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Original article

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

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ABSTRACT

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 Arabic 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 by 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.

1. Introduction

OECD/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.,

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2018a, 2018b). 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 20th largest worldwide in the bakery product's trade, importin about 3 million tons at about $4.9 billion (Agriculture and Agri-Food Canada, 2017). Bakery waste was the largest food wastage in SA, making up to about 53% of the total food wasted Capone et al., (2016). The dried Arabic bread waste (DABW) is mainly generated during the processing and marketing value chain. Rochell (2018), Gain Report, (2019) and De Verdal et al. (2011). Waste products, such as DABW, could be utilized as an energy source due to their high content of digestible carbohydrates such as sugar and starch (Ottoboni et al., 2019; Catalá-Gregoria et al., 2009) estimated the total feed cost at about 50–70% of the total poultry production costs worldwide. Gain Report (2019) reported that the cost of broiler meat production ranges between $1.60–1.87 per kg in SA. Broilers' meat production in SA reached approximately 710 thousand metric tons (MT) in 2018, while the estimated broiler meat consumption was approximately 1.33 million MT in 2019.

Corn is the main conventional source of energy in poultry diets (Ayanrinde et al., 2014). It constitutes about 60% of the inputs needed for poultry feed (Andam et al., 2017). Accordingly, a high amount of corn is annually imported which adds more costs to the present expensive poultry diet. SA imports about 3.6 million tons of corn annually at the cost of about $ 692, 61 million (FAO, 2016). Energy is the most expensive part of poultry diets; hence, to increase the economic returns and income over feed cost (IOFC) of the poultry industry, the cost of the energy source in poultry diets must be decreased (Robert et al., 2014). Bakery products, mainly Arabic bread waste is one of the notable food wastes in SA. Dry Arabic bread waste (DABW) can be used to substitute corn in feeding poultry to reduce poultry production costs (Al-Rugaie et al., 2011). DABW contains no anti-nutritional factor that replaces corn in broilers' diet as it is rich in energy, vitamins, and low in fiber (Al-Tulaihan et al., 2004; Dabron et al., 1999; Stefanello et al., 2016). In turn, it will benefit poultry producers and the poultry industry in general.

Broilers meat is sold as a whole carcass or carcass chopped to meet consumers' various tastes and preferences, which in turn leads to an increase in production costs and economic returns of the broilers meat industry (Cevger et al., 2004). The highly-priced section of broilers' carcass is breast meat. Small variations in the yield of breast meat would result in great economic return (Scheuermann et al., 2003). However, there was an inverse correlation between breast meat and abdominal fat, which might lead to differences in the desire for fattening and producing breast meat. Chickens that accumulate high amounts of fat in the carcass are usually characterized by low breast meat production (Bartov and Plavnik, 1998). The most important criteria of preferring one raw material over another including but are not limited to the following: sustainability, variability, cost, crude fiber, anti-nutritional factor, mycotoxins, and digestion coefficient. Variability was analyzed based on waste from many bakeries from different origins by Evonik (n = 591; from 2010 to 2015); the data revealed great variability in amino acids profile listed as follows:

- Coefficient of variation (CV, %) of lysine (31.66), Met (23.7), M + C (21.72), Thr (25.11), Trp (23.39), Arg (27.35), ILe (22.63), leu (25), and Val (23.51) (AMINDat 5.0®). Similarly, the level of Na and Cl were questionable in bakery meals. One study revealed that Na% and Cl% levels were 0.93 and 1.37, respectively (Saleh et al., 1996), and another study showed that their levels were 3.2 and 0.12, respectively (Al-Tulaihan et al., 2004). Meanwhile, Na level under the current study was 0.44%, as shown in Fig. 1a and 2b.
- The variation in amino acid profile, Na and Cl, may cause great concern in feed quality and thus in broiler performance.
- Under the current study, the increase in bakery inclusion resulted in an increase in Na content that exceeded the breed requirement by 80 and 100% in both the starter and the finisher rations, respectively. Meanwhile, the same inclusion percentages decreased Cl level below the minimum requirement that becomes limiting at 100% in starter and 80 and 100% in the finisher diet.

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 (Fouad 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-

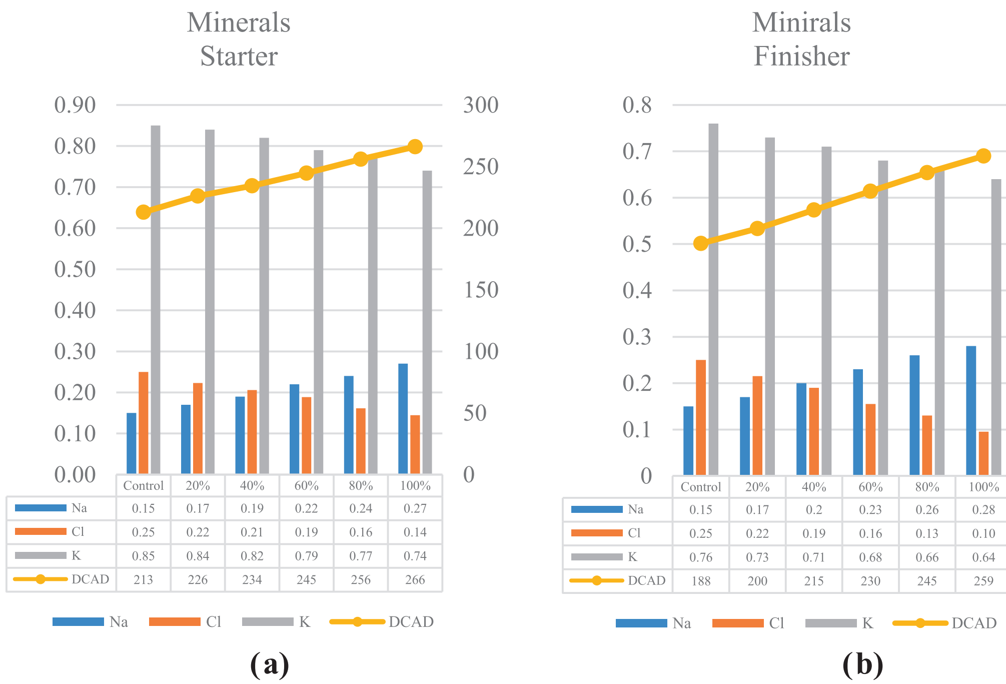

Fig. 1. Impact of corn substation levels with bakery meal on electrolytes balanced.

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).

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

Approximate analysis	EDABW	Corn*
TMEn (kcal g-1)1	3.854	3.470
Approximate analysis (g kg^{-1})		
Moisture	63.600	110.000
CP	129.900	85.000
Ether extract	15.900	38.000
Crude fiber	5.300	22.000
Ash	15.300	12.000
Amino acids profile (%) essential amino adds		
Lysine	0.310	0.260
Methionine	0.260	0.180
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

True Metabolizable Energy (TME) was calculated according to the following equation of Dale et al (1990): TME (kcal kg^{-1}) –4,340–100. CF-40xAsh-30x Cp 10 × EE.
* NRC, 1994.

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).

Table 2
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)						Finisher phase (21–35 days of age)					
	0	20	40	60	80	100	0	20	40	60	80	100
Corn	537.000	428.600	322.000	214.300	107.200	0.000	627.800	502.100	376.500	251.200	125.600	0.000
Bakery waste product	0.000	107.200	214.300	321.500	428.600	537.000	0.000	125.600	251.200	376.500	502.100	0.27.800
Soybean meal	364.900	364.000	349.300	334.200	319.100	321.900	297.200	280.700	264.300	247.900	248.600	230.000
Bran	0.000	3.800	21.500	40.000	58.200	44.500	1.200	21.900	29.800	63.060	62.600	86.500
Corm oil	19.700	48.300	45.500	43.000	40.400	40.400	36.100	33.000	0.000	26.700	27.000	22.600
Sand	10.000	10.000	10.000	10.000	10.000	20.000	0.000	0.000	13.100	0.000	0.000	0.000
Limestone	13.700	13.300	12.900	12.600	12.200	11.500	14.000	13.500	17.800	12.700	12.100	11.700
Di Calcium phosphate	17.100	17.300	17.200	17.100	17.100	17.700	17.600	17.600	2.100	17.400	17.600	17.600
Salt	3.400	2.800	2.200	1.600	1.000	0.500	3.400	2.700	2.000	1.300	0.700	0.000
Premix	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	1.900	2.000	2.000	2.000
DL-Methionine	2.000	2.200	2.300	2.500	2.600	2.800	0.700	0.900	0.020	1.200	1.400	1.500
L-Lysine	0.200	0.500	0.800	1.200	1.600	1.700	0.000	0.000		0.040	0.300	0.300
ME (Kcal g-1)2	3.172	3.203	3.182	3.162	3.192	3.213	3.17.9	3.169	3.149	3.166	3.171	3.189
CP (N%, 6.25)3	22.800	22.900	22.600	23.100	22.600	23.100	20.080	20.230	19.970	20.200	20.190	20.340
Calcium (gkg-1)	9.800	10.100	10.100	9.900	10.000	10.200	10.200	10.000	10.100	10.000	9.900	10.000
AP (gkg-1)4	5.000	5.000	5.000	5.000	5.000	5.000	4.500	4.500	4.500	4.500	4.500	4.500
Lysine (g kg −1)	13.300	13.300	13.300	13.300	13.300	13.300	10.000	10.000	10.000	10.000	10.000	10.000
Met + Cys (g kg^{-1})[5]	9.300	9.300	9.300	9.300	9.300	9.300	7.200	7.200	7.200	7.200	7.200	7.200

Note: premix: (per ton diet: Vit A 6000.000 IU, Vit D 1500.000; Vit E 20.000 IU, Vit K 1.000 mg, Vit B1 1 mg, Vit B2, 3000 mg, Vit B6 2000 mg, Vit B12 10 gm, niacin 20,000 mg, folic acid 500 mg, pantothenic acid 5.000 g, biotin 50 mg, antioxidant 60.000 mg, Co 100 ppm, Cu 5,000 ppm, I 500 ppm, Fe 20.000 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*	500
Soybean	1290
Bran	520
Corn oil	3500
Sand	40
Limestone	110
Di-calcium phosphate	2200
Salt	270
Premix	9000
Dl-methionine	13,000
L-Lysine	5000

Sources: ARASCO, Saudi Arabia. 2018.
* Yousef Attia. Personal communication. King Abdulaziz University. Saudi Arabia. 2018.

Table 4
Average market wholesale, retail prices, and margins of broilers in Saudi Arabia, 1999–2018 (SR kg^{-1}).

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.
* Predicted values using simple liner regression SPSS.
** Wholesale prices are calculated based on the average marketing margin for the known data period.

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). Despise 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

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

Performance and nutrient utilization	Replacement level of (EDABW) (%)						SEM	Pr. < f
	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 (%)								
Body composition	0	20	40	60	80	100	SEM	Pr. > f
Live body weight (g)	100	104.24	98.12	98.88	99.52	100.96	0.88	0.23
live body weight (g/kg)								
Carcass weight	100	103.8	103.4	104.8	102.3	101.5	0.71	0.37
Abdominal fat	100	89.80	130.70	110.20	113.60	108.86	5.6	0.32
Edible offal[1]	100	90.1	90.5	81.9	83	79.5	3.1	0.52
Eviscerated carcass	100	104.9	103.9	93.8	103.4	101.8	1.66	0.3
eviscerated carcass (g/kg)								
Breast	100	98.8	98.3	97.1	96.1	98.7	0.56	0.99
Back	100	105.6	107.7	98.8	101.4	101.4	1.40	0.09
Drums plus thigh	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 costs 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 diet at a ($p < 0.05$) significance level.

On the other hand, as economic returns were assumed constant for all substitution levels, the estimated net economic returns were found positively 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 higher the broilers' net economic returns. Results showed a great potential to generate positive net economic returns using EDABW in broilers' diets at different substitution levels for whole carcasses as well as carcass cuts. At an average retail price, the estimated net economic returns of using the EDABW in broilers' diets increased by about 3.5%, 4.4%, 5.8%, 6.4%, and 6.8% at substitution levels of 20%, 40%, 60%, 80%, and 100% respectively, in comparison with those of the control ($p < 0.05$) significant level. Similarly, the estimated net economic returns of using the EDABW in broilers diets increased, at an average wholesale price, by about 4.3%, 5.3%, 7.1%, 7.8%, and 8.3% at substitution levels of 20%, 40%, 60%, 80%, and 100% respectively, in comparison with those of the control diet at a ($p < 0.05$) significant level (Table 7).

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.

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 wholesale 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 prices, 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 prices at about 3.9%, 4.8%, 6.4%, 7.1%, and 7.6% 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.

3.4.3. 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 7
Economic analysis of the whole broilers' carcass.

Economic indicators	Retail price (SR kg^{-1})							Wholesale price (SR kg^{-1})						
	Substitution level of the EDABW (%)													
	0	20	40	60	80	100	SEM	0	20	40	60	80	100	SEM
Broilers feed cost **(percentage change from control)**	3.35	3.18 (−5.1)	3.14 (−6.3)	3.07 (−8.4)	3.04 (−9.3)	3.02 (−9.9)	0.05	3.35	3.18 (−5.1)	3.14 (−6.3)	3.07 (−8.4)	3.04 (−9.3)	3.02 (−9.9)	0.05
Total broilers production cost **(percentage change from control)**	4.36	4.13 (−5.1)	4.08 (−6.3)	3.99 (−8.4)	3.95 (−9.3)	3.93 (−9.9)	0.07	4.36	4.13 (−5.1)	4.08 (−6.3)	3.99 (−8.4)	3.95 (−9.3)	3.93 (−9.9)	0.07
Economic return	10.62							9.5						
Net economic returns for whole carcass **(percentage change from control)**	6.27	6.49 (3.5)	6.54 (4.4)	6.63 (5.8)	6.67 (6.4)	6.69 (6.8)	0.06	5.15	5.37 (4.3)	5.42 (5.3)	5.51 (7.1)	5.55 (7.8)	5.57 (8.3)	0.06

Table 8
Economic compare son of the net economic returns from whole and eviscerated carcass sales (SR kg^{-1}).

Economic indicators	Retail price (SR kg^{-1})							Wholesale price (SR kg^{-1})						
	Substitution level of the EDABW (%)													
	0	20	40	60	80	100	SEM	0	20	40	60	80	100	SEM
Net economic returns for whole carcass (SR kg^{-1}) (percentage change from control)	6.27	6.49 (3.5)	6.54 (4.4)	6.63 (5.8)	6.67 (6.4)	6.69 (6.8)	0.06	5.15	5.37 (4.3)	5.42 (5.3)	5.51 (7.1)	5.55 (7.8)	5.57 (8.3)	0.06
Carcass cuts:														
Economic returns of breast (SR kg^{-1})	37.87							36.77						
Net economic returns of breast (SR kg^{-1}) (percentage change from control)	33.34	33.57 (0.7)	33.63 (0.8)	33.72 (1.1)	33.76 (1.2)	33.79 (1.3)	0.07	32.41	32.63 (0.7)	32.68 (0.8)	32.78 (1.1)	32.81 (1.2)	32.84 (1.3)	0.07
Economic returns of wings (SR kg^{-1})	11.12							10.02						
Net economic returns of wings (SR kg^{-1}) (percentage change from control)	6.60	6.83 (3.3)	6.88 (3.9)	6.98 (5.2)	7.02 (5.7)	7.04 (6.0)	0.07	5.67	5.89 (3.9)	5.94 (4.8)	6.03 (6.4)	6.07 (7.1)	6.09 (7.6)	0.06
Economic returns of drums and thighs (SR kg^{-1})	16.6							15.6						
Net economic returns of drums and thighs (SR kg^{-1}) (percentage change from control)	12.25	12.47 (1.8)	12.52 (2.2)	12.61 (3.0)	12.65 (3.3)	12.67 (3.5)	0.06	11.25	11.47 (2.0)	11.52 (2.4)	11.61 (3.2)	11.65 (3.6)	11.67 (3.8)	0.06
Average net economic returns for eviscerated carcass (SR kg^{-1}) (percentage change from control)	17.51	17.73 (1.3)	17.78 (1.6)	17.87 (2.1)	17.91 (2.3)	17.94 (2.5)	0.07	16.44	16.66 (1.3)	16.71 (1.7)	16.80 (2.2)	16.84 (2.5)	16.87 (2.6)	0.06

Table 9
Parametric analysis of EDABW cost.

Items	Starter								
Ingredients	bakery cost (SR ton^{-1})					Finisher			
	500	698	850	869	891	500	850	869	891
Corn	36.99	42.53	47.88	48.84	56.83	44.94	54.83	60.42	64.08
Soybean meal 48%	34.85	34.34	34.85	34.94	35.77	26.97	27.90	28.46	28.84
Bakery meal	**22.52**	**17.22**	**10.91**	**9.75**	**0**	**22.88**	**11.23**	**4.46**	**0**
DCP	1.87	1.91	1.95	1.96	2.03	1.72	1.80	1.85	1.89
Oil	1.82	2.02	2.44	2.53	3.28	1.71	2.49	3.00	3.34
lime	0.74	0.74	0.73	0.73	0.72	0.74	0.73	0.72	0.72
Methionine	0.31	0.32	0.32	0.32	0.31	0.22	0.22	0.22	0.22
Salt	0.30	0.30	0.30	0.31	0.33	0.30	0.30	0.37	0.38
Premix	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
lysine HCl	0.21	0.23	0.22	0.22	0.20	0.17	0.15	0.14	0.14
Threonine	0.09	0.10	0.10	0.09	0.09	0.05	0.04	0.04	0.04
Sod. bicarbonate					0.13				0.06
Corn replacement (%)	**35**	**25**	**16**	**14**	**0**	**30**	**14**	**6**	**0**
feed cost\SAR	975	1020	1046	1048	1050	889	979	982	983
Saving\SAR	75.04	30.37	4.22	2.13	0	93.25	3.12	0.98	0

envisages 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 ([rofitability), 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
20	11.88	1800.24	19.12	17.10	3.29	3.18	1.80	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	**17.49**	**15.64**	**3.35**			**14.14**	**12.29**
20%	**18.88**	**16.86**	**3.18**	**1.56**	**1.39**	**15.69**	**13.68**
Saving feed cost				−0.17	−0.17		
Carcass				1.63	1.46		
Breast				−0.16	−0.16		
Wing				−0.02	−0.02		
Drums and thighs				−0.06	−0.06		
SEM				**0.35**	**0.32**		
40%	**17.50**	**15.62**	**3.14**	**0.22**	**0.18**	**14.36**	**12.48**
Saving feed cost				−0.21	−0.21		
Carcass				0.34	0.30		
Breast				−0.23	−0.23		
Wing				−0.03	−0.03		
Drums and thighs				−0.08	−0.08		
SEM				**0.09**	**0.08**		
60%	**18.00**	**16.35**	**3.07**	**0.80**	**0.71**	**14.93**	**13.29**
Saving feed cost				−0.29	−0.29		
Carcass				0.88	0.79		
Breast				−0.38	−0.38		
Wing				−0.03	−0.03		
Drums and thighs				0.048	0.049		
SEM				**0.22**	**0.20**		
80%	**17.51**	**15.61**	**3.04**	**0.33**	**0.28**	**14.47**	**12.57**
Saving feed cost				−0.31	−0.31		
Carcass				0.51	0.46		
Breast				−0.51	−0.51		
Wing				−0.03	−0.03		
Drums and thighs				0.05	0.05		
SEM				**0.16**	**0.15**		
100%	**17.80**	**15.90**	**3.02**	**0.64**	**0.59**	**14.78**	**12.89**
Saving feed cost				−0.33	−0.33		
Carcass				0.49	0.44		
Breast				−0.17	−0.17		
Wing				−0.03	−0.03		
Drums and thighs				0.021	0.021		
SEM				**0.16**	**0.15**		

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 replacements were 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 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 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 SAR/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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