg mass, and improved feed conversion ratio, but feed intake was not affected. Replacement of yellow corn with SMSK did not affect egg quality parameters. The hens in the SMSK 10% and SMSK 15% groups had the highest fertility, hatchability, post-hatch chick weight, and number followed by those in the SMSK 20% group. Groups given varying levels of SMSK had the lowest rate of embryonic mortality. Carcass weight and dressing percentage were positively affected by the 10% and 15% SMSK diet, except for the heart, pancreas, and spleen. Hematological indices were not influenced by dietary SMSK except for higher platelets in the SMSK 20% group. Total protein, aspartate aminotransferase, alanine aminotransferase, and alkaline phosphatase levels were similar among treatments. In SMSK groups, serum total cholesterol, triglycerides, and malondialdehyde levels decreased significantly, whereas IgG and catalase levels increased. These findings indicated that SMSK up to 20% could be considered a successful nutritional and health approach and can be partially substituted for YC with no adverse impact on the productive, reproductive and physiological performance of laying hens.

**Keywords:** Antioxidant status, Egg quality, Egg production, Laying hens, Lipids profile, Mango Seed Kernel, Replacement

## INTRODUCTION

The high cost of feed remains the most constraint for poultry production, accounting for about 70-80% of total expenditures in Egypt. Maize as the main energy source in poultry feed accounts for between 50 and 55% of most poultry feed (Vieites et al., 2014). It is used equally in humans' nutrition thus creating intense competition between humans and livestock. This necessitated the search for alternatives like agro-industrial by-products that could wholly or partially replace maize such as mango seed kernel (Kperegbeyi and Onwumere, 2007). Mango (*Mangifera indica Linn*.) is the main fruit crop in Egypt, Egyptian production reached 1.091.535 tons in a harvested area of 265.509 (Hamdy et al., 2021). Since mangoes contain between 9-40% of inedible kernels, a significant amount of kernel waste is generated during industrial processing, causing major disposal issues (Berardini et al., 2005). Therefore, using this massive volume of kernel waste to feed chicken could have an important role in bridging the problem of scarcity and competition in feed. Mango seed kernel (MSK) has been reported to be a good source of carbohydrates, as well as a high amount of fats that combine to give metabolizable energy (ME) comparable to that of corn (Diarra et al., 2011). Ravindran and Sivakanesan (1996) reported that only 52.5% of MSK carbohydrates were metabolized by poultry. The protein content of dried MSK (6-13%) has a good essential amino acid profile, especially in terms of lysine and methionine comparable to that of corn (Fowomola, 2010; Diarra et al., 2011). Mango seed kernel (MSK) is an alternative because they have appreciable amounts of calcium, potassium, magnesium, unsaturated fatty acids, vitamins C, E, and A, phenolic compounds, and antioxidants (Huber et al., 2012; Kittiphoom, 2012). Moreover, MSK is rich in essential oils, such as stearic and oleic acids that could be fractionated to produce olein and stearin (Gunstone, 2006; Kittiphoom, 2012). It was reported that 50% and 75% of maize can be substituted by boiled MSK in broiler diets without negative effects on blood parameters (Diarra et al., 2011). Although it has a high content of nutrients, the use of MSK in poultry feed is limited due to the presence of anti-nutritional agents, including tannins, cyanogenic glucosides, flavonoids, alkaloids, saponins, and phytates, (Dakare et al., 2012), however, these anti-nutritional agents may not present major constraints to MSK feeding in poultry. Odunsi (2005) found that when maize was replaced with above 10% of raw MSK, the laying rate of hens, egg mass, feed intake, and feed efficiency were decreased, while the internal egg quality was not affected by a substitution ratio of up to 25%. These findings indicated that raw MSK could not easily substitute maize in laying hens' diet. Processing, as soaking, may allow for higher levels of MSK inclusion. However, there was a scarcity of information in Egypt about mango kernel's nutritional potential as a poultry feed. Therefore, this study was carried out to investigate the effects of partial substitution of yellow corn by mango seed kernel on reproductive performance, fertility, hatchability, carcass characteristics, and blood components of layer hens.

## MATERIALS AND METHODS

### Ethical approval

The present study was performed at El-Sabahia Poultry Research Station, Animal Production Research Institute (APRI), Agricultural Research Center. All the experimental procedures were permitted by the ethics of the Institutional Animal Care and Use Committees of City Scientific Research and Technological Applications (Protocol No. 56-2Y-3022), Alexandria, Egypt. Chickens were cared for using husbandry guidelines derived from El-Sabahia Poultry Research Station standard operating procedures.

### Collection and preparation of mango seed kernel

Mango seeds were obtained from a juice factory, Alexandria Governorate, Egypt. To obtain the kernel, mango seeds were cut open with a knife to reveal the kernel, and then diced to minimize particle size. Kernels were soaked with tap water for three days at room temperature to decrease the anti-nutritional factors and air-sundried for three days. Dried kernels were ground in a mill into a powder and kept in an airtight closed bottle until further chemical analysis. The chemical analysis of mango seeds kernel powder as a feed substitute is presented in Table 1.

**Table 1.** The chemical composition of soaked mango seed kernel

| Items | Mango seed kernel |
|---|---|
| **Chemical analysis (Percentage on a dry matter basis)** | |
| Organic matter | 97.26 |
| Crude protein | 6.42 |
| Crude fiber | 3.18 |
| Crude fat | 5.66 |
| Nitrogen free extract | 82.00 |
| Ash | 2.74 |
| Neutral detergent fibre | 29.24 |
| Acid detergent fiber | 18.32 |
| Acid detergent lignin | 5.66 |
| Hemicellulose | 10.92 |
| Cellulose | 12.66 |
| ME (Kcal/kg diet) | 3255.24 |
| **Minerals composition (mg/kg)** | |
| Sodium | 2985.11 |
| Potassium | 7457.63 |
| Calcium | 387.27 |
| Magnesium | 1688.44 |
| Zinc | 38.84 |

ME: Metabolizable energy

### Laying hens, diets, and experimental design

A total of 120 of the local *Gimmizah* breed (108 females + 12 males) at 32 weeks of age were randomly assigned to four treatment groups, with three replicates and each replicate consisted of 9 hens + 1 cock per $m^2$. The treatments were yellow corn (YC) replaced by soaked MSK at 0, 10, 15, and 20% levels in the hen diets. All birds were housed in a well-ventilated room at an ambient temperature that fluctuated between 28.6°C and 20.3°C and 55-60% relative humidity with 16 hours of light to 8 hours of darkness under similar managerial and hygienic conditions. The poultry was placed on wheat straw litter at a depth of 5 cm during the experiment period. Hens were fed experimental diets for two weeks (preliminary period) for adaptation. Feed and water were offered *ad libitum* throughout the experiment period of 12 weeks (32 to 44 weeks of age). The basal diet was supplied to meet the nutrient requirements according to the Agriculture Ministry Decree (1996). The calculated analysis of the experimental diets was performed based on Feed Composition Tables for animal and poultry feedstuffs used in Egypt (2001) as shown in Table 2.

**Table 2.** Ingredient of the experimental diets and calculated analysis (percentage on a dry matter basis)

| Item | SMSK 0% | SMSK 10% | SMSK 15% | SMSK 20% |
|---|---|---|---|---|
| **Ingredients (%)** | | | | |
| Yellow corn | 64.04 | 57.636 | 54.434 | 51.232 |
| Soybean meal (44%) | 20.15 | 19.08 | 18.13 | 17.83 |
| Corn gluten (60%) | 5.13 | 6.20 | 7.15 | 7.45 |
| Soaked mongo seed kernel | 0.0 | 6.404 | 9.606 | 12.808 |
| Vegetable oil | 1.2 | 1.2 | 1.2 | 1.2 |
| Salt | 0.3 | 0.3 | 0.3 | 0.3 |
| Dicalcium phosphate | 1.07 | 1.07 | 1.07 | 1.07 |
| Limestone | 7.75 | 7.75 | 7.75 | 7.75 |
| Vitamin and mineral Premix[1] | 0.31 | 0.31 | 0.31 | 0.31 |
| DL-methionine | 0.05 | 0.05 | 0.05 | 0.05 |
| **Calculated analysis[2](%)** | | | | |
| Crude protein | 17.32 | 17.26 | 17.34 | 17.32 |
| Ether extract | 3.84 | 3.87 | 3.90 | 3.99 |
| Calcium | 3.42 | 3.49 | 3.51 | 3.58 |
| Available phosphorus | 0.588 | 0.596 | 0.601 | 0.613 |
| Methionine | 0.336 | 0.331 | 0.327 | 0.321 |
| Lysine | 0.875 | 0.866 | 0.861 | 0.855 |
| ME (Kcal/kg) | 2836.45 | 2837.49 | 2840.70 | 2843.63 |

[1]Three kg of vitamin-mineral premix per ton of feed supplied per kg of diet: Vitamin A 12,000 IU, Vitamin D3 3,000 IU, Vitamin E 40 mg, Vitamin K3 3 mg, Vitamin B1 2 mg, Vitamin B2 6 mg, Vitamin B6 5 mg, Vitamin B12 0.02 mg, niacin 45 mg, biotin 0.075 mg, folic acid 2 mg, pantothenic acid 12 mg, manganese 100 mg, zinc 600 mg, iron 30 mg, copper 10 mg, iodine 1 mg, selenium 0.2 mg, cobalt 0.1 mg. [2]According to Feed Composition Tables for animal and poultry feedstuffs used in Egypt (2001). SMSK: Soaked mango seed kernel.

### Chemical analyses

Samples of the soaked mango seed kernel (SMSK) powder and feed were finely ground through a 1-mm screen in a Cyclotec mill (Cyclotec 1093; Foss, Germany) and stored prior to chemical analysis. Moisture content was determined in dried samples in an oven at 70°C to a constant weight. The content of CP (N 6.25) was determined according to Kjeldahl's Method No. 978.04 (AOAC, 2005). The ether extract (EE) was determined according to the Soxhlet extract method No. 930.09 (AOAC, 2005). The content of ash was determined by Method No. 930.05 (AOAC, 2005). The contents of neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) were determined according to the method of Van Soest et al. (1991). The value of nitrogen-free extract (NFE) was calculated by the difference method. The calculation for nitrogen-free extract is NFE (%) = 100% – (EE % + CP % + Ash % + CF %). The metabolizable energy (ME) content was calculated according to Steel and Torrie (1980) as ME (kcal/kg) = 432 + 27.91 (CP + NFE + 2.25 × EE). Hemicellulose was calculated as Hemicellulose (%) = NDF (%) - ADF (%). Cellulose was calculated using the equation of Cellulose (%) = ADF (%) - ADL (%).

### Productive parameters

Individual weights of hens were recorded weekly to determine the final body weight, and body weight change (final body weight-initial body weight) was calculated. Feed intake was recorded daily and feed conversion ratio (FCR, g of feed/g of egg) was calculated. Egg weight, egg number, and egg production were recorded daily throughout the experiment. Egg mass g/hen/day (egg number × egg weight) was calculated.

**Egg quality traits**

Egg quality traits were measured monthly using 15 eggs from each treatment group. Exterior and interior egg quality parameters (percentages of albumen, yolk, shell, shell thickness, egg shape index, and Haugh unit) were determined according to Romanoff and Romanoff (1949). The egg yolk visual color scale was determined by matching the yolk with one of the 15 bands by Roche yolk color Fan (Vuilleumier, 1969). Yolk index (YI) was measured according to Funk (1948), and surface area (SA) according to Carter (1970).

**Hatchability measurements**

Fertility percentage was calculated as the number of fertile eggs/number of eggs set × 100, hatchability percentage was calculated as the number of hatched chicks/ number of fertile eggs × 100, embryonic mortalities, and body weight, and the number of hatched chicks were recorded on the day of hatch.

**Carcass traits**

At the end of the experiment, three hens per treatment were randomly chosen, individually weighed, and slaughtered. Hens were manually eviscerated, liver, heart, spleen, gizzard, intestinal and caecal weights, and pancreas, abdominal fat, ovary, oviduct, and yellow follicles weights were recorded. Data of carcass traits were expressed as a percentage of live body weight. Intestinal, caecal, and oviduct lengths were measured (cm).

**Blood constituents**

At the end of the experiment, 5 ml of blood samples collected randomly from 9 hens per treatment from the brachial vein were allocated into sterilized tubes and non-heparinized tubes. The hematological analysis was performed immediately after the collection of the blood. Heparinized blood samples were analyzed for white blood cell counts (WBC), total red blood cell counts (RBC), hemoglobin content (Hb), packed cell volume (PCV) mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC), mean corpuscular volume (MCV), the standard deviation in red cell distribution width (RDW-SD), coefficient variation of red cell distribution width (RDW-CV), and platelet count (PLT). Serum in non-heparinized blood tubes was separated by centrifuging at 4°C and 2000 × g for 15 minutes. Thereafter, sera were transferred into Eppendorf tubes and stored at -20°C until further analysis. The following serum metabolites: total protein, albumin, globulin, A/G, total cholesterol, triglycerides, aspartate aminotransferase (AST), alanine transferase (ALT), and alkaline phosphatase (ALP) were determined spectrophotometrically using commercial diagnostic kits provided by (Biodiagnostic Co. Giza, Egypt) according to the procedure outlined by the manufacturer. While, globulin was calculated as (total protein-albumin). Catalase and malondialdehyde (MDA) were determined using commercial kits and a spectrophotometer (Shimadzu, Japan) according to the manufacturers' instructions. Immunoglobulins (IgG, and IgM) were determined using kits (Bethyl Laboratories, Montgomery, TX, USA). The ELISA procedure was performed according to the manufacturer’s protocol.

**Economic efficiency**

Economic efficiency was calculated from the input-output analysis which was calculated based on the experimental feed price and egg production during the experiment period. Economic efficiency values were calculated from the price of the experimental diet and eggs produced as net revenue per unit of the total cost of feed consumed. The European Efficiency Factor (EEF) was calculated according to the method described by Nilipour (1998) at the end of the experiment period.

**Statistical Analysis**

Data were subjected to statistical analyses in a one-way analysis of variance using general linear model procedures of SAS/STAT (Statistical Analysis System, version 9.3, SAS Institute Inc., Cary, NC, USA) (SAS, 2011). The obtained data were tested by an analysis of variance with a one-way design to test the treatment at each sampling, according to the following model:

$$Y_{ij} = \mu + T_i + \mathcal{E}_{ij}$$

Where, $y_{ij}$ denotes the measured value, $\mu$ is the overall mean effect, $T_i$ signifies the $i^{th}$ treatment effect, and $\mathcal{E}_{ij}$ refers to the random error associated with the $j^{th}$ hens assigned to the $i^{th}$ treatment. Significant differences among the treatments were determined at $p < 0.05$. All results are presented as least-squares means

## RESULTS AND DISCUSSION

### Chemical composition of soaked mango seed kernel

The result of the chemical analysis of SMSK content showed organic matter (OM), crude protein (CP), crude fiber (CF), NFE, ash, and ME were 97.26%, 6.42%, 3.18%, 82.0%, 2.74%, and 3255.24 kcal/kg, respectively (Table 1). The composition of the kernel also showed appreciable mineral content. The contents of CP, CF, ash, and NFE in SMSK are in agreement with those of (Odunsi, 2005; Nzikou et al., 2010), which were similar to the current results. The EE content in SMSK was lower than the value reported by Jadhav and Siddiqui (2010), who observed 9% ether extract. The ME value of the current study was in line with (Diarra et al., 2011; Admasu et al., 2020). The chemical composition of SMSK differed from other studies which could be attributable to mango variety, growing environment, handling, and processing methods (Kansci et al., 2008; Diarra et al., 2011; Admasu et al., 2020). The composition of the kernel revealed low levels of protein and fiber but a high content of carbohydrates making it an energy-rich ingredient that could be used to replace corn in poultry feed.

### Productive performance

The effect of different levels of SMSK on layers productivity is summarized in Table 3. The results showed that chickens fed a diet containing SMSK at different levels resulted in not only higher egg production ($p < 0.05$), but also a significant increase in egg weight, egg number, and egg mass ($p < 0.05$), compared to the control group. Feed intake was not significantly differed between the treatment groups ($p > 0.05$), meanwhile, the FCR was better for hens given different levels of SMSK compared to those fed the control diet ($p < 0.05$). Furthermore, hens in the SMSK 10% group had the highest ($p < 0.05$) final body weight and body weight change, however, these weights decreased in the SMSK 20% group, with no differences between the layers on 15% SMSK and control groups.

**Table 3.** Effect of replacing corn with soaked mango seed kernel on productive performance of Gimmizah laying hens at 44 weeks of age

| Parameters | Treatments | | | | P value |
|---|---|---|---|---|---|
| | SMSK 0% | SMSK 10% | SMSK 15% | SMSK 20% | |
| Egg production (%) | 0.66 ± 0.02[b] | 0.74 ± 0.01[a] | 0.71 ± 0.02[a] | 0.72 ± 0.03[a] | 0.033 |
| Egg weight (g) | 51.77 ± 0.31[b] | 52.99 ± 0.44[a] | 53.29 ± 0.47[a] | 52.91 ± 0.26[a] | 0.028 |
| Egg number | 71.42 ± 2.15[b] | 80.58 ± 0.4.03[a] | 76.98 ± 2.78[a] | 77.71 ± 3.92[a] | 0.015 |
| Egg mass (g/hen/d) | 35.22 ± 1.24[b] | 39.50 ± 2.12[a] | 37.94 ± 1.07[a] | 38.07 ± 2.01[a] | 0.021 |
| Feed intake (g/h/d) | 130.33 ± 1.01 | 128.17 ± 3.74 | 131.34 ± 2.43 | 129.56 ± 1.46 | 0.737 |
| FCR (g feed/ g egg) | 2.52 ± 0.02[a] | 2.42 ± 0.05[b] | 2.46 ± 0.02[b] | 2.45 ± 0.03[b] | 0.009 |
| Initial body weight (g) | 1840.50 ± 44.06 | 1828.1 ± 38.83 | 1838.0 ± 45.51 | 1811.5 ± 39.04 | 0.846 |
| Final body weight (g) | 1997.67 ± 10.74[b] | 2066.4 ± 11.49[a] | 2007.6 ± 10.66[b] | 1980.41 ± 7.35[c] | 0.016 |
| Body weight change (g) | 157.17 ± 9.88[b] | 238.29 ± 11.51[a] | 169.61 ± 13.06[b] | 98.91 ± 14.79[c] | 0.022 |

[a-c] different superscripts in the same row differed significantly at $p < 0.05$. SMSK: Soaked mango seed kernel, FCR: Feed conversion ratio

Concerning the productive performance criteria, MSK can be recycled after anti-nutritional factors were removed and might be considered a potentially valuable source of antioxidants and employed as a feed ingredient (Ajila et al., 2007; El Boushy and van der Poel, 2000). Mango seed kernels were soaked and air-dried before being ground into a powder and blended with the ingredients of the experimental diets in this study to avoid the adverse effects of anti-nutritional factors in MSK. The results showed that replacing YC with 20% SMSK in hen diets improved egg production, egg weight and number, egg mass, and FCR ($p < 0.05$) without having a significant influence on feed intake ($p > 0.05$). The present results are inconsistent with Odunsi (2005) who observed a decrease in egg production rate, egg mass, feed consumption, feed efficiency, and increased weight loss in hens when maize was replaced with more than 10% raw MSK. While the result in body weight change in the SMSK 20% group agrees with Odunsi (2005). The results of the present study revealed that replacing YC with SMSK in the diet of layer hens had no effect on feed intake demonstrating its acceptability. The current result agrees with Beyene et al. (2019) reported that replacing maize grain with MSK had no effect on dry matter intake, however, the present result disagrees with the result of the same author that FCR and egg production were unaffected. The present result is inconsistent with Diarra et al. (2010) who found no significant differences in feed intake between the control group and the group fed 40% boiled MSK replacement by maize, however, the FCR was significantly improved when 60% of maize was replaced. As reported by Diarra et al. (2011), processing the mango kernel using a method such as boiling reduces the tannin content in the kernel. A certain minimum daily feed intake is necessary to satiate the poultry's appetite and to allow the digestive tract to function properly, which may indicate the normal palatability of MSK diets. These findings suggest that SMSK could be an effective corn substitute for improving digestion and preventing digestive disorders in the hens' gut. Consequently, SMSK, which is a non-competitive and non-conventional feedstuff, was found to be useful as an economic substitution for energy materials such as corn for animals (Omer et al., 2019). Generally, the current result indicated that replacing YC with SMSK in laying hens' diets improved the feed conversion ratio, whereas decreased the final body weight and the change in body weight. The present result agrees with those of Kumar et al. (2010) who reported improved FCR with increased MSK doses in the diet of broilers. Beyene et al. (2019) found that body weight change did not differ among treatments when fed on MSK. However, Admasu et al. (2020) reported that replacing maize with boiled MSK at 40% in the diet of broilers did not affect FCR, but improved final body weight. Govindappa et al. (2022) revealed no significant difference in body weight, feed intake, feed efficiency, and survivability between control and treatment groups when Giriraja birds were fed with graded levels of MSK powder. Previous studies showed that the inclusion of some residues/ wastes (apple, banana, chicory, cabbage, citrus, grape, mango, pineapple, peas, and pumpkin) in the diets of poultry and livestock significantly improved animal reproductive traits (Nkosi et al., 2016; Alnaimy et al., 2017).

**Egg quality**

No significant effect was observed due to partial substitution of dietary YC with SMSK on all egg quality traits ($p > 0.05$, Table 4). The findings of this study are consistent with the report of Odunsi (2005) who reported that the internal egg quality characteristics were not affected by a substitution rate of up to 25%. Beyene et al. (2019) reported no significant effect on the substitution of maize with MSK on albumen and yolk weight and height, and Haugh unit, shell quality parameters. There was no difference among treatments in eggshell weight and thickness which could be explained by the calcium levels of the treatment diets laid within the recommended range. Albumin quality is not significantly affected by feeding, but the decrease in Haugh unit is affected by the age of the hen and the egg storage conditions (Williams, 1992). Thus, the absence of difference in these parameters between the treatments indicated that replacing YC with MSK up to 20% does not affect the Haug unit. The albumen height determines the Haugh unit of the egg. The greater the albumen height, the greater the Haugh unit and the better egg quality. But in this study, albumen height did not differ significantly between treatments ($p > 0.05$). Haugh unit referenced was within the recommended range of 70-100, indicating good quality of the eggs (Lewko and Ornowicz, 2009). Yolk index values were within the acceptable range 0.33-0.50 for fresh eggs (Ihekoronye and Ngoddy, 1985). Odunsi (2005) found no differences in yolk weight and height, color, and yolk index between hens fed on SMSK and control diets.

**Table 4.** Effect of replacing corn with soaked mango seed kernel on egg quality traits of Gimmizah laying hens

| Parameters | Treatments | | | | p value |
|---|---|---|---|---|---|
| | **SMSK 0%** | **SMSK 10%** | **SMSK 15%** | **SMSK 20%** | |
| Egg shape index (%) | 77.06 ± 0.73 | 76.44 ± 0.65 | 76.88 ± 0.71 | 76.74 ± 0.67 | 0.851 |
| Egg shell weight (%) | 5.81 ± 0.46 | 5.75 ± 0.39 | 5.77 ± 0.42 | 5.75 ± 0.41 | 0.687 |
| Shell thickness (mm) | 0.39 ± 0.05 | 0.38 ± 0.03 | 0.38 ± 0.04 | 0.38 ± 0.03 | 0.773 |
| Haugh unit (%) | 92.59 ± 0.56 | 92.70 ± 0.58 | 92.93 ± 0.56 | 93.05 ± 0.66 | 0.884 |
| Yolk weight (%) | 17.23 ± 1.06 | 17.21 ± 1.31 | 17.23 ± 1.52 | 17.14 ± 0.99 | 0.891 |
| Yolk index (%) | 4.32 ± 0.12 | 4.31 ± 0.09 | 4.30 ± 0.13 | 4.26 ± 0.10 | 0.793 |
| Yolk color score | 8.07 ± 0.67 | 7.93 ± 0.59 | 7.82 ± 0.53 | 7.85 ± 0.61 | 0.659 |
| Albumen weight (%) | 31.18 ± 2.41 | 30.85 ± 2.19 | 31.09 ± 2.27 | 30.94 ± 2.33 | 0.699 |

SMSK : Soaked mango seed kernel

**Fertility and hatchability**

The results of fertility and hatchability traits are presented in Table 5. Hens in the SMSK treatment groups had the highest fertility and hatchability percentages, followed by the SMSK 20% group ($p < 0.05$). There were significant differences in embryonic mortality between the treatment groups at all development phases ($p < 0.05$). Groups of hens given varying levels of SMSK had the lowest rate of embryonic mortality in the early, middle, and late phases of development compared with those of the control group. The pip embryo's weight was unaffected. The number and weight of post-hatched chicks produced by hens were highest in the SMSK 10% and SMSK 15% groups, followed by those produced by the SMSK 20% group ($p < 0.05$). These results disagree with those of Beyene et al. (2015) who found that replacing maize with MSK up to 100% did not indicate significant differences in fertility, hatchability, and quality of hatched chicks. There is scarce information on the effect of MSK on egg fertility, hatchability, and hatched chick weight in laying poultry. As documented by Hocking et al. (2002) who reported that insufficient nutrients in breeders' diets led to poor hatchability rate. On the other hand, the contents of crude protein and energy of the treatment diets were effective on egg fertility and hatchability which was confirmed by the present results. Tona et al. (2004) reported that there is a positive correlation between egg weight and hatching chick weight. Similarly, the present result showed that the weight of hatched chicks was significantly increased when hens were fed a diet containing SMSK up to 20%, and this result could be attributed to the improvement of egg weight by replacing the yellow corn with 20% SMSK in the diets. Several studies have reported that a diet rich in protein and sufficient energy has been shown to improve egg weight and hatching chick weight (Gunawardana et al., 2008; King'ori et al., 2010; Shim et al., 2013). There was a significant decrease in embryonic mortality at all phases of development between the SMSK treatment groups ($p < 0.05$). The crude protein and energy contents of treatment diets were comparable; thus, no nutritionally related embryonic mortality was expected. Similarly, Hocking et al. (2002) observed that hens fed a high-protein diet had a decreased embryonic mortality rate than hens fed a low-protein diet.

**Carcass characteristics**

The two groups SMSK 10% and SMSK 15% had the highest carcass weight, dressing percentage, and relative weight of intestine, proventriculus, ovary, Oviduct, and the number of yellow follicles, as well as had the longest length of intestine, caecum, and oviduct, while the SMSK20% group had the lowest values compared with the control group (Table 6). The relative weight of the heart, pancreas, and spleen did not differ between SMSK and control groups. Hens in the SMSK 20% group had the lowest relative weight of caecum and gizzard and abdominal fat but had the highest relative weight of liver compared with the other SMSK and control groups. The present findings are consistent with those of Odunsi (2005) who observed increased liver weight in broilers fed raw MSK at 20% as a maize substitute compared with the control diet, whereas heart and spleen weights were not affected by the substitution. Diarra (2015) reported that replacing maize with cooked MSK up to 25% had no adverse effect on liver and heart weights. The increased liver weight on the raw MSK diet could be a response to toxic substances that were overcome through processing, as the liver is primarily concerned with detoxification by converting toxic substances into easily excreted forms (Diarra, 2015).

**Table 5.** Effect of replacing corn with soaked mango seed kernel on hatchability traits, embryonic mortality, and chick weight of Gimmizah laying hens

| Parameters | Treatments | | | | p value |
|---|---|---|---|---|---|
| | SMSK 0% | SMSK 10% | SMSK 15% | SMSK 20% | |
| Fertility (%) | 95.98 ± 0.84 $^{b}$ | 97.91 ± 0.78$^{a}$ | 96.80 ± 0.71$^{ab}$ | 97.50 ± 0.79$^{a}$ | 0.034 |
| Hatchability (%) | 90.74 ± 0.24$^{c}$ | 94.61 ± 0.43$^{a}$ | 94.60 ± 0.44$^{a}$ | 91.64 ± 0.37$^{b}$ | 0.001 |
| **Embryonic mortality phases (%)** | | | | | |
| Early | 2.00 ± 0.27$^{a}$ | 1.33 ± 0.19$^{b}$ | 1.11 ± 0.20$^{b}$ | 1.11 ± 0.18$^{b}$ | 0.026 |
| Middle | 1.00 ± 0.26$^{a}$ | 0.89 ± 0.25$^{ab}$ | 0.67 ± 0.24$^{b}$ | 0.44 ± 0.17$^{b}$ | 0.033 |
| Late | 3.33 ± 0.49$^{a}$ | 1.67 ± 0.36$^{b}$ | 2.11 ± 0.48$^{b}$ | 1.56 ± 0.35$^{b}$ | 0.016 |
| Pip | 0.78 ± 0.22 | 0.56 ± 0.18 | 0.68 ± 0.20 | 0.78 ± 0.24 | 0.828 |
| **Post-hatch chick quality** | | | | | |
| Hatched chicks (Number) | 69.67 ± 1.02$^{c}$ | 74.11 ± 0.91$^{a}$ | 73.26 ± 0.88$^{a}$ | 71.48 ± 0.99$^{b}$ | 0.001 |
| Hatched chicks weight (g) | 33.06 ± 0.57$^{c}$ | 36.96 ± 0.83$^{a}$ | 36.90 ± 0.69$^{a}$ | 34.01 ± 0.47$^{b}$ | 0.012 |

[a-c] different superscripts in the same row differed significantly at $p < 0.05$. SMSK: Soaked mango seed kernel.

In this study, the highest value of the liver weight of the SMSK 20% group was within the normal range for layer hens, therefore hepatotoxicity related to SMSK feeding of 20% was not expected. Abdullahi (2012) found no negative effects of substituting 100% of dietary maize with SMSK on liver and spleen weights of broilers, but heart weight increased with increasing SMSK levels in the diet. However, Amao and Siyanbola (2013) observed lower liver, heart, and pancreas weights when fed broilers 30% dry heat-treated MSK substitute for maize and compared with the control. Diarra et al. (2010) found that MSK treatment had no significant influence on any of the carcass yields or abdominal fat. They also reported that a boiled MSK diet may substitute up to 60% of maize in broiler diets with no deleterious impacts on growth, carcass parameters, or health.

**Table 6.** Effect of replacing corn with soaked mango seed kernel on carcass traits of Gimmizah laying hens at 44 weeks of age

| Parameters | Treatments | | | | p value |
|---|---|---|---|---|---|
| | SMSK 0% | SMSK 10 % | SMSK 15% | SMSK 20% | |
| Live body weight (g) | 1728.33 ± 110.53 | 1831.67 ± 109.72 | 1806.67 ± 106.89 | 1738.33 ± 103.58 | 0.647 |
| Carcass (g) | 1076.67 ± 0.18[b] | 1179.00 ± 0.31[a] | 1166.67 ± 0.25[a] | 1036.33 ± 0.10[c] | 0.006 |
| Dressing (%) | 62.47 ± 0.23[b] | 64.49 ± 0.28[a] | 64.76 ± 0.30[a] | 59.59 ± 0.27[c] | 0.001 |
| Intestine weight (%) | 96.67 ± 0.94[b] | 103.07 ± 1.84[a] | 102.33 ± 1.93[a] | 85.67 ± 1.85[c] | 0.001 |
| Intestine length, (cm) | 174.16 ± 0.99[b] | 181.67 ± 1.16[a] | 181.33 ± 1.13[a] | 167.00 ± 0.96[c] | 0.001 |
| Caecum weight (%) | 22.69 ± 0.42[a] | 22.33 ± 0.37[a] | 22.67 ± 0.35[a] | 20.15 ± 0.30[b] | 0.018 |
| Caecum length, (cm) | 24.05 ± 1.03[b] | 26.33 ± 1.36[a] | 27.33 ± 1.41[a] | 21.33 ± 0.80[c] | 0.012 |
| Gizzard (%) | 27.66 ± 2.71[ab] | 32.33 ± 2.41[a] | 30.07 ± 2.29[a] | 25.67 ± 2.71[b] | 0.025 |
| Proventriculus (%) | 9.68 ± 0.22[b] | 10.83 ± 0.29[a] | 11.07 ± 0.24[a] | 8.83 ± 0.25[c] | 0.001 |
| Liver (%) | 45.83 ± 0.31[b] | 45.90 ± 0.37[b] | 45.93 ± 0.26[b] | 47.25 ± 0.46[a] | 0.015 |
| Heart (%) | 8.37 ± 0.84 | 9.03 ± 0.69 | 8.93 ± 0.77 | 8.83 ± 0.70 | 0.744 |
| Pancreas (%) | 5.28 ± 0.66 | 4.74 ± 0.59 | 5.33 ± 0.45 | 4.84 ± 0.54 | 0.683 |
| Spleen (%) | 3.33 ± 0.31 | 3.27 ± 0.24 | 3.08 ± 0.20 | 3.33 ± 0.28 | 0.867 |
| Abdominal fat (%) | 80.68 ± 2.22[a] | 74.61 ± 1.89[b] | 72.93 ± 2.71[b] | 56.33 ± 1.02[c] | 0.011 |
| Ovary (%) | 7.54 ± 0.23[b] | 9.03 ± 0.31[a] | 8.80 ± 0.27[a] | 6.37 ± 0.19[c] | 0.007 |
| Yellow follicles (%) | 58.00 ± 2.97[a] | 60.67 ± 3.02[a] | 57.67 ± 2.91[a] | 45.33 ± 2.62[b] | 0.028 |
| Yellow follicles number | 6.33 ± 0.39[b] | 7.00 ± 0.48[a] | 7.00 ± 0.48[a] | 5.00 ± 0.41[c] | 0.016 |
| Oviduct (%) | 55.33 ± 3.15[b] | 65.33 ± 3.26[a] | 62.33 ± 2.98[a] | 51.00 ± 2.37[c] | 0.031 |
| Oviduct length (cm) | 61.73 ± 1.33[b] | 67.69 ± 1.12[a] | 66.67 ± 1.26[a] | 52.44 ± 0.73[c] | 0.001 |

[a-c] different superscripts in the same row differed significantly at $p < 0.05$. SMSK: soaked mango seed kernel.

**Blood hematological, biochemical, and immunological parameters**

The results in Table 7 indicate the influence of SMSK on blood hematological, biochemical and immunological parameters for layer hens. There were no significant differences in the values of WBCs, RBCs, lymphocytes, neutrophils, monocyte, eosinophil, hemoglobin, MCH, RDW-CV, and RDW-SD between treatment groups. The SMSK 10% group had significantly lower PCV and MCV values, however, the SMSK 0% and 20% groups had greater platelets than the other treatment groups, with no significant differences between the SMSK 0% and SMSK 20% groups or between the SMSK 10% and SMSK 15% groups ($p < 0.05$). A significant increase in MCHC value was observed in the SMSK 10% group compared to the other groups ($p < 0.05$). The addition of SMSK at different levels in *Gimmizah* hens' diet did not affect the blood-related biochemical traits such as total protein, AST, ALT, and ALP (Table 7).

The results revealed a significant ($p < 0.05$) decrease in albumin, and albumin/ globulin ratio in SMSK 15% and SMSK 20% groups, with no significant differences between SMSK10% and SMSK 0% groups or between SMSK 15% and SMSK 20% groups. Hens fed with different levels of SMSK had the lowest ($p < 0.05$) values of total cholesterol and triglycerides, with no significant differences between the SMSK groups. The results of serum immunoglobulin, IgG, and IgM for *Gimmizah* hens are shown in Table 7. The IgG concentration was significantly increased with increasing SMSK in the hen diet, whereas the addition of SMSK in the hen diet had no effect on the concentration of IgM ($p < 0.05$). Although the SMSK groups had significantly higher serum catalase concentration than the control group, however, the SMSK 0% group had significantly greater MDA concentration than the SMSK groups ($p < 0.05$).

**Table 7.** Effect of replacing corn with soaked mango seed kernel on hematological, biochemical, and immunological parameters of Gimmizah laying hens

| Parameters | Treatments | | | | p value |
|---|---|---|---|---|---|
| | SMSK 0% | SMSK 10 % | SMSK 15% | SMSK 20% | |
| **Blood hematology** | | | | | |
| White blood cell $\times 10^3/\mu L$ | 12.34 ± 1.65 | 12.89 ± 1.41 | 12.12 ± 1.49 | 12.43 ± 1.33 | 0.927 |
| Lymphocyte (%) | 67.67 ± 6.75 | 69.33 ± 6.93 | 65.08 ± 6.08 | 71.67 ± 7.12 | 0.682 |
| Neutrophils (%) | 23.67 ± 6.73 | 23.33 ± 4.42 | 26.67 ± 7.33 | 23.67 ± 6.84 | 0.904 |
| Monocyte (%) | 5.33 ± 0.62 | 5.66 ± 0.66 | 5.00 ± 0.55 | 5.03 ± 0.53 | 0.467 |
| Eosinophil (%) | 3.42 ± 0.35 | 3.07 ± 0.21 | 3.37 ± 0.29 | 3.67 ± 0.39 | 0.624 |
| Red blood cell $\times 10^6/\mu L$ | 3.29 ± 0.43 | 3.41 ± 0.37 | 3.52 ± 0.51 | 3.49 ± 0.49 | 0.672 |
| Platelets | 11.00 ± 1.24[a] | 7.00 ± 1.21[b] | 7.67 ± 0.96[b] | 10.00 ± 1.19[a] | 0.032 |
| Haemoglobin (g/dl) | 10.54 ± 0.30 | 10.61 ± 0.45 | 10.69 ± 0.47 | 11.03 ± 0.42 | 0.441 |
| PCV (%) | 38.9 ± 2.16 [a] | 34.4 ± 1.88[b] | 39.3 ± 2.21[a] | 40.3 ± 2.27[a] | 0.036 |
| MCV (fL/cell) | 11.82 ± 0.2[a] | 10.09 ± 0.18[c] | 11.16 ± 0.26[b] | 11.26 ± 0.21[b] | 0.002 |
| MCH (pg) | 3.20 ± 0.19 | 3.11 ± 0.14 | 3.04 ± 0.11 | 3.16 ± 0.16 | 0.814 |
| MCHC (g/dl) | 27.09 ± 1.11[b] | 30.84 ± 1.12[a] | 27.20 ± 0.98[b] | 27.37 ± 1.03[b] | 0.016 |
| RDW-CV | 11.57 ± 1.47 | 11.77 ± 1.61 | 10.20 ± 1.88 | 12.00 ± 1.76 | 0.525 |
| RDW-SD | 25.37 ± 2.89 | 25.93 ± 2.54 | 27.53 ± 2.66 | 28.27 ± 2.94 | 0.633 |
| **Blood biochemical parameters** | | | | | |
| Total protein (g/dl) | 3.47 ± 0.28 | 3.36 ± 0.22 | 3.27 ± 0.25 | 3.21 ± 0.29 | 0.774 |
| Albumin (g/dl) | 1.61 ± 0.19[a] | 1.44 ± 0.27[ab] | 1.29 ± 0.22[b] | 1.13 ± 0.31[b] | 0.021 |
| Globulin (g/dl) | 1.86 ± 0.06[b] | 1.92 ± 0.12[ab] | 1.98 ± 0.11[a] | 2.08 ± 0.14[a] | 0.032 |
| Albumin/Globulin ratio | 0.87 ± 0.13[a] | 0.75 ± 0.12[ab] | 0.65 ± 0.11[b] | 0.54 ± 0.14[b] | 0.029 |
| Total cholesterol (mg/dl) | 195.67 ± 5.06[a] | 85.33 ± 8.63[b] | 76.00 ± 14.66[b] | 59.33 ± 26.84[b] | 0.007 |
| Triglyceride (mg/dl) | 251.67 ± 31.65[a] | 112.60 ± 11.64[b] | 99.46 ± 9.46[b] | 94.67 ± 22.53[b] | 0.002 |
| AST (U/L) | 24.06 ± 3.07 | 25.33 ± 2.66 | 27.27 ± 3.16 | 25.62 ± 2.37 | 0.698 |
| ALT (U/L) | 11.67 ± 2.15 | 13.07 ± 2.22 | 12.43 ± 1.85 | 13.37 ± 2.16 | 0.837 |
| ALP (U/L) | 851.33 ± 137.62 | 751.67 ± 116.94 | 735.33 ± 125.75 | 719.67 ± 135.71 | 0.547 |
| **Immunological parameters** | | | | | |
| IgG (mg/dl) | 39.47 ± 1.13[c] | 42.80 ± 1.28[b] | 43.63 ± 1.31[ab] | 44.97 ± 1.41[a] | 0.016 |
| IgM (mg/dl) | 11.67 ± 1.52 | 10.49 ± 1.37 | 11.13 ± 1.33 | 10.32 ± 1.47 | 0.673 |
| **Antioxidant status** | | | | | |
| Catalase (U/L) | 25.94 ± 4.65[b] | 35.86 ± 4.11[a] | 36.22 ± 3.74 [a] | 39.97 ± 5.05[a] | 0.009 |
| MDA (mmol/l) | 2.69 ± 0.13[a] | 2.01 ± 0.19[b] | 1.94 ± 0.21[b] | 1.76 ± 0.27[b] | 0.008 |

[a-c] different superscripts in the same row differed significantly at $p < 0.05$. SMSK: Soaked mango seed kernel, PCV: Packed cell volume, MCH: Mean corpuscular hemoglobin, MCHC: Mean corpuscular hemoglobin concentration, MCV: Mean corpuscular volume, RDW-SD: Standard deviation in red cell distribution width, RDW-CV: Coefficient variation of red cell distribution width, AST: Aspartate aminotransferase, ALT: Alanine transferase, ALP: Alkaline phosphatase, MDA: Malondialdehyde.

The impact of dietary treatments on the host was evident in hematological indices. The results of the present study agree with Soomro et al. (2013) who found that utilizing mangchico pulp as a supplement at rates of 2, 3, and 4% /kg had no effect on hemoglobin, RBCs, and WBCs counts. Similarly, Odunsi (2005) reported that replacing MSK with maize at 0, 5, 10, 15, 20, and 25% in broiler feed had no effect on lymphocyte count. However, Moustafa et al. (2019) stated that replacing 10, 15, and 20% of corn with MSK in the cockerels' diets had a significant impact on hemoglobin, PCV%, $RBC_S$, $WBC_S$, lymphocytes, and neutrophils counts. Odunsi (2005) found that replacing maize with 10% MSK significantly increased the hemoglobin content of broilers. Amao and Siyanbola (2013) reported that substituting maize with dry heat-treated MSK up to 20% in broiler feed increased hemoglobin concentration. The present findings on most blood hematological parameters were comparable indicating that the immune status of hens fed SMSK substitute YC in the diet can be attributed to the presence of various phenolic compounds in MSK treatment diets, which have an antioxidant effect (Ahmed, 2014) and cause the health-promoting properties of MSK, including analgesic, antioxidant, anti-microbial, and anti-inflammatory activities, which were confirmed by previous results obtained by other researchers (Cojocaru et al., 1986; Anila and Vijayalakshmi, 2003; Garrido et al., 2004).

The findings of this study agree in part with those of Moustafa et al. (2019) who reported that cockerels fed 10% MSK had the highest total protein and globulin levels, but that there were no significant differences between the MSK 20% and control groups. Odunsi (2005) found that replacing MSK with maize by 10% in the diet of broilers increased total protein and globulin levels. However, Amao and Siyanbola (2013) found that the total protein level was significantly high in broilers fed 10% heat-treated MSK. In terms of total cholesterol and triglycerides, our findings are consistent with those of Moustafa et al. (2019) who observed that increasing MSK levels as a substitute for corn in a significant reduction in plasma cholesterol when compared with the control group. Zhang et al. (2017) reported that dietary 0.28% mango saponin supplementation reduced plasma total cholesterol levels in cockerels. This could be explained by the presence of mangiferin in mango saponin. The hypocholesterolemia effect of MSK may be related to containing components of flavonoids that may inhibit lipid peroxidation that regulates cholesterol synthesis. More so, the determinants of proper liver function; ALT, AST, and ALP demonstrated that the liver is normal and healthy among the treatments since ALT, AST, and ALP liver function test values do not differ significantly among treatments ($p > 0.05$). This is also an indicator of the nutritional adequacy of all diets because of the blood response to feeding. Abang et al. (2018) showed that serum ALT of quails given sun-dried MSK diet treatments was within the normal range but Serum AST of quails fed 25% sun-dried mango kernel meal was below the lower limit among the treatments.

In the current study, the improvement in immune response and antioxidant status may be attributed to the fact that MSK contains various phenolic compounds that are considered antioxidant agents (Cojocaru et al., 1986). Moustafa et al. (2019) reported that the use of MSK at 10% and 15% replacement of corn caused a significant increase in IgG and IgM values compared with the control group, whereas, no significant differences were observed between 20% SMSK and control groups. All examined blood parameters were equivalent to those reported as normal for poultry in the literature (Faniyi, 2002). The fact that blood parameters between the treatments are similar to their normal values implies that all diets are nutritionally adequate. Since the blood profile provides a helpful investigation and demonstrative tool in nutritional assessment and health implications, there is evidence to further suggest that dietary tannin levels were below the thresholds as described by Smith (2001). Hematology and biochemistry in the broilers were not affected when dietary maize was replaced with 100% soaked MSK (Abdullahi, 2012), 60% boiled MSK (Diarra et al., 2010), and 30% dry heat-treated MSK (Amao and Siyanbola, 2013). These findings suggested that when considering MSK as an ingredient of poultry feed, a variety of criteria such as species, age, processing method, and environmental conditions need to be considered.

### Economic efficiency

The economic efficiency of using SMSK as a partial substitute for yellow corn for laying hens was shown in Table 8. The SMSK utilized as a corn substitute demonstrated higher economic efficiency than the control group. The relative economic efficiency of corn substituted with 20% SMSK rose by about 28% compared with the control group. Similarly, Moustafa et al. (2019) reported that the feed cost/kg weight gain of cockerels was lower in the group fed 10% MSK as a yellow corn substitute.

**Table 8.** Economic efficiency of Gimmizah laying hens fed yellow corn and soaked mango seed kernel diets

| Parameters | Treatments | | | |
|---|---|---|---|---|
| | **SMSK 0%** | **SMSK 10%** | **SMSK 15%** | **SMSK 20%** |
| EEF | 228.78 | 266.97 | 255.15 | 233.28 |
| Egg number/hen | 178.56 | 201.44 | 192.44 | 194.27 |
| Price/ egg (L.E) | 1.50 | 1.50 | 1.50 | 1.50 |
| Total price of eggs /hen (L.E) | 267.84 | 302.16 | 288.66 | 291.41 |
| Feed intake (g/h/d) | 130.33 | 128.17 | 131.34 | 129.56 |
| Total feed intake/hen (kg) | 11.73 | 11.54 | 11.82 | 11.66 |
| Price/ ton feed (L.E) | 6085.485 | 5801.178 | 5680.397 | 5526.141 |
| Total feed cost/hen (L.E) | 71.38 | 66.94 | 67.14 | 64.43 |
| Net revenue/hen (L.E) | 196.46 | 235.22 | 221.52 | 226.98 |
| Economic efficiency | 2.75 | 3.51 | 3.30 | 3.52 |
| Relative economic efficiency (%) | 100 | 127.64 | 120.00 | 128.00 |

SMSK: Soaked mango seed kernel. EEF: European Efficiency Factor. Price/ egg (L.E.), according to the local market price at the experimental time. Total price of eggs /hen (L.E.) = egg number/ hen × Price/ egg (L.E.). Daily feed intake (g). Total feed intake/hen, kg = (FI (g/hen/day) /1000) X 30 days (Experiment period, days). Price/ Kg feed (L.E.), based on the average price of diets during the experimental time. Total feed cost/hen (L.E.) = total feed intake/hen, kg × price/ Kg feed (L.E.). Net revenue/hen (L.E.) = total price of eggs /hen (L.E.) - total feed cost/hen (L.E.). Economic efficiency = net revenue / hen (L.E.)/ total feed cost/ hen (L.E.). L.E: Egyptian pound

## CONCLUSION

Based on this study, soaked mango seed kernel (SMSK) up to 15% can be considered a successful nutritional and health approach and can be replaced partially by yellow corn in the laying hen diet without any deleterious impact on productivity, fertility, hatchability, quality of hatched chicks, or physiological performance. In terms of economic efficiency, SMSK at different levels outperformed the control group. These findings encourage further research on the application of SMSK as a substitute for yellow corn in poultry feed.

## DECLARATIONS

### Authors' contribution

Farag, Moustafa, El-Saadany, and Abu Hafsa created the idea and designed the study. Farag and Abu Hafsa collected data. Abu Hafsa wrote the paper and performed the statistical analysis. Abu Hafsa drafted the manuscript and approved the final manuscript. All authors checked and confirmed the final analysis data and the last revised manuscript before publication in the journal.

### Competing interests

The authors declared that they have no competing interests.

### Data availability statement

The data presented in this study are available on request from the corresponding author.

### Consent to publish

All authors informed their consent prior to inclusion in the study.

### Ethical consideration

Ethical issues (including plagiarism, consent to publish, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy) have been checked by the authors before the submission. The final results of the statistical analysis have been also checked and confirmed by all authors.

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