Technical and economic potentials of the unconventional extruded dried Arabian bread wastes in broilers diets

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A B S T R A C T

Food waste is one of the major global challenges that have adverse socioeconomic and environmental impacts. Therefore, studying food waste utilization potentials and minimizing its negative consequences becomes imperative. This study aims to assess the technical and economic potentials of substituting corn with unconventional extruded dried Arabian Bread waste (EDABW) in broilers’ diets, in terms of broilers’ performance, carcass characteristic, economic net returns, and income over feed cost (IOFC). One hundred eighty unsexed one-day-old broiler birds of Ross breed were distributed randomly in six treatments (0, 20, 40, 60, 80, and 100% EDABW group) of isocaloric and isonitrogenous diets in a completely randomized design with six replicated (5 chicks/replicate). The investigated traits were broilers’ performance (live body weight, total feed intake, total feed conversion ratio, and total weight gain). Other traits such as carcass weight, abdominal fat, edible offal (liver, heart, and gizzard), eviscerated (breast muscles, drum and thigh muscles, and wings) were weighed and expressed based on a live body weight. Results showed that the 20% replacement level of corn with EDABW generated the highest increase in the live body weight and the eviscerated carcass at about 4.24% g and 4.90%, respectively. On the other hand, the economic analysis showed potential reductions in the broilers’ diet cost and the total broilers’ production cost as the levels of corn substitution with unconventional EDABW increased. The reductions were estimated at 5.1%, 6.3%, 8.4%, 9.3%, and 9.9% at substitution levels of 20%, 40%, 60%, 80%, and 100%, respectively as compared to the control diet. The results also showed a potential increase in the net economic returns of broiler meat as the increase in substitution levels ranged between 3.5–06.8% and 4.3–8.3% as compared to the control diets using the average retail and wholesale prices of broiler meats, respectively. In addition, the maximum IOFC was estimated potentially at a 20% substitution level of corn with EDABW. Conclusively, the study results show promising technical and economic potentials for unconventional EDABW in broilers’ diets that could lead to a thriving industry of unconventional broilers’ diets with high net economic returns and maximum IOFC.

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1. Introduction

OCECD/FAO (2016) estimated that poultry meat would reach the highest production and consumption levels by 2025, surpassing beef, lamb, and pork meat. Such estimation was based, mainly, on the affordability and accessible source of protein with a low-fat content of chicken meat (King et al., 2017a). However, the expansion of broiler production worldwide and in Saudi Arabia is susceptible to the high production cost associated with the ever-increasing cost of conventional poultry feedstuff (Adegbenro et al., 2020) and to the import restrictions caused by the Covid-19 pandemic outbreak (Hafez and Attia, 2020). Accordingly, the use of affordable unconventional locally produced raw materials, alternative energy sources, as well as new technologies in the processing are required for higher diet compositions flexibility (Epao, 2015), for the reduction of poultry diets production cost (Onifade, 1993), and the feasibility enhancement of poultry production (Adegbenro et al., 2020; Truong et al., 2019; Al-Harthi et al.,...
Substantial efforts were made to improve the use of these unconventional feeding resources in monogastric diets (Epao et al., 2017).

FAO (2009) reported that the increasing demand for corn would lead to an increase in its future price. Therefore, the poultry industry must look for corn alternatives, such as the use of bakery waste to reduce production costs. Bakery waste has the potential unconventional energy source that could be used in poultry production across the world, and the highest nutritional percentage of treated bakery waste in broiler feeds was estimated at the range of 10–100% (Al-Tulaihan et al., 2004; Al-Ruqaie et al., 2011). The dried bakery products were found sufficiently accessible and cheaper poultry diets compared to maize (Truong et al., 2019; Yadav et al., 2014). The inclusion of 30% bread waste in broilers diets significantly reduced the feed costs, production, feed/kg weight gain, and raised the profit margin (Oke, 2013).

During the last decade, the growth rate of the population in Saudi Arabia (SA) was estimated at 28.5%, from about 26 million in 2008 to about 33.4 million in 2018 (General Authority for Statistics, 2018). Such population increase has been linked with the increase in food demands. Thus, SA has imported large amounts of food products to satisfy its population’s needs. However, a high proportion of imported food products is wasted, causing significant negative consequences in the environment and economy. Baig et al. (2018) estimated the total annual food waste in SA at about 427 kg per capita, 35% of which were baked products. SA is ranked the 26th largest worldwide in the bakery product’s trade, importing about 3 million tons at the cost of about $ 692,61 million (FAO, 2018a, 2018b). Substantial efforts were made to improve the use of these unconventional feeding resources in monogastric diets (Epao et al., 2017).

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One of the most important anti-nutritional factors that may develop during the heat process of baking is a Maillard reaction. Maillard reaction will happen between lysine and the reducing sugars, resulting in lowering reactive lysine (Gilani et al., 2012). Reactive lysine, therefore, is the amount of available lysine that will be used for protein synthesis. Moreover, according to AMINO-Dat 5.0®, the SID coefficient (standard ileal digestibility) of corn is 91%. Meanwhile, the bakery residue SID coefficient was 85% (Rostagno et al., 2017).

Additionally, Blok and Dekker (2017) revealed that the maize SID coefficient was 90%, and the bread meal was 70%. The latter statement implies that bakery meal residues may deliver lower available lysine compared to corn. Lysine significantly enhances lean meat production, and the reduction of carcass fatness can be achieved by adding lysine (Fouda and El-Senousey, 2014). This study is targeted to assess the technical and economic potentials of using unconventional EDABW in broilers' diets, with more emphasis on broilers' performance, carcass characteristics, economic net returns, and income over diet costs of broilers' diets in the whole carcass and eviscerated carcass (breast, drums, thigh, and wings).

The novelty of this study lies in its originality not only in tackling one of the major challenging environmental issues that relate to the utilization of food wastes as an unconventional broilers' diet but also, in assessing its technical and economic potentials. Thus, this study will contribute significantly to the future development of the broilers industry in Saudi Arabia and the globe, and it aligns with the international patterns towards the circular economy.

2. Material and methods

The EDABW was collected from local commercial bakeries in the Riyadh region (SA). It was cleaned to eliminate any mold con-
tamination as well as foreign materials, dried in a forced convection oven (Advantech, FG-220, Japan) at 65 °C for 24 h, then crushed into small pieces, and ground to powder using an electric grinder (Moline M-06, Italy) with a 1.4 mm steel screen. A twin-screw extruder (Model MPF19:25, APV-Baker, UK) was used to pellet powdered (EDABW) by the manufacturing setting. The extruded pelleting process was performed at 70 °C and pellets were 4 mm in diameter. The extruded pellets were crushed using a roller mill before being incorporated with feed ingredients. Samples of the EDABW were then analyzed in triplicate for protein, moisture, crude fiber, ash, and ether extract in accordance with AACC (1994). Minerals content were determined by wet ashing of bread waste samples (Osborne and Voogt, 1978). Na and K concentrations were determined using an atomic absorption spectrophotometer. IL, model 251. Total Phosphorus (P) was determined using the Vanado-molybdate calorimetric procedure. Amino acids were determined using High-Performance Liquid Chromatography (HPLC, model 1993, Shimadzu, Japan) method as described in AOAC (1990) (Table 1).

2.1. Experimental set up

One hundred eighty one day old Ross broilers males were weighted individually and randomly assigned to the treatments. Six replicates were applied in this experiment. Electrically heated battery cages were used to house 5 birds each. Continuous incandescent lighting was present throughout the experimental duration. The chickens were given starter feeds up to d 21, then by finisher diets up to d 35. The starter and finisher dietary treatments had as a control corn-based diet with 0% EDABW and five different diets using 20, 40, 60, 80, and 100% EDABW inclusion percentage to substitute corn in the basal diet. The corn in the 0% EDABW treatments of starter and finisher diets were respectively 53.7% and 62.78%. Acid washed sand (10 g kg⁻¹) was incorporated with the diet. Sand with a particle size of 40 mesh (~595 μm) was soaked in 4 NHCL for a day and washed thoroughly to remove the acid. The sand was then oven-dried at 100 °C, cooled, and stored to be included in the feed. The tested feeds' formulations were isocaloric and isonitrogenous (Table 2). Water and feed were ad libitum. At the end of the experimental period, six chickens per dietary treatment were randomly selected after being fasted overnight and slaughtered according to the Islamic method (Attia et al., 2016).

![Fig. 1. Impact of corn substitution levels with bakery meal on electrolytes balance.](image-url)

Table 1  Comparison of approximate analysis acids and minerals profile of EDABW and Corn.

| Approximate analysis        | EDABW | Corn* |
|----------------------------|-------|-------|
| True Metabolizable Energy (TME) | 3.854 | 3.470 |
| Approximate analysis (g kg⁻¹) |       |       |
| Moisture                   | 63.600 | 110.000 |
| Crude fiber                | 15.900 | 38.000 |
| Ash                        | 15.300 | 22.000 |
| Amino acids profile (%) essential amino acids |       |       |
| Lysine                     | 0.310  | 0.260 |
| Methionine                 | 0.260  | 0.130 |
| Phenyl alanine             | 0.750  | 0.380 |
| Tyrosine                   | 0.340  | 0.300 |
| Leucine                    | 0.570  | 1.000 |
| Isoleucine                 | 0.490  | 0.290 |
| Valine                     | 0.340  | 0.400 |
| Threonine                  | 0.510  | 0.290 |
| Arginine                   | 0.460  | 0.380 |
| Histidine                  | 0.280  | 0.230 |
| Non-essential amino acids  |       |       |
| Aspartic acid              | 0.740  | –     |
| Alanine                    | 0.280  | –     |
| Serine                     | 0.700  | 0.370 |
| Glutamic acid              | 4.720  | –     |
| Glycine                    | 0.510  | 0.330 |
| Minerals profile (mg/100 g) |       |       |
| Calcium                    | 178.000 | 20.000 |
| Phosphorus                 | 198.000 | 280.000 |
| Sodium                     | 440.000 | 20.000 |
| Potassium                  | 160.000 | 300.000 |
| Magnesium                  | 60.000  | 120.000 |
| Zinc                       | 97.000  | 1.800 |
| Iron                       | 52.000  | 4.500 |

NRC, 1994.
Ingredients composition of broilers starter and finisher feeds (g kg⁻¹) with different levels of EDABW.

| Ingredients                                | Replacement level of bakery waste products (%) |
|--------------------------------------------|-----------------------------------------------|
|                                            | Starter Phase (1–21 days of age)              |
|                                            | 0      | 20     | 40     | 60     | 80     | 100    |
| Corn                                       | 537.000| 428.600| 322.000| 214.300| 107.200| 0.000  |
| Bakery waste product                      | 0.000  | 107.200| 214.300| 322.000| 428.600| 537.000|
| Soybean meal                               | 364.900| 364.000| 349.300| 334.200| 319.100| 321.000|
| Bran                                       | 0.000  | 3.800  | 21.500  | 40.200  | 58.200  | 88.500  |
| Corm oil                                   | 19.700 | 48.300  | 45.500  | 43.000  | 40.400  | 40.400  |
| Sand                                       | 10.000 | 10.000  | 10.000  | 10.000  | 10.000  | 10.000  |
| Limestone                                  | 13.700 | 13.300  | 12.900  | 12.600  | 12.200  | 11.500  |
| Di Calcium phosphate                       | 17.100 | 17.300  | 17.200  | 17.100  | 17.100  | 17.100  |
| Salt                                       | 3.400  | 2.800   | 2.200   | 1.600   | 1.000   | 0.500   |
| Premix                                     | 2.000  | 2.000   | 2.000   | 2.000   | 2.000   | 2.000   |
| DL-Methionine                              | 2.000  | 2.200   | 2.300   | 2.500   | 2.600   | 2.800   |
| L-Lysine                                   | 0.200  | 0.500   | 0.800   | 1.200   | 1.600   | 2.000   |
| Met + Cys (g kg⁻¹)                         | 9.300  | 9.300   | 9.300   | 9.300   | 9.300   | 9.300   |

Note: premix: (per ton diet: Vit A 60000.000 IU, Vit D 15000.000; Vit E 20000.000 IU, Vit K 1.000 mg, Vit B1 1.000 mg, Vit B2 3000 mg, Vit B6 2000 mg, Vit B12 10 g, niacin 2000 mg, folic acid 500 mg, pantothenic acid 5.000 g, biotin 50 mg, antioxidant 60.000 mg, Co 100 ppm, Cu 5,000 ppm, Fe 20000 ppm, Mn 40.000 ppm, Se 100 ppm, Zn 30.000. CP = crude protein, ME = metabolizable energy, AP = available phosphorus was calculated on the basis of 30% available of phosphorus in plant product’s Met-Cys = methionine cysteine. (Al-Ruqaie et al., 2011)

Chickens were processed to determine the carcass yield, abdominal fat, breast muscle, and drum and thigh weights as expressed on a live body weight basis. Measurements were also conducted for body weight gain, feed intake, and feed conversion ratio.

2.2. Economic analysis

Studying the economic potentials of the unconventional EDABW in broilers’ diets relied on primary and secondary data. The field survey method was used to calculate and to estimate the main feed industry economic indicators for several poultry feed factories in the considered study areas (Riyadh, Western region, Eastern region, and Hail) using a questionnaire form especially prepared for this purpose. The survey questionnaire aimed to identify the general status of the poultry feed industry in SA and to estimate the operational costs of the poultry feed industry (Table 3).

Average retail and wholesale market prices of poultry meat at local markets and the imported poultry meat were obtained from officially published data of a number of government agencies such as the Department of General Statistics and Information, Ministry of Environment, Water, and Agriculture for the 1999–2015 period, and FAO. A simple linear regression equation was determined to predict the missing annual values of retail, wholesale prices, and marketing margin of broilers in SA, as shown in Table 4.

The economic potentials analysis of the unconventional EDABW in broilers’ diets focused mainly on estimating economic returns, net economic returns, IOFC, some extra value calculation for the whole and eviscerated carcass such as the infeasibility point of EDABW inclusion to broilers diets, and maximum profitability level of substitution at retail and wholesale prices.

### Table 3
Feed cost structure of broilers production in Saudi Arabia (SR ton⁻¹).

| Ingredients                | Average cost |
|----------------------------|--------------|
| Corn                       | 600          |
| Bakery waste product*Leaves| 500          |
| Soybean                    | 1290         |
| Bran                       | 520          |
| Corn oil                   | 3500         |
| Sand                       | 40           |
| Limestone                  | 110          |
| Di-calcium phosphate       | 230          |
| Salt                       | 270          |
| Premix                     | 9000         |
| DL-methionine              | 13,000       |
| L-Lysine                   | 5,000        |

**Sources:** ARASCO, Saudi Arabia. 2018.

* Predicted values using simple linear regression SPSS.

** Table 4 **

| Year  | Wholesale price | Retail price | Marketing margin |
|-------|-----------------|--------------|------------------|
| 1999  | 7.59            | 8.5          | 0.91             |
| 2000  | 7.44            | 8.4          | 0.96             |
| 2001  | 7.07            | 8.1          | 1.03             |
| 2002  | 7.03            | 8.1          | 1.07             |
| 2003  | 7.10            | 8.2          | 1.10             |
| 2004  | 7.06            | 8.2          | 1.14             |
| 2005  | 7.13            | 8.3          | 1.17             |
| 2006  | 7.42            | 8.6          | 1.18             |
| 2007  | 8.91            | 10           | 1.09             |
| 2008  | 9.52            | 10.6         | 1.08             |
| 2009  | 9.92            | 11.0         | 1.08             |
| 2010  | 9.70            | 10.83        | 1.13             |
| 2011  | 8.88            | 10.12        | 1.24             |
| 2012  | 9.61            | 10.83        | 1.22             |
| 2013  | 12.98           | 13.94        | 0.96             |
| 2014  | 12.79           | 13.81        | 1.01             |
| 2015  | 12.60           | 13.67        | 1.07             |
| 2016  | 12.26           | 13.40        | 1.13             |
| 2017  | 12.63           | 13.77        | 1.14             |
| 2018  | 12.94           | 14.10        | 1.16             |

**Sources:** Ministry of Environment, Water, and Agriculture. Saudi Arabia. Data from 1999 to 2015.
2.3. Statistical analysis

Statistical analysis in broilers’ diets was performed on the collected data of the unconventional EDABW by the GLM procedures (SAS, 2008). The least significant difference (LSD) was used to test the significant differences between means at the 0.05 probability level.

3. Results and discussion

3.1. Chemical analysis of the EDABW

Al-Ruqaie et al., 2011 as well as Al-Tulaihan et al., 2004 indicated that the proximate analysis of EDABW as compared to corn (Table 1) indicated that the former contains more energy than corn. The high energy of the EDABW is mainly as a result of high carbohydrates content. In addition, the protein percentage in EDABW is higher than corn. The amino acid content of EDABW compares positively to that of corn and is complementary to that of soybean, which is the main source of protein in broilers’ feeds. Most of the essential amino acids are higher, while leucine and valine are lower in EDABW than corn (Al-Ruqaie et al., 2011). However, Al-Tulaihan et al. (2004) claim that EDABW is poor in methionine and lysine content, which is not in line with the results of this study. They also recorded that the methionine content was higher in the EDABW (0.281%) as compared to yellow corn; this finding agrees with the results of this study.

3.2. Broilers performance

The effects on performance after replacing dietary corn with EDABW are presented in Table 5. The replacement of dietary corn up to 100% with EDABW did not significantly impact on total BWG, total FI, as well as FCR at d35. However, chickens fed 80% and 100% EDABW diets had higher feed intake and FCR in comparison with chickens in the control treatment. These chickens showed reductions in total BWG in comparison with chickens in the control treatment.

3.3. Carcass characteristics of broilers

3.3.1. Carcass and abdominal fat weights

Table 6 shows that the effects on carcass characteristics after 35 days of the age of feeding different levels of EDABW as a substitution to corn in broilers’ diets. Carcass weight of broilers fed the different diet formulation that included EDABW showed insignificantly (p < 0.05) increases as compared to birds fed the control treatment (Table 6). The numerical increase in carcass weight could be due to the lower crude fiber content of EDABW (5.300 g kg⁻¹) as compared to corn (22.55 g kg⁻¹), as shown in Table 1. This might be because broilers tend to eat more when the diet is low in crude fiber due to its high palatability. Al-Ruqaie et al. (2011) reported that broilers that were fed the control diet had a total feed intake of 3380.6 g, which is lower than broilers which were fed 80% and 100% EDABW as a substitution to corn. In addition, EDABW contains no anti-nutritional factors, which is why its inclusion in broiler diets led to a numerical increase in feed intake. However, these increases did not reach the significance level at (p < 0.05). EDABW contains no anti-nutritional factor and can be a good substitution for corn in broilers’ diet because it is rich in energy as well as vitamins and low in fiber (Stefanello et al., 2016; Al-Tulaihan et al., 2004; Dabron et al., 1999). Increasing EDABW supplementation to 20%, 40%, 60%, 80%, and 100% increased carcass weight by about 3.8%, 3.4%, 4.8%, 2.3%, and 1.5% respectively, as compared to the control diet. However, the highest increase was recorded for chicks fed on diets containing 60% EDABW diet. Meanwhile, broilers fed a 100% EDABW diet recorded the lowest increase in carcass weight (Table 6).

Abdominal fat (Table 6) showed the lowest percentage (7.9%); however, when the broilers were fed diets containing 20% EDABW, the abdominal fat percentages increased for all other EDABW substitutions. There were no significant differences between treatments on abdominal fat content at (p < 0.05), as shown in Table 6. The increase of abdominal fat might be the result of the reduction in dietary protein due to Maillard reactions during the baking process or due to the decrease in the lysine digestibility of the EDABW (Saleh et al., 1996; Anonymous, 1993; Dale, 1992; Parsons, 1991; Harrison et al., 1990). Despite that, Dale (1992) indicated that there was no enough evidence to support the hypothesis since the availability of lysine was not influenced in the diets that contain dry bakery products (6%) as well as synthetic lysine. Also, the numerical increase in abdominal fat could be due to amino acid imbalance. Other amino acids were usually expressed as a percentage of lysine (Emmert and Baker, 1997). Carlos et al. (2014) indicated that the lower the digested lysine, the more the abdominal fat. The latter can be explained by the fact that an increase in the amino acid-lysine ratio will be oxidized and nitrogen will be excreted (Lemme, 2003) or can be used as an expensive source of energy (Storlie, 2012). The latter may be attributed to the increase in abdominal fat in the case of Maillard’s reaction. It is known that in both the remnants of bakeries and maize yellow the energy content is very high. Still, the challenge lies in the balance of protein with energy as any imbalance in this ratio will lead to the deposition of fat (Steiner et al., 2008). The high-fat content of poultry is considered the main challenge that influences poultry meat production (Zhou et al., 2006). Generally, excessive fat accumulation has negative impacts on the producers and the consumers since it is regarded as low valued dietary energy waste. In addition, it causes reductions in carcass yield reductions and adversely influences consumer the acceptability (Emmerson, 1997).

3.3.2. Eviscerated carcass weight

Table 6 indicates insignificant differences between broilers fed control diets and those fed with a substitution level of 20%, 40%, 60%, 80%, and 100% EDABW on breast weight, back, drums and thighs, and wings. The breast weight has an inverse relationship with the substitution levels of corn. The higher was the level of substitution of corn with EDABW, the lower the breast weight. The broilers fed 20% EDABW showed the lowest breast weight reduction (1.24%), followed by the broilers fed 100% EDABW (1.31%). Broilers accumulating high amounts of fat in their carcass usually produced low amounts of breast meat (Bartov and Plavnik, 1998).

No significant differences in drums and thighs were recorded in weight between the broilers fed different diets at (p < 0.05). Moreover, the broilers fed 20% and 40% EDABW had the lowest, 3.27% and 4.32%, in comparison with those of the control diet (Table 6). Further, the broilers fed 60%, 80%, and 100% EDABW showed the highest drums as well as thigh weight increase (2.72%) in comparison with those of the control diet (Table 6).

Table 6 shows that the wings weight was increased in broilers fed different levels of EDABW, although no significant differences (p < 0.05) were recorded between broilers in the control diet. The broilers fed 60%, 80%, and 100% EDABW diets had the highest increase in wings weight (18.18%), followed by broilers fed 40% EDABW (16.14%), and then broilers fed 20% EDABW (12.73%), in c diet.

3.4. Economic analysis

The economic potential of using the EDABW in broilers’ diets at different substitution levels was analyzed in terms of broilers feed.
Carcass characteristics of broilers at 35 days of age fed graded levels of the unconventional EDABW as a replacement for corn in their diets.

| Performance and nutrient utilization | Replacement level of (EDABW) (%) |
|-------------------------------------|----------------------------------|
|                                     |  0  |  20  |  40  |  60  |  80  | 100  |
| Total feed intake (%)               |  100 |  97.3 |  98.2 |  99.8 | 100.7 | 103.2 | 0.84 | 0.29 |
| Total weight gain (%)               |  100 | 103.1 | 100.2 | 101.5 |  99.8 |  97.2 | 0.80 | 0.53 |
| Feed conversion ratio (%)           |  100 |     94  |   98.1 |   98.2 | 100.9 | 100.4 | 1.03 | 0.04 |

Table 6: Carcass characteristics of broilers at 35 days of age fed graded levels of the unconventional EDABW as a replacement for corn in their diet.

| Replacement level of corn with EDABW (%) |
|-----------------------------------------|
|                                        |  0  |  20  |  40  |  60  |  80  | 100  |
| Live body weight (g)                    | 100 | 104.24 | 98.12 | 98.88 | 99.52 | 100.96 | 0.88 | 0.23 |
| Live body weight (g/kg)                | 100 | 103.8  | 103.4 | 104.8 | 102.3 | 101.5  | 0.71 | 0.37 |
| Carcass weight                         | 100 | 90.1   | 90.5  | 81.9  | 83    | 79.5   | 3.1  | 0.52 |
| Edible offal1                          | 100 | 104.9  | 103.9 | 93.8  | 103.4 | 101.8  | 1.66 | 0.30 |
| Carcass weight                         | 100 | 89.80  | 130.70| 110.20| 113.60| 108.86 | 5.6  | 0.32 |
| Abdominal fat                          | 100 | 112.7  | 116.1 | 118.2 | 118.2 | 118.2  | 2.92 | 0.37 |
| Eviscerated carcass                    | 100 | 105.6  | 107.7 | 98.8  | 101.4 | 101.4  | 1.40 | 0.09 |
| Eviscerated carcass (g/kg)             | 100 | 96.7   | 95.7  | 102.7 | 102.7 | 102.7  | 1.31 | 0.47 |
| Wings                                  | 100 | 112.7  | 116.1 | 118.2 | 118.2 | 118.2  | 2.92 | 0.37 |

1 Edible offal = liver + heart + gizzard. All results compared with the control as percentage.

costs, total production costs, economic returns, net economic returns, IOFC for whole carcass and eviscerated carcass, infeasibility point of EDABW inclusion in broilers' diets, and maximum profitability level of substitution at retail and wholesale prices (Table 7).  

3.4.1. Whole carcass economic analysis

Broilers feed and total production costs were found inversely correlated with the substitution levels of EDABW in broilers' diets at the average retail and wholesale prices. The higher the substitution level of EDABW was, the lower the broiler's feed and production costs. The estimated broilers feed cost and total production cost decreased by about 5.1%, 6.3%, 8.4%, 9.3%, and 9.9% at replacement levels of 20%, 40%, 60%, 80%, and 100%, respectively, in comparison with those of the control. Accordingly, the impact of substituting corn with EDABW in broilers' diets at different substitution levels as compared to that of the control was more profitable for the whole carcass compared to the eviscerated carcass.

At an average retail price of the eviscerated carcass, the estimated net economic returns of using the EDABW in broilers' diets increased by about 1.3%, 1.6%, 2.1%, 2.3%, and 2.5% at replacement levels of 20%, 40%, 60%, 80%, and 100%, respectively, in comparison with those of the control diet at a (p < 0.05) significant level. Similarly, the estimated net economic returns of using the EDABW in broilers' diets increased, at an average retail price, by about 1.3%, 1.7%, 2.2%, 2.5%, and 2.6% at replacement levels of 20%, 40%, 60%, 80%, and 100% respectively, as compared to those of the control (p < 0.05) (Table 8).

In terms of eviscerated carcass cuts, the economic analysis showed that substituting corn with EDABW in broilers' diets resulted a steady growth in net economic returns of each eviscerated carcass cuts (breast, wings, and drums and thigh). At an average retail price, the maximum net economic returns were observed for wings at about 3.3%, 3.9%, 5.2%, 5.7%, and 6.0% at replacement levels of 20%, 40%, 60%, 80%, and 100% respectively, as compared to those of the control (p < 0.05). Similarly, the maximum net economic returns were observed for wings at the average wholesale price, by about 3.9%, 4.8%, 6.4%, 7.1%, and 7.5% at replacement levels of 20%, 40%, 60%, 80%, and 100% respectively, as compared to those of the control (p < 0.05). The estimated net economic returns of the other carcass cuts, including breast, drums, and thighs, followed same trends of steady growth at different substitution levels as compared to that of the control. Accordingly, the impact of substituting corn with EDABW in broilers' diets was more profitable for the whole carcass compared to the eviscerated carcass at different substitution levels with a (p < 0.05) significant level, as shown in Table 8.

3.4.2. Eviscerated carcass economic analysis

As the average market prices of the eviscerated carcass were assumed to be constant, the economic returns of the eviscerated carcass were estimated invariant at all substitution levels. However, the estimated net economic returns of the eviscerated carcass, including breast, wings, drums, and thighs, were found positively correlating with the substitution levels of EDABW in broilers' diets. The higher the substitution level of EDABW was, the higher was the net economic returns for carcass cuts. Results showed a steady growth of estimated net economic returns of using the EDABW in broilers' diets at different substitution levels for the eviscerated carcass. 

3.4.3. Parametric analysis of EDABW cost

Parametric analysis was applied to identify the breaking price point at which EDABW cost would become infeasible. Table 9

Table 5: Performance and nutrient utilization of broilers fed graded levels of unconventional extruded EDABW as a replacement for corn in their diets.

| Performance and nutrient utilization | Replacement level of (EDABW) (%) |
|-------------------------------------|----------------------------------|
|                                     |  0  |  20  |  40  |  60  |  80  | 100  |
| Total feed intake (%)               |  100 |  97.3 |  98.2 |  99.8 | 100.7 | 103.2 | 0.84 | 0.29 |
| Total weight gain (%)               |  100 | 103.1 | 100.2 | 101.5 |  99.8 |  97.2 | 0.80 | 0.53 |
| Feed conversion ratio (%)           |  100 |     94  |   98.1 |   98.2 | 100.9 | 100.4 | 1.03 | 0.04 |

3.4.3. Parametric analysis of EDABW cost

Parametric analysis was applied to identify the breaking price point at which EDABW cost would become infeasible. Table 9
ensurages that EDABW becomes infeasible when the price of bakery reaches up to 891 SR ton⁻¹, which represents an increase of about 78.2% from the basal cost (500 SR ton⁻¹). The price tolerance by which the inclusion level of EDABW does not get affected was found to be below 698 SR ton⁻¹ (22.52%) and below 840 SR ton⁻¹ (22.88%) in starter and finisher diets, respectively. The analysis also indicated that maximum corn replacement is 35% and 30% in starter and finisher diets, respectively. The percentages used were to keep the level of both sodium and chloride without excess or limitation (Table 9).

3.4.4. Extra value calculation of using EDABW

3.4.4.1. Extra value calculation for the whole carcass. The increase in EDABW inclusion did not affect broiler performance. Carcass weights were numerically different although the 20% corn replacement (11.88%) was 153.54 g greater than the control group. The
**Table 10**

Extra value calculation for the whole carcass.

| Corn replacement % | Bakery inclusion % (weighted average) | Carcass weight/ g | Retail carcass price/bird /SR | Wholesale carcass price/bird/ SR | FI/kg | Feed cost/kg/SR | Extra value (profitability), SR/bird (retail) | Extra value (profitability), SR/bird (wholesale) | Potential saving in feed SR/kg | IOFC (retail) | IOFC (wholesale) |
|---------------------|--------------------------------------|-------------------|-------------------------------|---------------------------------|------|----------------|-------------------------------------------|-------------------------------------------|-------------------------------|----------------|------------------|
| 0                   | 0.00                                 | 1646.70           | 17.49                         | 15.64                           | 3.38 | 3.35          | 14.14                                      | 12.29                                      | 14.14                          | 12.29                      |
| 20                  | 11.88                                | 1800.24           | 19.12                         | 17.10                           | 3.29 | 3.18          | 1.63                                       | -0.17                                      | 15.94                          | 13.92                      |
| 40                  | 23.74                                | 1678.55           | 17.83                         | 15.95                           | 3.32 | 3.14          | 0.55                                       | 0.52                                       | -0.21                          | 14.69                      | 12.81                      |
| 60                  | 35.57                                | 1729.36           | 18.37                         | 16.43                           | 3.37 | 3.06          | 1.16                                       | 1.07                                       | -0.29                          | 15.30                      | 13.36                      |
| 80                  | 47.38                                | 1694.85           | 18.00                         | 16.10                           | 3.40 | 3.04          | 0.82                                       | 0.77                                       | -0.31                          | 14.96                      | 13.06                      |
| 100                 | 59.37                                | 1692.91           | 17.98                         | 16.08                           | 3.49 | 3.02          | 0.82                                       | 0.78                                       | -0.33                          | 14.96                      | 13.07                      |
| SEM                 | 9.06                                 | 21.59             | 0.23                          | 0.21                            | 0.03 | 0.05          | 0.20                                       | 0.17                                       | 0.03                           | 0.25                       | 0.22                       |

Notes:
- Feed saving per bird = difference in feed cost.
- Extra value on carcass/bird = difference in carcass price.
- Extra value = difference between extra value on carcass and saving in feed cost.
- Carcass price = 10.62/kg.
- IOFC = income over feed cost (SAR) = Carcass price - Feed cost.

**Table 11**

Extra value calculation for eviscerated carcasses.

| Corn replacement % | Carcass cuts Price/ SR (retail) | Carcass cuts Price/ SR (wholesale) | Feed cost/ bird/SR | Extra value of carcass cuts (retail) | Extra value of carcass cuts (wholesale) | IOFC (retail) for carcass cuts | IOFC for carcass cuts (wholesale) |
|---------------------|---------------------------------|-----------------------------------|-------------------|-------------------------------------|----------------------------------------|-------------------------------|-----------------------------------|
| Control 20%         | 17.49                           | 15.64                             | 3.35              | 1.56                                | 1.39                                   | 14.14                         | 12.29                             |
| Saving feeding cost | -0.17                           |                                   |                   |                                     |                                        |                               |                                   |
| Carcass 40%         | 18.88                           | 16.86                             | 3.18              | 0.22                                | 0.18                                   | 14.36                         | 12.48                             |
| Saving feeding cost | -0.21                           |                                   |                   |                                     |                                        |                               |                                   |
| Carcass 60%         | 17.50                           | 15.62                             | 3.14              | 0.35                                | 0.32                                   | 14.05                         | 12.18                             |
| Saving feeding cost | -0.34                           |                                   |                   |                                     |                                        |                               |                                   |
| Carcass 80%         | 18.00                           | 16.35                             | 3.07              | 0.09                                | 0.08                                   | 14.93                         | 13.29                             |
| Saving feeding cost | -0.29                           |                                   |                   |                                     |                                        |                               |                                   |
| Carcass 100%        | 17.51                           | 15.61                             | 3.04              | 0.22                                | 0.20                                   | 14.47                         | 12.57                             |
| Saving feeding cost | -0.31                           |                                   |                   |                                     |                                        |                               |                                   |
| Carcass SEM         | 17.80                           | 15.90                             | 3.02              | 0.16                                | 0.15                                   | 14.78                         | 12.89                             |
| Saving feeding cost | -0.33                           |                                   |                   |                                     |                                        |                               |                                   |
| Notes:              | Overall extra value = extra value of carcass - extra value of breast, wing, and drum. |
|                     | Carcass price = 10.62 SAR/kg (retail) and 9.5 (wholesale). |
|                     | Breast price = 37.87 SAR/kg (retail) and 36.77 (wholesale). |
|                     | Drum and thigh price = 16.6 SAR/kg (retail) and 15.6 (wholesale). |
|                     | Wings = 6.6 SAR/kg (retail) and 5.67 (wholesale). |
numerical difference might be because of the effect of in-group variation that may raise the quality issues of using EDABW. Therefore, the value of using EDABW did not effect on broiler performance but maximized the IOFC. Complete replacement of corn (59.37%) increased the profitability by 0.82 and 0.78 SR/bird for retail and wholesale respectively. Meanwhile, 20% of corn replacement was 1.8 and 1.63 SR/bird in retail and wholesale, respectively (Table 10).

3.4.4.2. Extra value calculation for eviscerated carcass. Marketing profitability of the whole carcass broilers meat might be influenced by the high production cost and the various health challenges. Marketing cut-up broilers' meat may increase profitability due to the varying chopping costs. The greatest value of the carcass cuts was found to be breast meat that cost about 37.87 SR/kg (retail) and 36.77 (wholesale), followed by drums and thighs that cost about 16.6 SR/kg (retail) and 15.6 (wholesale), and wings that cost about 6.6 SR/kg (retail) and 5.67 (wholesale). In this context, the main attractive part of the carcass becomes breast meat. Nutritionally, lysine, and methionine are responsible for maximizing breast meat yield (Hickling et al., 1990). Notably, it was found that there is an adverse relationship between breast meat yield and abdominal fat (Bartov and Plavnik, 1998). The latter is not as desirable as it may reflect unusable energy.

Economic analysis showed that the IOFC of overall carcass cuts was reduced as compared to the whole carcass IOFC. In 100% corn replacement, the differences in the IOFC were 0.64 and 0.60 SAR/bird in retail and wholesale, respectively. Meanwhile, in the 20% corn replacement groups, the IOFC were 1.55 and 1.39 SR/bird in retail and wholesale, respectively. These reductions were due to the reduction in breast meat weights compared to 100% corn, as shown in Table 11.

4. Conclusion

Studying the technical and economic potentials of substituting corn-based diets with the unconventional EDABW in broilers’ diets show a thriving future for the unconventional food wastes industry worldwide, and, consequently, positive economic and the environmental effects. The findings of this scientific investigation show promising technical and economic potentials of substituting the unconventional EDABW in broilers’ diets during the whole production period (1–35 d), in terms of broilers performance, carcass yield, carcass characteristic, economic net returns, and IOFC. The findings showed that the 20% replacement level of corn with EDABW generated the highest increase in the live body weight and the eviscerated carcass at about 4.24% g and 4.90%, respectively. In addition, it shows the outperformance of the whole carcass over the eviscerated carcass, in term of the generated net economic returns and IOFC. Further scientific investigations are recommended to enhance the knowledge on the variability of EDABW, considering the digestion coefficient of amino acids in the formulation as an alternative to the total content of amino acid for maximizing the benefits from carcass cuts.

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