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Effects of different triticale inclusion levels on broilers' growth parameters: A meta-analysis

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ABSTRACT

Triticale is currently used in poultry nutrition as an alternative energy source to conventional cereals like maize and wheat. Many articles emphasized controversial results regarding its inclusion levels on broiler growth parameters. This study aimed to evaluate the overall impact of triticale and its appropriate incorporation level on the growth performance of broiler chickens via a meta-analysis. In February and April 2022, papers investigating the influence of triticale on broiler's live body weight (LBW), body weight gain (BWG), feed intake (FI), and feed conversion ratio (FCR) were identified on Google Scholar, PubMed, and Science Direct. Based on the eligibility criteria of PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, 19 articles were recorded and divided into 62 experiments according to the inclusion percentages of triticale. Using the random-effects models, Hedges' g effect size of dietary triticale treatment was calculated to determine the standardized means difference (SMD) at a 95 % confidence interval (95 % CI). The triticale inclusion in the diet increased the broiler's BWG, FI, and FCR but decreased the broiler's LBW. The meta-regression showed that there was a positive correlation between the inclusion of triticale from 0 to 20 % and the broiler's LBW and FI. Although the funnel plot and the Egger linear test suggested significant publication bias for the LBW factor, this study remains valuable for understanding the impact of triticale on broiler growth parameters. In conclusion, the inclusion of triticale up to 20 % in broiler diets could be recommended to obtain optimal performance.

1. Introduction

The feed cost, representing around 60 % of the total charges in broiler production, has always been an important factor to consider when it comes to improving productivity in the modern broiler industry (Ahiwe et al., 2018). The current high price of main cereals (wheat, maize) led numerous researchers to look for cheaper alternatives with similar nutritive properties. Triticale, a hybrid plant resulting from the crossing between wheat and rye, has been used to replace corn (Lim et al., 2021) and wheat (Alijošius et al., 2018). It has also a low price and its grains contain good energy and protein levels comparable to other cereals (Lim et al., 2021). Indeed, the starch or energy content of triticale cultivars has been reported to vary from 63.8 to 67.6 % with a protein level of 10.5 to 14.6 % (Dennett et al., 2013). Moreover, triticale has shown high yield potential even under hard growing conditions and could be a very good option for raising cereal production globally (Alijošius et al., 2016). Several experiments investigated the effect of different triticale inclusion levels on broiler performance during the last 30 years (Asker et al., 2011; Flores et al., 1994; Gheorghe et al., 2017). However, these studies highlighted a variety of controversial results concerning the effects of triticale on broiler's growing parameters.

Vieira et al. (1995) eventually found that the impact of triticale up to

Abbreviations: LBW, Live body weight; BWG, Body weight gain; FI, Feed intake; FCR, Feed conversion ratio; SMD, Standardized mean difference; CI, Confidence interval; SD, Standard deviation; SE, Standard error; SR, Systematic review; PRISMA, Preferred reporting items for systematic reviews and meta-analyses; SYRCLE, Systematic review center for laboratory animal experimentation; CSV, Comma-separated value; I^2, Higgins statistics; k, Number of studies; Q, χ^2 statistic; τ^2, Heterogeneity variance of the true effect sizes; τ, Standard deviation of the true effect sizes; df, Degree of freedom; QM, Model sum of the square; T0-20 %, Inclusion of triticale from 0 to 20 %; T21-50 %, Inclusion of triticale from 21 to 50 %; and T51-100 %, Inclusion of triticale from 51 to 100 %.

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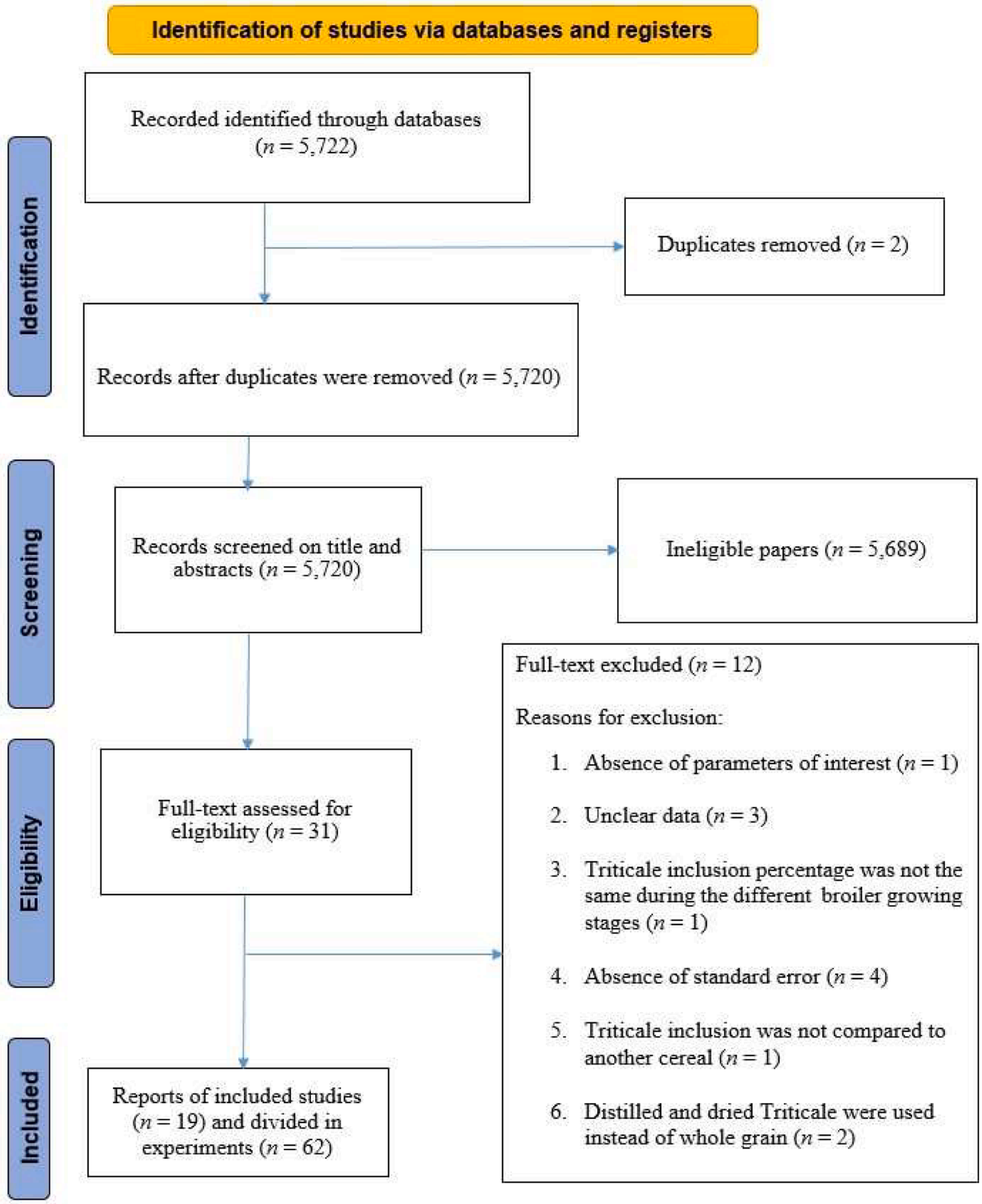

Fig. 1. Systematic literature search selection process. The PRISMA diagram details the applied search and selection process. (this figure must be in color).

40 % in the diet is similar to maize on the broilers' weight. Likewise, Al-Athari and Al-Bustany (1997) reported that the inclusion of triticale up to 20 % had approximately the same influence on the body weight as the control diet. Another article suggested no difference between the control and experimental groups regarding the productivity of broilers when fed grain portions consisting of 100 % triticale as the main energy source (Boros, 1999). Korver et al. (2004) found no significant impact of triticale on feed consumption.

On the other hand, Karaalp and Ozsoy's (2001) outcomes showed that more than 30 % of triticale in broiler diets decreased the yield performance and the feed efficiency and did not improve even when the enzyme was added to triticale. In the same way, Al-Athari and Al-Bustany (1997) found that the inclusion of triticale over 40 % induced an important reduction in body weight. Also, Osek et al. (2010) suggested that the complete replacement of wheat with triticale had negative impacts on the broiler's body weight gain and feed efficiency. Concerning the feed intake, Zarghi and Golian. (2009) noticed an increasing effect on this parameter. These opposite findings show that more accurate research is required to clearly understand the effects of triticale inclusion percentages on broiler growing factors. Indeed, this context stirs a need to summarize the findings across all the published papers and determine the triticale appropriate level in broiler nutrition. The meta-analysis, a tool of fundamental importance to obtain an unbiased assessment of the available pieces of evidence (Balduzzi et al., 2019) is one of the best ways to achieve this target. It can effectively detect the true effect of an intervention by systematically aggregating study outcomes, considering the sources of heterogeneity between studies and a proportional and valid increase in the sample size (Ogbuewu et al., 2022). Numerous articles investigated the effect of triticale on broilers' growth performance. However, none of them examined the effect of several triticale inclusion levels on broilers' growth parameters using a meta-analysis. To complete the knowledge lacking in this domain, the present study aimed to get precise results about the triticale effect on broiler's growing parameters and determine the appropriate triticale

Table 1
Studies used in the data set and information for meta-analysis.

Author (Year)	Broiler strains	Broiler numbers	Triticale percentages (%)	Factors of analysis[a]
Asker et al. (2011)	Ross, Cobb	630	25; 50; 75; 100	LBW, BWG, FI, FCR
Hermes and Johnson (2004)	Avian x Hubbard	1200	5; 10; 15	LBW, FCR
Gheorghe et al. (2017)	Cobb	600	50	LBW, FI, FCR
Mahbub et al. (2011)	Cobb	240	20; 40; 60; 80; 100	LBW, BWG, FI, FCR
Alijošius et al. (2016)	Ross	400	15	LBW, FCR
Başer and Yetişir (2014)	Ross	960	50; 100	LBW, FI, FCR
Kliseviciute et al. (2014)	Ross	1000	2; 4; 6; 8	LBW, FI, FCR
Vieira et al. (1995)	Ross	230	10; 20; 30; 40	BWG, FI, FCR
Zarghi and Golian (2009)	Ross	500	25; 50; 75; 100	LBW, FI, FCR
Abdelrahman et al. (2008)	Ross	300	25; 50	LBW, FI, FCR
Al-Athari and Guenter (1988)	Cobb	600	25; 50; 75; 100	BWG, FI, FCR
Azmal et al. (2007)	Starbro	220	20; 30; 40; 50	LBW, BWG, FI, FCR
Zarghi et al. (2010)	Ross	500	19; 38; 57; 75	LBW, BWG, FI, FCR
Flores et al. (1994)	Unknown	100	100; 100; 100	BWG, FI, FCR
Proudfoot and Hulan (1988)	Arbor Acres	1920	15; 30; 45	LBW, FCR
Rundgren (1988)	Hybro	240	100; 100; 100	LBW, FI, FCR
Jozefiak et al. (2007)	Cobb	192	100	LBW, FCR
Korver et al. (2004)	Ross, Hubbard	300	100	LBW, BWG, FI, FCR
Brum et al. (2000)	Unknown	780	25; 50; 75; 100	BWG, FI, FCR

[a] LBW: Live body weight; BWG: Body weight gain; FI: Feed intake; FCR: Feed conversion.

inclusion level for optimal performance via a meta-analysis.

2. Materials and methods

2.1. Data collection

A literature search was performed using the PRISMA 2020 statement: an updated guideline for systematic reporting reviews (Page et al., 2021). The articles were collected using keywords such as "triticale" and "broiler", or a combination thereof from Google Scholar (https://scholar.google.com/ (accessed on February 07, 2022)), PubMed (https://pubmed.ncbi.nlm.nih.gov/ (accessed on April 12, 2022)), and Science Direct (https://www.sciencedirect.com/ (accessed on April 12, 2022)). These two keywords were used to increase the probability of obtaining eligible papers since some studies assessed the parameters of interest without mentioning them in the title and abstract. Articles were considered as the study subjects regardless of the year of publication.

2.2. Inclusion and exclusion criteria

In the present meta-analysis, a study was judged eligible when the following criteria were met: *In vivo* study, (1) investigating the effect of dietary triticale inclusion level as treatment; (2) comparing the effect of one or multiple triticale inclusion level (s) to other cereals (maize, wheat…) effects; (3) using the broilers as an experimental animal; (4) reporting at least one response of growing parameters (live body weight, LBW; body weight gain, BWG; feed intake, FI; feed conversion ratio, FCR) with the respective variance (standard deviation, SD or standard error, SE). On the other hand, the review articles, studies in which triticale was the unique basal diet, and experiments using other animals than broilers were excluded.

2.3. Assessment of risk of bias

The risk of bias for the included papers was assessed via the SYRCLE (systematic review center for laboratory animal experimentation)'s risk of bias (RoB) tool (Hooijmans et al., 2014). The articles were evaluated according to the 10 following categorical domains of bias: selection bias (domains 1–3), performance bias (domains 4 and 5), detection bias (domains 6 and 7), attrition bias (domain 8), reporting bias (domain 9), and others (domain 10) (Hooijmans et al., 2014). Each domain was reported in one of three categories: "Yes" indicated a low risk of bias, "No" indicated a high risk of bias, and "Unclear" indicated an unclear risk of

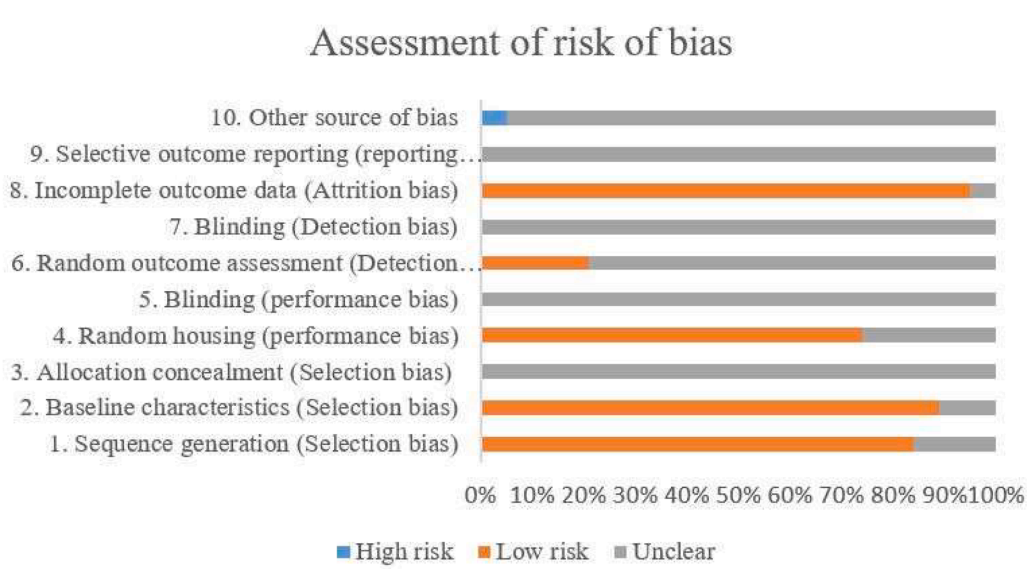

Fig. 2. Risk of bias presented as the percentage of the 19 articles. (this figure must be in color).

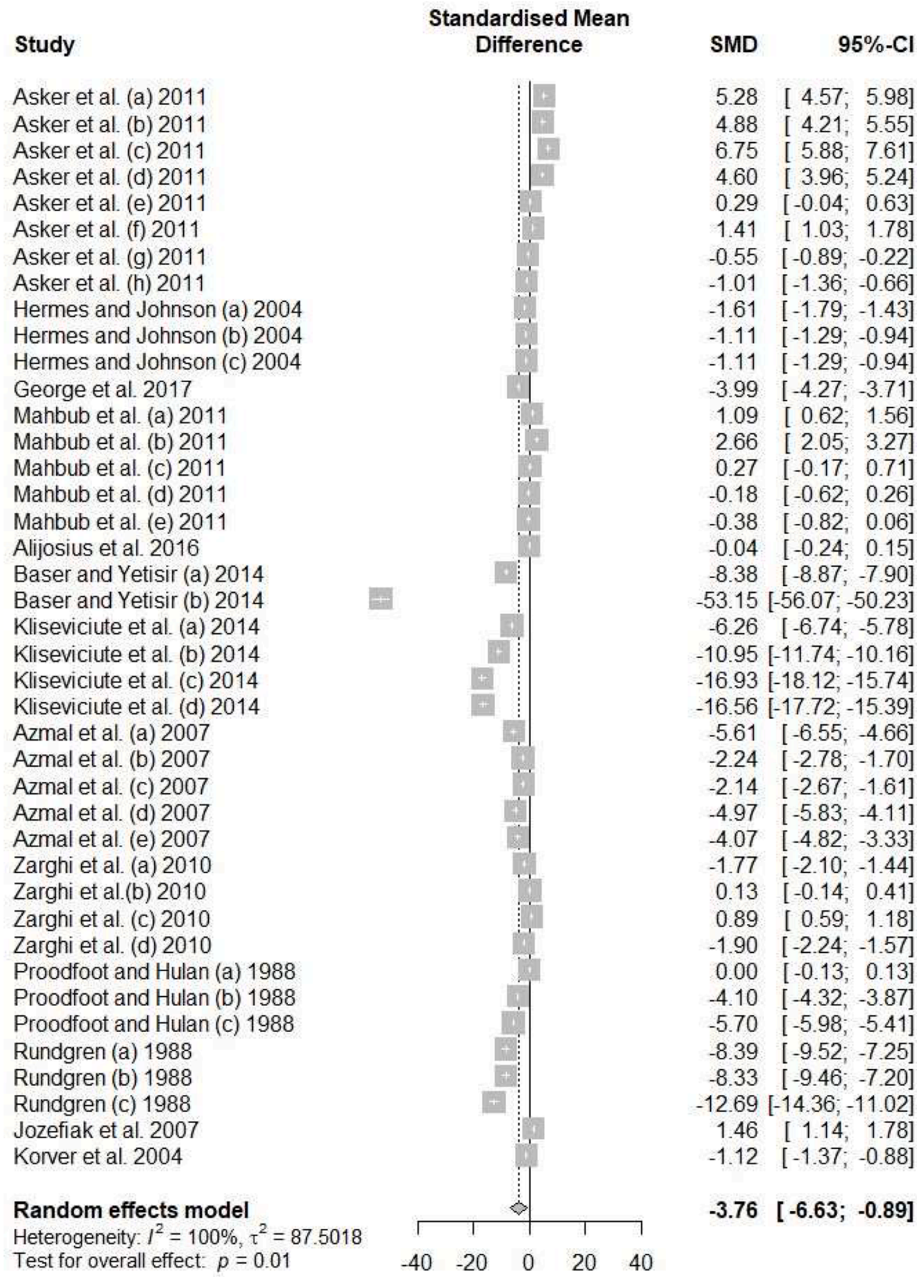

Fig. 3. Effect of Triticale on broilers' LBW.

bias.

2.4. Data collection

The eligible publications were compiled using an electronic form created in Microsoft Excel (Microsoft Corp., Redmond, WA, USA). Extracted study characteristics included (1) author, (2) year of publication, (3) experimental starting age (4) experimental period (5) broiler strain (6) treatment. Extracted outcome data included (1) live body weight, (2) body weight gain, (3) feed intake, and (4) feed conversion ratio.

2.5. Data analysis

The totality of statistical analyses was made using R software (version 4.1.0, R Development Core Team, 2021, http://www.r-project.org (accessed on 14 April 2022)) with the meta, and metafor packages, and all hypothesis verifications were conducted within the 5 % significance level. The means of the experimental units (control and treatment) were registered as continuous result data. The data were introduced in a comma-separated value (CSV) file and then submitted to R software. Four meta-analyses were run separately for the broiler's growing parameters studied (LBW, BWG, FI, and FCR). The variations in triticale effects on broiler growing performance were calculated with the standardized mean difference (SMD) analysis. The effect size of each experimental unit comparing diet with or without triticale inclusion level was calculated for each outcome variable with Hedges' g. The random-effects model was considered where the data were displayed as SMD between the control and treatment. This model was selected for the study because heterogeneity is usually present at different levels in pooled analysis (Ogbuewu et al., 2022). Cochran's Q test was performed to evaluate the statistical heterogeneity of the effect size, and the heterogeneity was identified by the I^2 value. The I^2 statistic could be defined as the percentage of variation in the effect sizes that are not induced by

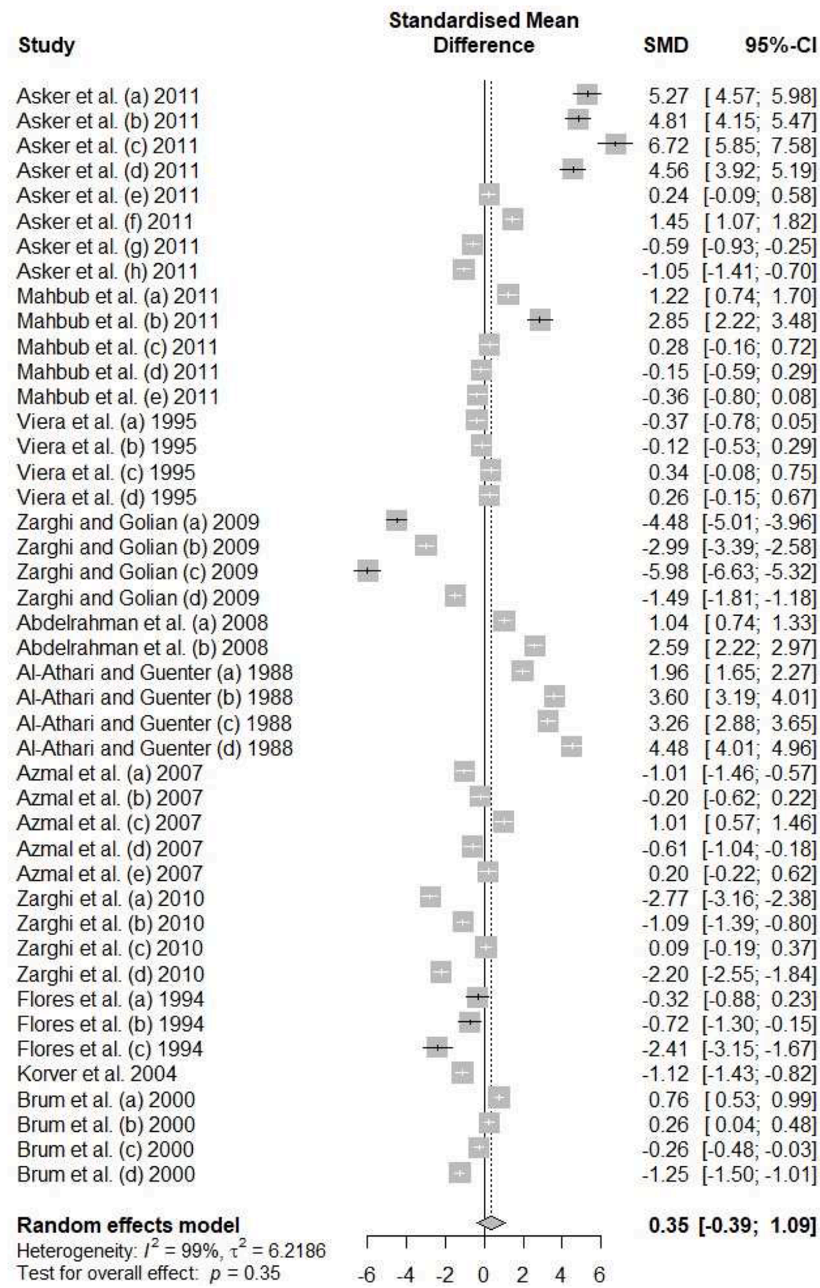

Fig. 4. Effect of Triticale on broilers' BWG.

sampling error (Harrer et al., 2022). The meta-ANOVA and meta-regression tests were conducted to investigate whether the triticale incorporation percentages and the broiler strains could influence the heterogeneity of the effect size. Finally, publication bias was analyzed to confirm the validity of the study results and to assess the risk of bias in individual studies. The funnel plots were drawn to visualize the bias, and Egger's linear test was performed to precisely evaluate the publication bias with numerical data as previously described by Ahn et al. (2022).

3. Results

3.1. Data set

The PRISMA flow diagram in Fig. 1 summarizes the process of our search strategy. A total of 5722 citations were identified in different databases (Google Scholar: 5540, PubMed: 16, Science Direct: 166). The duplicates and inappropriate studies were removed during the screening process for specific reasons. Finally, 19 papers were registered for data extraction and meta-analysis. Since some studies had numerous treatments (various triticale inclusion percentages), the 19 articles were divided into 62 experiments. The articles were divided into experiments according to each study's triticale inclusion percentages. An experiment was defined as the control diet associated with one triticale inclusion percentage. The data sets and experimental conditions of the 19 studies recorded after complete screening are presented in Table 1. These studies were published between 1988 and 2017. The experiments were majoritarian made using broilers of Ross, Cobb, Starbro, Avian × Hubbard, Hybro, Arbor Acre, and Ross × Hubbard strains. The triticale inclusion level in these studies varied from 0 to 100 %.

3.2. Assessment of risk of bias

The results of the assessment of the risk of bias for the 19 studies are presented in Fig. 2. Considering the sequence generation (domain 1), 16

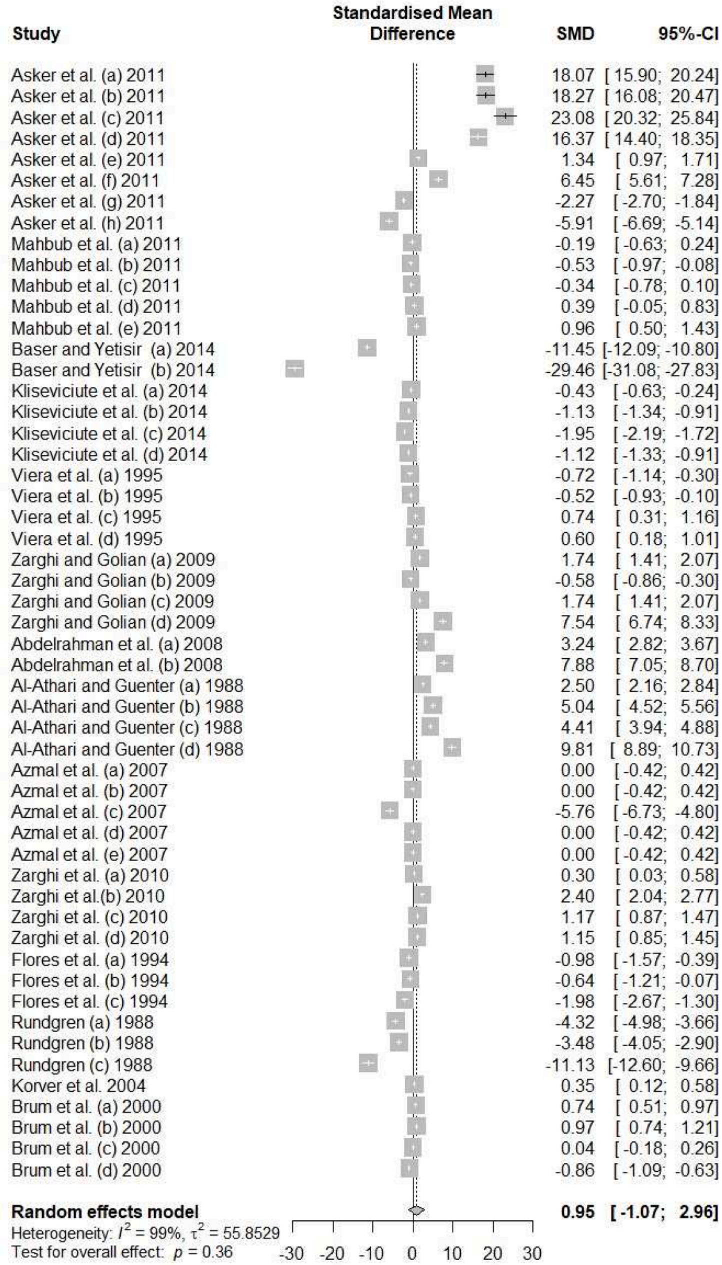

Fig. 5. Effect of Triticale on broilers' FI.

of the 19 articles (84 %) had low risks of bias, and 3 articles (16 %) had unclear risks of bias. For baseline characteristics (domain 2), 17 of the 19 articles (89 %) had low risks of bias, and 2 articles (11 %) had unclear risks of bias. For allocation concealment (domain 3), all the articles (100 %) had unclear risks of bias. For random housing (domain 4), 14 of the 19 articles (74 %) had low risks of bias, and 5 articles (26 %) had unclear risks of bias. Concerning the blinding of the caregivers (domain 5), all 19 articles had unclear risks of bias. In the random outcome assessment (domain 6), 79 % of the articles had unclear risks of bias, while 21 % had low risks of bias. For blinding of outcome assessors (domain 7), all 19 articles had unclear risks of bias. The incomplete outcome data assessment (domain 8) suggested that 95 % of articles had low risks of bias, and 5 % had unclear risks of bias. For selective outcome reporting (domain 9) all 19 articles had unclear risks of bias. For the other sources of bias (domain 10), 18 of the 19 articles (95 %) had unclear risks of bias and one article (5 %) had high risks of bias.

In sum, the 19 papers used in this meta-analysis had approximately 62 % of unclear risk of bias, 37 % of low risk of bias, and 1 % of high risk of bias.

3.3. Effects of triticale on broilers' growth parameters

Figs. 3–6 show the effect of triticale on broilers' growth parameters using random-effects models. The triticale inclusion in the broiler's diet decreased the LBW (SMD = -3.76) and increased BWG (SMD = 0.3516), FI (SMD = 0.9485), and FCR (SMD = 0.6818). However, the impact of triticale was significant ($p < 0.05$) only on LBW and FCR. These results suggested that dietary triticale had negative effects ($p < 0.05$) on LBW and FCR but insignificant influences ($p > 0.05$) on BWG and FI. The significant effects of triticale on LBW and FCR are confirmed by their confidence intervals with 0 excluded (LBW 95 % CI: [-6.63; -0.89]; FCR 95 % CI: [0.03; 1.34]). In the same way, the non-significant effects of triticale on BWG and FI are reinforced by the inclusion of 0 in their confidence intervals (BWG 95 % CI: [-0.39; 1.09]; FI 95 % CI: [-1.07;

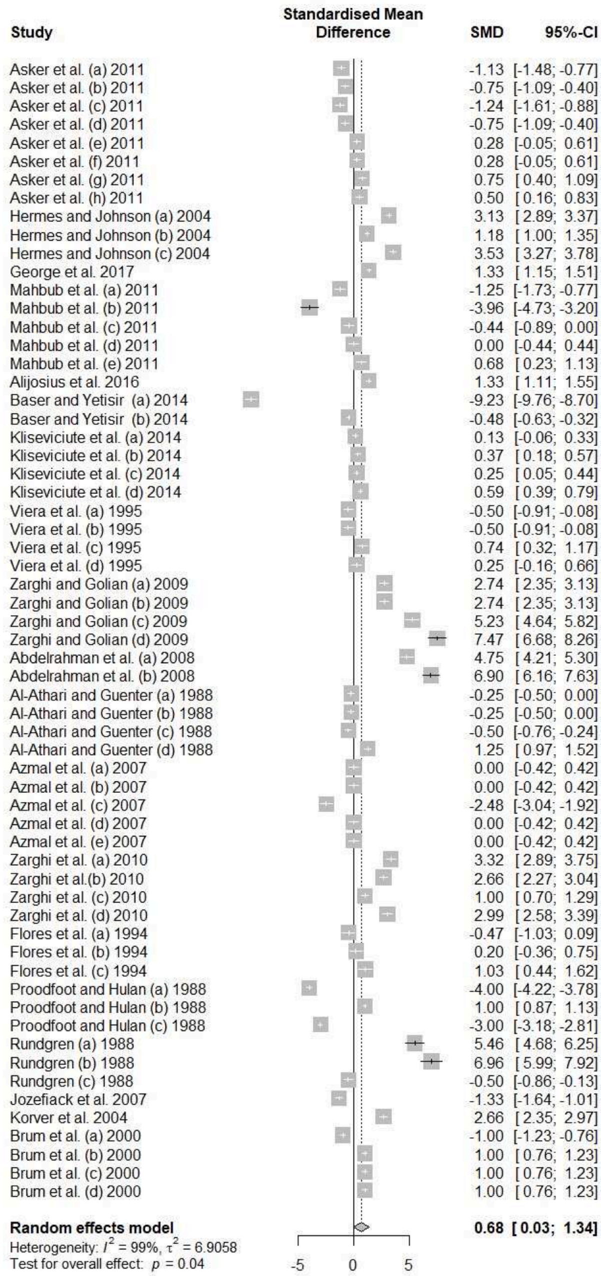

Fig. 6. Effect of Triticale on broilers' FCR.

2.96]). The heterogeneity of the effect sizes was evaluated by calculating I^2 and τ^2 values. For every factor (LBW, BWG, FI, and FCR), I^2 values were above 75 % in the included studies, suggesting that all factors had significant levels of heterogeneity. The highest I^2 and τ^2 values were for LBW ($I^2 = 99.6$ %, $\tau^2 = 87.5018$) while the lowest were for BWG ($I^2 = 98.9$ %, $\tau^2 = 6.2186$).

3.4. Effects of triticale inclusion intervals on broilers growth parameters using moderator analysis

An additional moderator analysis was performed because of significant heterogeneities ($I^2 > 75$ %) observed on every growing parameter. The results of a meta-ANOVA analysis of triticale on LBW, BWG, FI, and FCR are presented in Tables 2 and 3. Firstly, the studies were divided into three groups (Table 2) to investigate the appropriate triticale inclusion interval: T0-20 % (inclusion of triticale from 0 to 20 %); T21-50 % (inclusion of triticale from 21 to 50 %); and T51-100 % (inclusion of triticale from 51 to 100 %). Even though all the results were not significant ($p > 0.05$), the meta-ANOVA revealed that T21-50 % had a lower decreasing effect on LBW (SMD = -1.4407) than T0-20 % (SMD = -4.8357) and T51-100 % (SMD = -4.8804). T0-20 % decreased the BWG (SMD = -0.5447) and FI (SMD = -0.5876) while T21-50 % and T51-100 % increased them (BWG and FI). However, the increasing effects of T21-50 % on BWG and FI were greater than that of T51-100 % on the same parameters. Table 2 also showed that all the triticale inclusion intervals had positive effect sizes on FCR. Nevertheless, the highest increasing effect on FCR was noticed with T51-100 % (SMD = 1.3352) followed by T0-20 % (SMD = 0.5071) and T21-50 % (SMD = 0.1141).

A second sub-group analysis was conducted to study the effect of triticale according to the broiler strains (Table 3). Therefore, the eligible papers were divided into different groups of broiler strains for every parameter (LBW, BWG, FI, and FCR). The results showed that LBW was significantly decreased ($p < 0.05$) by triticale inclusions on Avian × Hubbard (SMD = -1.2786), Arbor Acres (SMD = -3.2622), Starbro (SMD = -3.7700), Ross (SMD = -6.1963), and Hybro (SMD = -9.7406) broilers strains. On the other hand, the LBW of Cobb strain's broilers (SMD = 0.0884) was significantly increased ($p < 0.05$) by the triticale in diets. For BWG, triticale induced positive outcomes ($p < 0.05$) in Ross (SMD = 0.2252) and Cobb strains (SMD = 1.3190) while it produced negative effects ($p < 0.05$) on Starbro (SMD = -0.1219) and Unknown strains (SMD = -0.5331). The triticale inclusion in the diet increased FI ($p < 0.05$) on Cobb strains (SMD = 1.6603) and Ross (SMD = 2.3445) but reduced it ($p < 0.05$) on Unknown (SMD = -0.3570), Starbro (SMD = -1.1247), and Hybro strains (SMD = -6.2650). Concerning FCR, the addition of triticale into the broiler diet led to positive effect sizes ($p < 0.05$) on Unknown (SMD = 0.3979), Ross (SMD = 1.1500), Avian × Hubbard (SMD = 2.6090), and Hybro strains (SMD = 3.9573) but negative effect sizes ($p < 0.05$) on Cobb (SMD = -0.1740), Starbro (SMD = -0.4836), and Arbor Acres (SMD = -1.9975).

After the meta-ANOVA tests, two meta-regression (Tables 4 and 5) were conducted according to each experiment's triticale percentages to deeply understand the source of heterogeneity in triticale effects. The first meta-regression (Table 4) was run in the sub-group analysis of the various triticale inclusion intervals (T0-20 %, T21-50 %, and T51-100 %). The results suggested that the regression models were not significant for BWG and FCR factors. However, significant results were noticed in T0-20 % effects on LBW (Estimate = 0.5971, QM = 6.4781, $p < 0.05$) and FI (Estimate = 0.0583, QM = 4.6886, $p < 0.05$). These outcomes are confirmed by the bubble plots (Fig. 7) showing an increasing trend of LBW and FI's standardized mean differences following the inclusion of triticale from 0 to 20 %. Indeed, LBW and FI's standardized mean differences seem to increase as triticale inclusion gets closer to 20 %.

The second meta-regression (Table 5) was made in the sub-group analysis of different broiler strains (Ross, Cobb, Starbro...) used in the present meta-analysis. The outcomes showed that there was a significant negative correlation between triticale percentages and Arbor Acres strain on LBW (Estimate = -0.1901, QM = 15.6357, $p < 0.05$). In the same way, BWG and FI exhibited significant negative correlations between triticale percentages and the group of unknown broiler strains (BWG: Estimate = -0.0261, QM = 10.9139, $p < 0.05$; FI: Estimate = -0.0285, QM = 16.5307, $p < 0.05$). However, the regression model was not significant ($p > 0.05$) for every strain regarding the FCR factor. The significant results are highlighted by the bubble plots in Fig. 8 exhibiting that Arbor Acres's LBW significantly decreased with the inclusion of triticale from 0 to 45 %. In addition, the BWG and FI of the unknown broilers were also progressively reduced by the inclusion of triticale from 0 to 100 % (Fig. 8).

3.5. Publication bias

A publication bias was conducted to emphasize the presence or absence of errors in this meta-analysis according to the analyzed factors (LBW, BWG, FI, and FCR). The funnel plots (Fig. 9) exhibited evident

Table 2
Meta-ANOVA analysis of triticale's effect on broilers' growth parameters according to the triticale inclusion intervals.

Variables[a]	Random-effect model[b]				Heterogeneity[c]					*p*-value
			95 % CI		I^2	τ^2	τ	Q	df	
	k	SMD	Lower	Upper						
LBW										
T0-20 %	13	-4.8357	-8.1864	-1.4850	99.6	37.8881	6.1553	3.07	2	0.2155
T21-50 %	13	-1.4407	-3.7404	0.8589	99.7	17.8228	4.2217			
T51-100 %	15	-4.8804	-12.0307	2.2699	99.5	199.3576	14.1194			
BWG										
T0-20 %	6	-0.5447	-1.5948	0.5053	97.3	1.6747	1.2941	3.66	2	0.1600
T21-50 %	19	0.9133	-0.1528	1.9793	98.9	5.5719	2.3605			
T51-100 %	19	0.0728	-1.2179	1.3635	99.0	8.1787	2.8599			
FI										
T0-20 %	10	-0.5876	-1.0145	-0.1606	95.9	0.4450	0.6671	4.54	2	0.1034
T21-50 %	20	2.5428	-0.3514	5.4370	99.4	43.4287	6.5900			
T51-100 %	23	0.2286	-3.6825	4.1397	99.5	91.3405	9.5572			
FCR										
T0-20 %	15	0.5071	-0.4613	1.4756	99.5	3.6361	1.9069	2.53	2	0.2829
T21-50 %	23	0.1141	-1.1594	1.3876	99.5	9.6657	3.1090			
T51-100 %	24	1.3352	0.3410	2.3293	98.7	6.1165	2.4732			

[a] LBW: Live body weight; BWG: Body weight gain; FI: Feed intake; FCR: Feed conversion ratio; T0-20 %: Inclusion of triticale from 0 to 20 %; T21-50 %: Inclusion of triticale from 21 to 50 %; and T51-100 %: Inclusion of triticale from 51 to 100 %.
[b] k: Study number; SMD: Standard mean difference; CI: Confidence interval.
[c] I^2: Higgins statistic; Q: χ^2 statistic; τ^2: Heterogeneity variance of the true effect sizes; τ: Standard deviation of the true effect sizes; df: Degree of freedom.

Table 3
Meta-ANOVA analysis of triticale's effect on broiler growth parameters according to the broiler's strain.

Variables[a]		Random-effect model[b]					Heterogeneity[c]			*p*-value
			95 % CI		I^2	τ^2	τ	Q	df	
	k	SMD	Lower	Upper						
LBW										
Ross	15	-6.1963	-13.7528	1.3601	99.8	222.703	14.9232	59.57	6	<0.0001
Cobb	11	0.0884	-0.9337	1.1105	99	2.9481	1.717			
Avian × Hubbard	3	-1.2786	-1.6008	-0.9563	89.7	0.073	0.2702			
Starbro	5	-3.77	-5.1489	-2.3912	94.6	2.3332	1.5275			
Arbor Acres	3	-3.2622	-6.5874	0.0629	99.9	8.6219	2.9363			
Hybro	3	-9.7406	-12.5114	-6.9697	90.5	5.5368	2.353			
BWG										
Ross	18	0.2252	-1.371	1.8215	99.3	11.8758	3.4461	28.21	4	<0.0001
Cobb	13	1.319	0.3487	2.2893	98.6	3.1391	1.7717			
Starbro	5	-0.1219	-0.8032	0.5595	91.7	0.5558	0.7455			
Unknown	7	-0.5331	-1.2823	0.216	96.9	0.9727	0.9863			
FI										
Ross	24	2.3445	-1.7816	6.4707	99.6	106.075	10.2993	14.52	5	0.0126
Cobb	13	1.6603	-0.5275	3.8481	99.3	16.1173	4.0146			
Starbro	5	-1.1247	-3.3426	1.0931	96.9	6.3183	2.5136			
Unknown	7	-0.357	-1.1193	0.4053	97.1	1.0105	1.0052			
Hybro	3	-6.265	-10.9728	-1.5572	97.8	17.0561	4.1299			
FCR										
Ross	25	1.15	-0.1243	2.4244	99.3	10.5232	3.2439	115.48	7	<0.0001
Cobb	15	-0.174	-0.809	0.461	97.4	1.536	1.2394			
Avian × Hubbard	3	2.609	1.1819	4.0362	99.3	1.5773	1.2559			
Starbro	5	-0.4836	-1.4373	0.47	93.9	1.1312	1.0636			
Unknown	7	0.3979	-0.2323	1.0281	97.3	0.6809	0.8252			
Arbor Acres	3	-1.9975	-1.1594	1.3876	99.9	6.9833	2.6426			
Hybro	3	3.9573	0.341	2.3293	99.4	15.4905	3.9358			

[a] LBW: Live body weight; BWG: Body weight gain; FI: Feed intake; FCR: Feed conversion ratio.
[2] k: Study number; SMD: Standard mean difference; CI: Confidence interval.
[c] I^2: Higgins statistic; Q: χ^2 statistic; τ^2: Heterogeneity variance of the true effect sizes; τ: Standard deviation of the true effect sizes; df: Degree of freedom.

publication bias for the LBW (A) through the grey data points, representing studies mostly concentrated on the left side. Indeed, these studies are mostly characterized by low standard errors (SE:] 0; 1[) and negative mean differences (SMD: [0; -20[) and have almost no equivalent on the right side of the plot. The other broiler parameters (BWG, FI, and FCR) showed apparent symmetrical funnel plots with approximately the same number of studies on each side of the vertical line representing the average effect size. The Egger's linear regression test (Table 6) confirmed these results by suggesting significant study bias only for the LBW (Bias = -9.5549; $p < 0.05$). The white data points on different funnel plots (Fig. 9) represent the studies added via the trim-and-fill procedure to correct the publication bias in our study. As presented in Table 7, the results of the trim-and-fill procedure showed negative effect sizes for LBW (SMD = -1.2172, $I^2 = 99.7$ %) and FI (SMD = -0.1291, $I^2 = 99.4$ %) while the BWG (SMD = 0.2005, $I^2 = 98.9$ %) and FCR (SMD = 0.3590, $I^2 = 99.4$ %) presented positive effect sizes. However, the trim-and-fill effects were not significant ($p > 0.05$) for all the growing parameters.

Table 4
Meta-regression analysis of triticale inclusion intervals' effect on broilers' growth parameters.

Variables[a]	Mixed effects model[b]								95 % CI	
	Estimate	SE	*p*-value	QM	τ^2	*T*	I^2	R^2	Lower	Upper
LBW										
T0-20 %	0.5971	0.2346	0.0109	6.4781	25.96	5.10	99.93	31.48	0.1373	1.0570
T21-50 %	-0.1247	0.1231	0.3109	1.0268	17.79	4.22	99.77	0.20	-0.3660	0.1165
T51-100 %	-0.3169	0.2704	0.2411	1.3740	194.29	13.94	99.97	2.54	-0.8469	0.2130
BWG										
T0-20 %	0.0403	0.1284	0.7534	0.0987	2.05	1.43	97.78	0.00	-0.2113	0.2920
T21-50 %	0.0252	0.0521	0.6282	0.2345	5.82	2.41	99.39	0.00	-0.0769	0.1274
T51-100 %	-0.0037	0.0454	0.9347	0.0067	8.67	2.94	99.56	0.00	-0.0927	0.0853
FI										
T0-20 %	0.0583	0.0269	0.0304	4.6886	0.31	0.56	93.53	30.55	0.0055	0.1110
T21-50 %	-0.0089	0.1415	0.9497	0.0040	45.90	6.78	99.90	0.00	-0.2863	0.2685
T51-100 %	-0.1411	0.1378	0.3057	1.0493	91.22	9.55	99.95	0.14	-0.4111	0.1289
FCR										
T0-20 %	-0.0351	0.0845	0.6782	0.1722	3.87	1.97	99.57	0.00	-0.2008	0.1306
T21-50 %	-0.0278	0.0629	0.6583	0.1956	10.04	3.17	99.76	0.00	-0.1511	0.0955
T51-100 %	0.0220	0.0359	0.5403	0.3750	6.30	2.51	99.51	0.00	-0.0483	0.0923

[a] LBW: Live body weight; BWG: Body weight gain; FI: Feed intake; FCR: Feed conversion ratio; T0-20 %: Inclusion of triticale from 0 to 20 %; T21-50 %: Inclusion of triticale from 21 to 50 %; and T51-100 %: Inclusion of triticale from 51 to 100 %.
[b] SE: Standard error; CI: Confidence interval; QM: Model sum of square; I^2: Higgins statistic; Q: χ^2 statistic; τ^2: Heterogeneity variance of the true effect sizes; τ: Standard deviation of the true effect sizes; R^2: Percentage of variation explained by the model; df: Degree of freedom.

Table 5
Meta-regression analysis of triticale effect on growth parameters of broilers strains.

Variables[a]	Mixed effects model[b]								95 % CI	
	Estimate	SE	*p*-value	QM	τ^2	*T*	I^2	R^2	Lower	Upper
LBW										
Ross	-0.0268	0.1116	0.8103	0.0576	239.06	15.46	99.98	0.00	-0.2454	0.1919
Cobb	-0.0106	0.0192	0.5801	0.3061	3.17	1.78	98.83	0.00	-0.0483	0.0270
Avian x Hubbard	0.0493	0.0287	0.0861	2.9454	0.03	0.18	80.70	54.76	-0.0070	0.1057
Starbro	0.0022	0.0576	0.9692	0.0015	3.15	1.77	96.42	0.00	-0.1108	0.1152
Arbor Acres	-0.1901	0.0481	<0.0001	15.6357	1.03	1.01	98.77	88.09	-0.2843	-0.0959
BWG										
Ross	0.0145	0.0312	0.6422	0.2158	12.46	3.53	99.65	0.00	-0.0467	0.0758
Cobb	-0.0098	0.0182	0.5902	0.2901	3.34	1.83	98.76	0.00	-0.0454	0.0258
Starbro	0.0202	0.0259	0.4348	0.6099	0.62	0.79	92.78	0.00	-0.0305	0.0710
Unknown	-0.0261	0.0079	0.0010	10.9139	0.31	0.56	92.34	68.07	-0.0415	-0.0106
FI										
Ross	0.0171	0.0705	0.8078	0.0592	110.67	10.52	99.97	0.00	-0.1209	0.1552
Cobb	-0.0030	0.0415	0.9418	0.0053	17.59	4.19	99.66	0.00	-0.0844	0.0783
Starbro	-0.0000	0.0927	1.0000	0.0000	8.55	2.92	99.29	0.00	-0.1817	0.1817
Unknown	-0.0285	0.0070	<0.0001	16.5307	0.24	0.49	90.21	76.24	-0.0423	-0.0148
FCR										
Ross	0.0147	0.0216	0.4979	0.4595	10.77	3.28	99.76	0.00	-0.0277	0.0571
Cobb	0.0139	0.0114	0.2212	1.4963	1.49	1.22	98.30	2.86	-0.0084	0.0362
Avian x Hubbard	0.0391	0.2490	0.8752	0.0247	3.08	1.76	99.66	0.00	-0.4489	0.5272
Starbro	-0.0000	0.0399	1.0000	0.0000	1.54	1.24	96.72	0.00	-0.0781	0.0781
Unknown	0.0110	0.0113	0.3295	0.9510	0.68	0.82	96.25	0.30	-0.0112	0.0332
Arbor Acres	0.0333	0.1731	0.8475	0.0370	13.47	3.67	99.95	0.00	-0.3060	0.3726

[a] LBW: Live body weight; BWG: Body weight gain; FI: Feed intake; FCR: Feed conversion ratio.
[b] SE: Standard error; CI: Confidence interval; QM: Model sum of square; I^2: Higgins statistic; Q: χ^2 statistic; τ^2: Heterogeneity variance of the true effect sizes; τ: Standard deviation of the true effect sizes; R^2: Percentage of variation explained by the model; df: Degree of freedom.

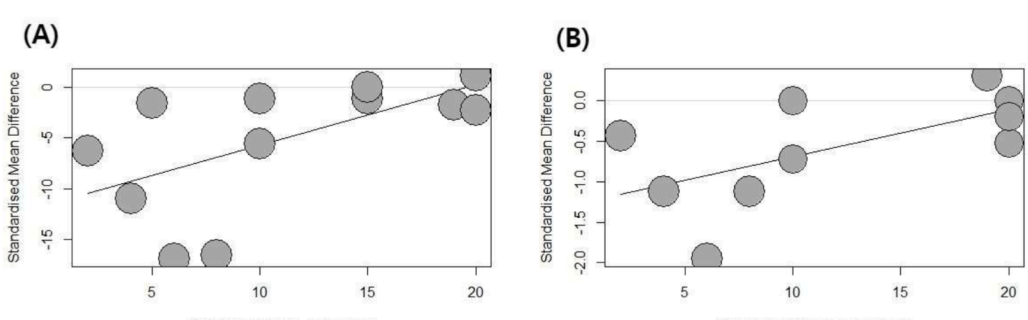

Fig. 7. Effect of T0-20 % on broilers' LBW and FI. (A): LBW; (B): FI.

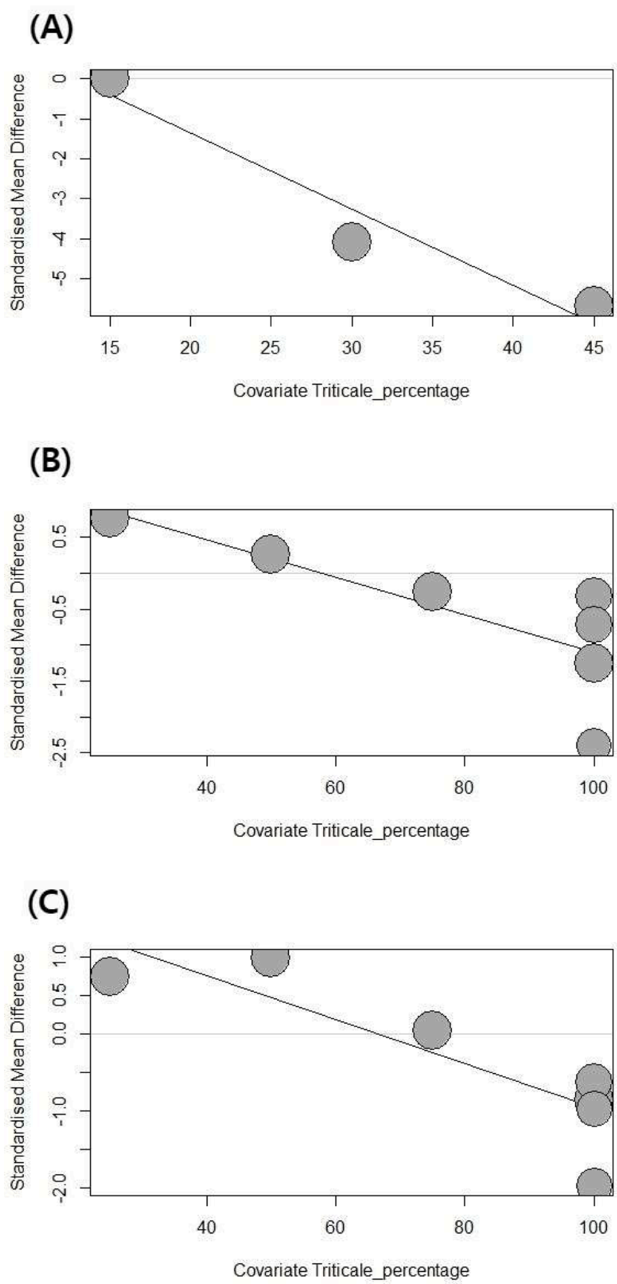

Fig. 8. Effect of triticale percentages on Abor Acres' LBW, BWG, and FI. (A): LBW; (B): BWG; (C): FI.

4. Discussion

The use of alternative energy sources to common cereals (maize, wheat…) is of constant interest in poultry. Some articles suggested the beneficial effects of cereal substitutes such as triticale on broilers' growth parameters (Abdelrahman et al., 2008; Asker et al., 2011). On the other hand, certain reports showed the negative impact of triticale inclusion on broiler performance (Flores et al., 1994; Hermes and Johnson, 2004; Zarghi and Golian, 2009). Since the triticale inclusion percentage could be the source of variation among these previous outcomes, the present meta-analysis investigated the effect of different triticale inclusion levels on broilers' growing parameters.

4.1. Assessment of risk of bias

The quality of a systematic review (SR) is strongly linked to the credibility of the data and the results of the included articles (Macleod et al., 2009). The Assessment of the risk of bias in specific studies is therefore necessary for SR. In the present meta-analysis, the evaluation of the risk of bias was conducted using SYRCLE's RoB tool for animal intervention studies. This tool was made to investigate methodological quality and has been adapted to fundamental aspects of bias in animal experiments (Hooijmans et al., 2014). Here, the assessment of the risk of bias revealed that the unclear risk of bias (62 %) was more present in our meta-analysis studies than the low risk of bias (37 %) and the high risk of bias (1 %). The high level of unclear risk of bias (62 %) could be due to the inclusion of articles (5) published before 2000 that might be characterized by a low level of clarity in explanation. In addition, the studies related to animal nutrition do not usually provide clear pieces of information about blinding bias and outcome assessment. Despite the significant unclear risk of bias in this meta-analysis, it remains valuable to investigate the effects of triticale on broilers' growth parameters because of the low percentage of high risk of bias (1 %).

4.2. Effect of triticale on growth parameters

The first results of this meta-analysis showed that the dietary triticale decreased the LBW ($p < 0.05$) while it had no significant impact ($p > 0.05$) on BWG, FI, and FCR. The significant decreasing effect of triticale on broiler's LBW reported in our study is confirmed by several authors (Gerry, 1975; Korver et al., 2004; Proudfoot and Hulan, 1988; Ruiz et al., 1987; Smith et al., 1989) and could be explained by the use of old triticale strains with high amount of anti-nutritional factors in the studies selected in our meta-analysis for the LBW parameter. Indeed, the triticale plant was recognized to contain a relatively high amount of soluble pentosans (Pettersson and Aman, 1988; Rundgren, 1988), trypsin inhibitors, alkyl-resorcinols, and pectins (Smith et al., 1989). Moreover, some researchers reported that the lower levels of lysine and methionine plus cysteine in triticale could negatively affect broiler performance when compared to corn (Proudfoot and Hulan, 1988) and wheat (Sell et al., 1962).

On the other hand, the similar effect of triticale diets compared to control treatment on broiler's BWG, FI, and FCR could be due to the utilization of recent triticale varieties with lower anti-nutritional factors in some studies included in the meta-analysis for these parameters. Indeed, Boros (1999) and Bielski et al. (2015) found new varieties of triticale with lower anti-nutritional factors improving its yield and nutritive value. This previous explanation could be also the reason for the absence of difference between the impact of control diets and different triticale inclusion intervals (T0-20 %, T21-50 %, and T51-100 %) on broilers' performance in the first sub-group analysis (meta-ANOVA).

It is well known that the strain is a factor influencing diet effects in broiler nutrition (Rahimi et al., 2006; Sarker et al., 2001; Hossain et al., 2011). This assertion seems corroborated by our findings showing diverse effects of triticale grains on broiler performance according to the strains. The results suggested that the Cobb and Ross strains had the best-growing performance with triticale diets. The main reason behind these outcomes could be the use of new or old broiler strains among the studies included in the present meta-analysis. Indeed, Table 1 shows that most of the articles using the Cobb or Ross strain were published after 2005 while the experiments using the remaining strains such as Arbor Acres, Hybro, or Hubbard were conducted before 2000. Therefore, the use of recent Cobb and Ross strains characterized by a higher physiological ability to handle the anti-nutritional factors contained in triticale would necessarily emphasize better performance than old broiler strains (Abror Acres, Hybro, Avian x Hubbard…). In addition, factors such as the rearing conditions, feed quality or triticale strains might also be the source of significant differences between the broiler strains. Proudfoot and Hulan (1988) suggested that damp litter conditions increased the negative impact of triticale on the broiler diet. Nevertheless, further investigations on the impact of triticale on specific broiler strains are

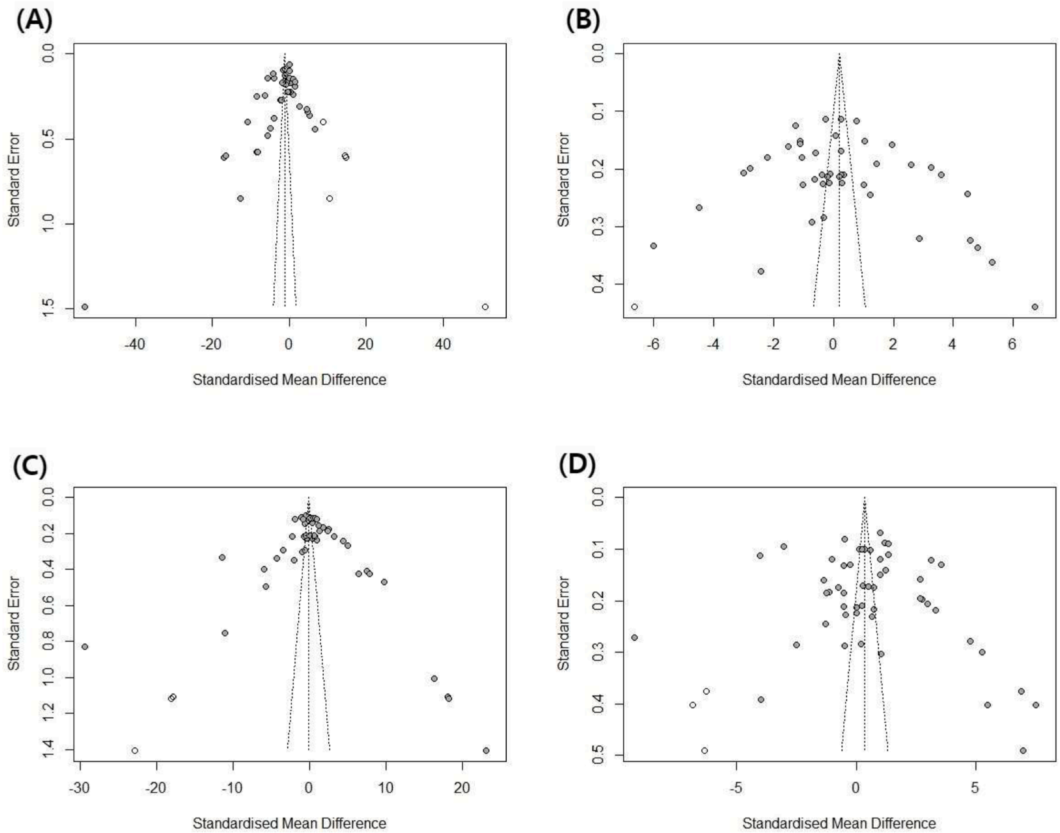

Fig. 9. Funnel plots to evaluate publication bias on broilers' growth parameters. (A): LBW; (B): BWG; (C): FI; (D): FCR.

Table 6
Egger's linear regression test for publication bias.

Items[a]	Bias	SE[b]	*t*-value[b]	df[b]	*p*-value
LBW	-9.5549	4.4459	-2.15	39	0.0379
BWG	5.8650	4.7451	1.24	42	0.2233
FI	3.7834	3.8133	0.99	51	0.3258
FCR	3.9153	3.9025	1.00	60	0.3198

[a] LBW: Live body weight; BWG: Body weight gain; FI: Feed intake; FCR: Feed conversion ratio.
[b] SE: Standard error; df: Degree of freedom; t-value: Relative difference in units of standard error.

Table 7
Trimmed effect size of triticale percentages on broilers' performance.

Items[a]	df[b]	Random effects model		Heterogeneity[b]		
		Effect size	*p*-value	Q(*p*-value)	I^2 (%)	τ^2
LBW	45	-1.2172	0.5146	13,471.94(0)	99.7	160.2738
BWG	44	0.2005	0.6159	4178.08(0)	98.9	7.1262
FI	55	-0.1291	0.9111	9126.68(0)	99.4	74.5432
FCR	64	0.3590	0.3311	9947.03(0)	99.4	8.8150

[a] LBW: Live body weight; BWG: Body weight gain; FI: Feed intake; FCR: Feed conversion ratio.
[b] I^2: Higgins statistic; Q: χ^2 statistic; τ^2: Heterogeneity variance of the true effect sizes; df: Degree of freedom.

recommended.

4.3. Meta-regression

The meta-regression model was conducted using the specific inclusion percentages as covariates to predict their effects on broilers' growth parameters in triticale inclusion intervals (T0-20 %, T21-50 %, T51-100 %) and broiler's strains (Ross, Cobb, Avian × Hubbard, Starbro, Unknown, Arbor Acres, Hybro) sub-group analyses. The results in the sub-group analysis of triticale inclusion intervals suggested that the regression models were not significant for BWG and FCR factors (Table 4). However, we noticed significant correlations in T0-20 % effects on LBW (Estimate = 0.5971, QM = 6.4781, $p < 0.05$) and FI (Estimate = 0.0583; QM = 4.6886; $p < 0.05$). These last results mean that the triticale percentages from 0 to 20 % tended to significantly increase the LBW and FI. The other triticale inclusion levels (T21-50 % and T51-100 %) had insignificant effects on LBW and FI (Table 4). Therefore, the meta-regression globally emphasized that T0-20 % had positive effects on LBW and FI (Fig. 7).

The outcomes in strains sub-group analysis (Table 5) revealed significant negative correlations between triticale percentages and Arbor Acres strain on LBW (Estimate = -0.1901, QM = 15.6357, $p < 0.05$) and between triticale percentages and the group of unknown broiler strains on BWG: Estimate = -0.0261, QM = 10.9139, $p < 0.05$ and FI: Estimate = -0.0285, QM = 16.5307, $p < 0.05$. These results mean that the different triticale percentages used in the studies of this meta-analysis significantly reduced the LBW in the Arbor Acres strain, and the BWG and FI in the group of unknown broilers strains (Fig. 8). However, further research would be necessary to fully understand the effect of triticale on broiler strains.

4.4. Analysis of heterogeneity and publication bias

Evident heterogeneities between studies ($I^2 > 75$ %) were observed for every growing factor (LBW, BWG, FI, and FCR), which might be associated with the various triticale varieties or inclusion percentages used in the studies of the meta-analysis. The triticale variety as a source of variation regarding the effect of triticale grains on broilers' performance could be evaluated in this study. However, the absence of some triticale strains' names in the included articles made it impossible to achieve.

Also, the quality of the studies used in this meta-analysis was assessed and a publication bias was found in the LBW factor (Egger's test $p < 0.05$). Publication bias could be defined as an error due to results published or not published depending on the characteristics or findings of the study. To clarify, publication bias appears when the published results do not represent all performed studies (Drucker et al., 2016), hence eventually changing the results of any meta-analysis. In our study, the publication bias found was corrected by the trim-and-fill procedure. Indeed, a trim-and-fill method is a convenient tool to identify and arrange publication bias. It consists of clearing the studies that induce the asymmetrical funnel plot so that the global effect estimates produced in the rest of the studies can be considered to be minimally influenced by publication bias (Ahn et al., 2022). Then, it involves adding the imputed missing studies in the funnel plot based on bias-adjusted overall estimates (Shi and Lin, 2019). The trimmed effect sizes showed that the triticale inclusion in the diet decreased LBW and FI but increased BWG and FCR. However, the effects induced were not significant, meaning that dietary triticale had no major positive or detrimental impact on broilers' growth parameters. These findings are similar to other results available in numerous articles (Johnson and Eason, 1988; Vieira et al., 1995).

We also observed that the heterogeneity remained high ($I^2 > 75$ %) for every factor after the execution of the trim and fill model, these results could be explained by the diverse broilers and triticale strains, environmental parameters (air movement, temperature, and humidity), or housing type used in the experiments included in our meta-analysis.

5. Conclusion

Finally, the results of our meta-analysis suggested that triticale inclusion in the broiler diet has similar effects to cereals such as wheat and corn on growth parameters. The meta-regression revealed positive effects of triticale inclusion up to 20 % on LBW and FI. Despite some risk of bias and publication bias observed in this study, it remains valuable to assess the global effect of triticale grains on broilers' growing parameters. Based on our findings, the incorporation of triticale from 0 to 20 % in broiler diets could be recommended for optimal results and a higher profit considering the low price of triticale. However, since the triticale effect on the broiler's performance seems to be related to the variety used in the experiment, we would suggest further investigation of the effect of different triticale varieties on broilers.

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CRediT authorship contribution statement

Junior Isaac Celestin Poaty Ditengou: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing. **Sangbuem Cho:** Conceptualization, Data curation, Methodology, Supervision, Validation, Writing – review & editing. **Sung-Il Ahn:** Data curation, Methodology, Supervision, Validation, Visualization, Writing – review & editing. **Byungho Chae:** Project administration, Resources. **Eunjeong Jeon:** Validation, Visualization. **Nag-Jin Choi:** Project administration, Resources, Supervision, Validation, Visualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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