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Review article

Replacement of maize by sorghum in broiler chicken diet: A meta-analysis study of its effects on production performance, mineral tibia content, intestinal villi and nutrient digestibility

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Abstract

Importance of the work: The demand for maize is increasing every year. Sorghum is well-known as a replacement feed for broiler chickens.

Objectives: To evaluate the effect of dietary sorghum inclusion (by replacing maize) in a broiler chicken diet on the production performance, mineral calcium (Ca) and phosphorus (P) tibia content, intestinal villi and nutrient digestibility using a meta-analysis technique.

Materials & Methods: The data originated from published scientific articles obtained using search engines (Scopus and Google Scholar). The next stage was the evaluation of suitability regarding the research topic and study objectives, after which 20 articles were selected for the database. The database was statistically analyzed using a mixed model, with the variable level of inclusion of sorghum in broiler chicken diets analyzed using a fixed effect, while the different experiments were analyzed using random effects.

Results: The inclusion level of sorghum in the broiler chicken diet did not significantly affect the main parameters of broiler chicken performance—average daily gain, feed conversion ratio, mortality and average daily feed intake. The dietary sorghum level did not significantly affect villus height, crypt depth or the tibia mineral content (Ca and P). Furthermore, the dietary sorghum inclusion level did not significantly affect dry matter and fat digestibility.

Main finding: Sorghum has a biological effect that is not different from maize, so sorghum is recommended to be used as an energy source in broiler feed.

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Introduction

Maize is major staple feed for poultry in the livestock industry but poses severe environmental issues every year through Indonesia (Sjofjan et al., 2021b). Mostly, Indonesia is still dependent on using soya bean meal, maize, and cassava as the staple diet for animals (Arifin et al., 2019). Adli (2021a, b) identified fluctuations in maize production from 19,612,435 t in 2015 up to 28,924,009 t in the 2019 valued at USD 233.47 million (Sjofjan et al., 2021b). In response to the Covid-19 pandemic, the Indonesian government imposed very strict rules on the import of goods and animals from other countries, including feed ingredients (Rohmi et al., 2021). Consequently, this encouraged research into alternative feed sources, with sorghum considered as one of the recommended feed ingredients to substitute for maize.

In some countries, in addition to maize, sorghum *(Sorghum bicolor)* is widely used as an energy source feedstuff in poultry feed (Mabelebele et al., 2018). Sorghum has been reported to have a nutrient composition comparable to maize (Rumler et al., 2021). Etuk et al. (2012) stated that compared to maize, sorghum has a higher protein content, but conversely, the energy and fat contents of maize are relatively higher than sorghum, while the amino acid contents in sorghum are comparable to maize. The lysine digestibility of sorghum has been reported to be similar to that of maize (da Silva et al., 2018). Several studies have shown that using sorghum as a substitute for maize has varied effects, some being positive regarding performance, while other experiments produced negative results (Torres et al., 2013; Fagundes et al., 2017; Saleh et al., 2019). Sorghum plants have the advantage of being able to grow under dry and hot climatic conditions (Deng et al., 2019; Emendack et al., 2021). In response to global warming, sorghum has become a plant that can be adaptive to future climate change, so it is necessary to maximize its use, including for feed ingredients. (Raza et al., 2019). Utilization of sorghum in the poultry diet is reported to have limitations, because sorghum has anti-nutritional compounds, such as tannin, kafirin and phytate. (Selle et al., 2018, 2021). Tannins bind nutrients to form complex compounds, making them resistant to breakdown in the digestive tract of poultry (Hassan et al., 2020). In addition, tannins have been reported to bind to protein and starch, thereby causing low protein and starch digestibility (Selle et al., 2010; Malisorn et al., 2020). Anwar et al. (2018) reported that most of the total P in sorghum is in the form of Phytate-P (81–83%). Phytate can bind protein and minerals so that it cannot be digested in the intestinal tract of poultry (Humer et al., 2015; Dersjant-li et al., 2021). Kafirin is one form of protein in sorghum, with studies showing that the composition of kafirin in sorghum protein is in the range 49–54% (Soto et al., 2018). Kafirin is low in the amino acids lysine, histidine and arginine (Li et al., 2011).

Experiments including sorghum in a broiler chicken diet have produced varied experimental results caused by many factors, including the inclusion level of sorghum in the chicken feed, the experimental methodology, the type and quality of sorghum, the age of the broiler chickens and feeding patterns (Crisol-Martínez et al., 2017). Such variation in experimental results makes it challenging to reach firm conclusions regarding the effects of dietary sorghum inclusion in a broiler chicken diet, so meta-analysis methodology is an alternative option (St-Pierre, 2001; Sauvant et al., 2008; Hidayat et al., 2020). Meta-analysis research uses data from existing studies that have been carried out systematically and quantitatively to obtain accurate conclusions (Sjofjan et al., 2021a). Accordingly, the current study aimed to evaluate the effects of different level of sorghum utilization in a broiler chicken diet on production performance, mineral content (Ca and P) of the tibia, intestinal villi and nutrient digestibility using meta-analysis methodology.

Materials and Methods

Database development

The meta-analysis study followed the method in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines reported by Selcuk (2019). The information entered in the study database originated from published scientific articles that were interrogated using search engines (Scopus and Google Scholar) using the keywords "sorghum" and "broiler chicken". In total, 100 articles were identified initially, but only 50 of these were suitable based on evaluation of the abstract, from which after examining the full text, 20 articles were obtained and included in the database (Table 1). The parameters entered in the database were: 1) performance of production (average daily gain (ADG), average daily feed intake (ADFI), feed conversion ratio (FCR), mortality and carcass percentage); 2) content of tibia minerals (Ca and P); 3) intestinal villi; and 4) digestibility of nutrient. The level of sorghum utilization in the broiler chicken diet ranged from 0 (control) to 67.6% (Table 1). The control treatment in each study used maize as the energy source feed ingredient. The level of use of maize in the control

Table 1 List of selected studies used as data sources in this meta-analysis study

No.	Reference	Period (d)	Sorghum inclusion in the diet (%)	Feed ingredients in control treatment
1	Manyelo et al. (2019)	1–42	0–57.92	Maize
2	Saleh et al. (2019)	15–27	0–56.6	Maize
3	Xu et al. (2017)	1–42	0–60	Maize
4	Batonon-Alavo et al. (2016)	8–27	0–32	Maize
5	Tandiang et al. (2014)	1–43	0–50	Maize
6	Torres et al. (2013)	1–42	0–51.33	Maize
7	Abbas and Musharaf (2008)	1–42	54–57.1	Maize
8	Nyamambi et al. (2007)	1–56	0–57.3	Maize
9	Kumar et al. (2007)	1–28	0–67.6	Maize
10	Kyarisiima et al. (2004)	1–21	0–50	Maize
11	Ambula et al. (2001)	1–21	0–60	Maize
12	Pour-Reza and Edriss (1997)	1–42	0–58	Maize
13	Nyachoti et al. (1996)	1–21	0–56.25	Maize
14	Jacob et al. (1996)	1–28	0–53.75	Maize
15	Ibrahim et al. (1988)	1–35	0–58	Maize
16	Dale et al. (1980)	1–28	0–66	Maize
17	Farahat et al. (2020)	1–42	0–54.29	Maize
18	George et al. (2017)	1–35	0–27.54	Maize
19	Hulan and Proudfoot (1982)	1–42	0–58	Maize
20	Pasquali et al. (2017)	1–42	0–59.88	Maize

treatment was similar to the highest level of use for sorghum. Importantly, in data tabulation each parameter was analyzed in the same unit, to facilitate processing.

Data analysis

The database contents were analyzed using a mixed model based on the meta-analysis method (Sauvant et al., 2008; St-Pierre, 2001; Hidayat et al., 2021). Two types of statistical model were used in the meta-analysis, based on the predictor variable being discrete or continuous (see Equations 1 and 2). Sorghum inclusion in the broiler chicken diet was defined as a fixed effect, whereas the different studies were determined as random effects (declared in the RANDOM statement). Equation 1 presents the linear mixed model (LMM) in the 1st order and Equation 2 presents the LMM model in the 2nd order:

$$Y_{ij} = \beta0 + \beta1\ Level_{ij} + Experiment_i + Experiment_i\ Level_{ij} + e_{ij} \quad (1)$$

$$Y_{ij} = \beta0 + \beta1\ Level_{ij} + \beta2\ Level_{ij} + Experimenti + Experimenti\ Level_{ij} + e_{ij} \quad (2)$$

where $\beta0 + \beta1\ Level_{ij}$ (1st order) and $\beta0 + \beta1\ Level_{ij} + \beta2$ Levelij (2nd order) are the fixed effects for $Experiment_i$ + $Experiment_i\ Level_{ij}$ (1st and 2nd order, respectively), β0 is the overall intercept value across all experiments, β1 is the linear regression coefficient of the 1st order, β2 is the linear regression coefficient of the 2nd order, $Level_{ij}$ is the additional level on the random effect.

When the respective quadratic regression model was not significant at $p < 0.05$, a linear regression model was applied. The model statistics used were the *p* value and the root mean square error, with significance tested at *p*-value <0.05. Additionally, a *p*-value between 0.05 and 0.10 indicated an effect tended to be significant. All statistical analyses were performed using the SAS Software version 9.1 (SAS, 2002). Results were presented as mean (± SD) values.

Results

Table 2 presents a statistical description of the data used. The mean dose based on all the data for sorghum utilization was 29.19 ± 22.82%. The minimum level of sorghum inclusion was 0% (control). All the control treatments used maize as an energy source feed ingredient. The maximum use of sorghum inclusion in this study was 67.60%. The mean ADG was 46.24 ± 25.08 g/bird/d, the mean ADFI was 78.08 ± 41.48 g/bird/d and the mean FCR was 1.78 ± 0.48. The mean levels of Ca and P in the tibia were 896.60 ± 474.95 mg/L and 334 ± 160.70 mg/L, respectively. The mean values for nutrient digestibility for dry matter, protein and fat were 63.60 ± 25.04%; 52.12 ± 31.94% and 87.88 ± 5.10%, respectively. The mean villus height and crypt depth were 907.15 ± 240.86 μm and 381.44 ± 406.37 μm, respectively.

Table 3 shows the influence of dietary sorghum level utilization on the broiler chicken diet of the observed parameters. The level of dietary sorghum utilization did not significantly influence the main parameters of broiler chicken production performance (ADG ADFI, FCR and mortality). The absence of significant effect indicated that sorghum could replace maize as the main energy source feed ingredient in the broiler chicken diet. The dietary sorghum inclusion level quadratically decreased ($p < 0.05$) the abdominal fat percentage. The low percentage of abdominal fat indicated better feed use efficiency. Unfortunately, the level of dietary sorghum inclusion decreased ($p < 0.05$) the carcass percentage. Dietary sorghum level utilization did not significantly affect intestinal villi (villus height and crypt depth) or the tibia mineral content (Ca and P). Furthermore, the dietary sorghum level did not significantly affect DM and fat digestibility. However, the dietary sorghum level significantly decreased the digestibility of protein and the apparent metabolizable energy nitrogen-corrected (AMEn).

Discussion

The results showed that the dietary sorghum level inclusion did not significantly influence the main parameters of broiler chicken production performance (ADG, ADFI, FCR and mortality). In this study the control treatment for sorghum was 0%, where the energy source in the control treatment diet used maize. The highest level of use of dietary sorghum in this study was 67.60%. These results indicated that the use of sorghum had similar effects as the use of maize on the production performance of broiler chickens. Another positive effect of using dietary sorghum was the reduced abdominal fat percentage, which is closely related to carcass quality, with low abdominal fat indicating high carcass quality (Masenya et al., 2021). Torres et al. (2013) reported that the use of sorghum had no impact on broiler performance.

Table 2 Summary of descriptive statistics of variables and parameters observed in this study

No.	Parameter	Unit	Mean	SD	Max	Min
1	Level of sorghum inclusion	%	29.16	22.82	67.60	0.00
2	ADG	g/bird/d	46.24	25.08	139.00	8.30
3	ADFI	g/bird/d	78.08	41.48	206.67	12.50
4	FCR	g/g	1.78	0.48	4.06	0.00
5	Mortality	%	7.14	4.69	15.00	1.56
6	Carcass percentage	%	72.73	3.30	81.20	68.09
7	Abdominal fat	%	1.92	0.60	2.86	0.65
8	Ca in tibia	mg/L	896.60	474.95	1480.00	376.00
9	P in tibia	mg/L	334.00	160.70	520.00	130.00
10	Liver	%	2.55	0.85	3.72	1.73
11	AMEn	MJ/kg DM	12.83	0.63	13.45	11.91
12	Dry matter digestibility	%	63.60	25.04	82.91	0.51
13	Protein digestibility	%	52.12	31.94	81.50	0.50
14	Fat digestibility	%	87.88	5.10	93.46	79.20
15	Villus height (VH)	μm	907.15	240.86	1528	571
16	Crypt depth (CD)	μm	381.44	406.37	1423.00	91.00
17	VH/CD	μm/ μm	0.88	0.17	1.10	0.55

Max = maximum value, Min = minimum value, ADG = average daily gain; ADFI = average daily feed intake; FCR = feed conversion ratio; AMEn = apparent metabolizable energy nitrogen-corrected; DM = dry matter; Ca = Calcium; P = Phosphorus

Table 3 Regression parameters for effects of level inclusion of dietary sorghum in broiler diet on performance, mineral content (Ca and P) of tibia, intestinal villi and nutrient digestibility

Parameter	Unit	Model	N	Intercept	SE Intercept	Slope	SE Slope	*p*-value	Sig.	RMSE	AIC
Broiler performance											
ADG	g/bird/d	L	224	42.15	4.52	0.0200	0.03180	0.5296	NS	1.773	1917.72
ADFI	g/bird/d	L	165	71.05	7.38	0.0648	0.03444	0.0617	NS	1.733	1555.41
FCR	g/g	L	202	1.72	0.11	0.0002	0.00074	0.7868	NS	1.703	124.79
Mortality	%	L	10	6.99	3.30	-0.0388	0.06902	0.5914	NS	0.872	66.06
Carcass percentage	%	L	15	71.95	1.05	-0.0113	0.00000	< 0.001	**	1.232	88.10
Liver	%	L	10	2.49	0.53	-0.0006	0.00177	0.7568	NS	0.828	22.41
Abdominal fat	%	Q	36	1.27	0.39	0.0183	0.00288	< 0.001	**		
						-0.0003	0.00005	< 0.001	**	1.319	74.04
Intestinal villi											
VH	µm	L	40	967.44	79.84	-1.3899	1.71997	0.4242	NS	1.365	548.50
CD	µm	L	34	549.00	412.57	-0.0469	0.34630	0.8932	NS	1.135	388.25
Ratio of VH/CD	µm/µm	L	10	0.92	0.18	-0.0012	0.00277	0.6658	NS	1.095	13.87
Mineral in tibia											
Ca	mg/L	L	10	876.68	506.38	0.6880	7.78093	0.9317	NS	0.874	140.89
P	mg/L	L	10	312.11	170.54	0.7558	2.62042	0.7804	NS	0.878	123.48
Nutrient digestibility											
Dry matter	%	L	39	60.69	12.14	-0.0066	0.00386	0.0964	NS	1.568	171.63
Protein	%	L	20	53.32	18.27	-0.0023	0.00103	0.0420	*	1.077	101.86
Fat	%	L	19	85.84	3.43	0.0055	0.0145	0.7100	NS	1.084	87.45
AMEn	MJ/kg DM	L	10	13.23	0.17	-0.0092	0.00134	0.0002	**	0.915	24.70

N = number; ADG = average daily gain; ADFI = average daily feed intake; FCR = feed conversion ratio; AMEn = apparent metabolizable energy nitrogen-corrected; VH = villus height; CD = crypt depth; Ca = calcium; P = phosphorus; Q = quadratic; L = linear; AIC = Akaike information criterion, where AIC is an estimator of the relative quality of statistical models for a given set of data (smaller is better); RMSE = root mean square error; NS = not significant; * = significant ($p < 0.05$); ** = significant ($p < 0.01$)

The current study showed that sorghum had a positive impact when used as an energy source in the broiler diet. Several reports showed that sorghum had a similar chemical composition to maize (Mabelebele et al., 2015; Sekhon et al., 2016; Masenya et al., 2021). The protein content, total P and available P in sorghum are slightly higher than for maize, but the metabolic energy, calcium and fat contents for maize are higher than for sorghum (Puntigam et al., 2021). Sorghum contains higher levels of the amino acids threonine, isoleucine, leucine, tyrosine, phenylalanine and valine than maize (Thomas et al., 2020) but lower contents of the amino acids lysine, methionine, tryptophan, histidine and cystine than maize. Furthermore, essential amino acid digestibility for sorghum and maize are similar (Brestensky et al., 2012). The crude fiber content of sorghum was slightly higher than for maize (Mabelebele et al., 2015; Sekhon et al., 2016; Masenya et al., 2021). The similar chemical compositions between sorghum and maize could explain why the dietary sorghum inclusion level did not significantly affect broiler chicken performance compared to the control. Sorghum was recommended to replace maize in a poultry diet (Getachew et al., 2016). The protein content of sorghum varies from 6% to 10% (Mofokeng et al., 2018). The main energy source on sorghum comes from starch which in sorghum is in the range 63–74% (Gerrano et al., 2014). Even though sorghum has anti-nutritional compounds, such as kafirin, phytate and tannin, the current meta-analysis study indicated such compounds had no impact on the production performance of broiler chickens. Furthermore, the anti-nutritional compounds in sorghum can be minimized using several methods (Hodges et al., 2021), including chemicals, mechanical detoxification and supplementation with amino acids and minerals (Qaku et al., 2020). Processing of sorghum by grinding and making pellets is a popular technique for increasing the nutritional value based on a physical method before use as poultry feed (da Silva et al., 2018). The current meta-analysis study showed that the dietary sorghum inclusion level did not significantly affect intestinal villi (VH, CD and their ratio VH/CD). Thus, the use of sorghum did not affect the surface area of intestinal villi which is where absorption of nutrients occurs, so that a higher villi surface area increases sites for nutrient absorption (Silva et al., 2015). Several reports have shown that tannin affected the villi surface area and subsequently reduced nutrient absorption in the gastrointestinal tract (Mahfuz et al., 2021). The physical and chemical properties of feed ingredients can affect the anatomy and histology of digestive organs (Silva et al., 2015). However, the current meta-analysis study did not identify any negative influences on intestinal villi from the dietary sorghum inclusion level in the broiler chicken diet.

The level of dietary sorghum inclusion did not significantly affect the tibia mineral content of Ca and P, indicating that although sorghum has anti-nutritional compounds (especially phytate that can bind minerals, such as Ca and P), the current results indicated that dietary sorghum did not reduce the P and Ca contents in the tibia. The Ca and P contents of the tibia are indicators of the absorption process in the small intestine for minerals from the diet. The lack of any significant effect of the dietary sorghum level inclusion on the tibia mineral contents (Ca and P) showed that the concentration of phytate in sorghum did not significantly disturb Ca and P digestion and absorption. Nevertheless, phytates are organic compounds composed of phytic acid and phosphorus in cereal grains (Gupta et al., 2015). Aureli et al. (2017) reported that the phytate-P content in sorghum was of 2.1–2.4 g/kg. However, in a report by Tasie and Gebreyes (2020) it was stated that sorghum was a cereal grain that had a high phytate content.

Sorghum utilization in broiler chicken diets significantly reduced protein digestibility and AMEn. The decrease in protein digestibility and AMEn in the current meta-analysis study was closely related to the anti-nutrients contained in sorghum (tannin and phytate) that can bind nutrients, especially protein and starch and forming undigestable complex bonds in the small intestine (Hodges et al., 2021). Decreasing the protein content and AMEn digestibility can affect the phytate binding activity. AMEn indicates the metabolic energy resulting from the digestion of all nutrients in the diet, including protein and starch (Romero et al., 2014). There are some limiting factors that affect the replacement of maize with sorghum, such as the digestive adaptation capacities of broiler chickens to the sensory environmental in terms of the characteristics of the feed given.

Conclusion

This meta-analysis study recommended utilization of sorghum as an energy source feedstuff in a broiler chicken diet. Using sorghum in the broiler diet had no significant effects on broiler chicken production performance, intestinal villi, tibia mineral content and nutrient digestibility compared to the control diet (a maize base diet). The results from the current study indicated that sorghum could be in chicken diets to reduce the dependence on maize.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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