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Distillers' grains for tropical Bos indicus beef cattle: a systematic review and meta-analysis of growth and carcass responses and the role of co-product type

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Abstract

Expansion of corn ethanol production in Brazil is increasing the supply of distillers' grains (DDG/DDGS), but response estimates come mostly from temperate *Bos taurus* cattle. This systematic review and meta-analysis quantified the effects of DDG/DDGS on intake, growth and carcass traits of tropical *Bos indicus* cattle and tested whether responses depend on co-product type. Web of Science, Scopus, PubMed and SciELO were searched following PRISMA 2020, and 15 controlled trials from Brazil and Cuba (nine feedlot and six protein-replacement trials) were included. Mean differences between DDG/DDGS arms and within-study controls were pooled by random effects, with cluster-robust variance, leave-one-group-out analysis, meta-regression on inclusion level and co-product class, and GRADE appraisal of certainty. DDG/DDGS increased hot carcass weight by 7.2 kg (95% confidence interval 4.7 to 9.7; seven studies; I^2 = 17%), an estimate that remained between 6.8 and 11.0 kg when any research group was removed. Average daily gain (+ 0.02 kg/d; −0.01 to 0.06; 14 studies) and final body weight were unchanged. Co-product type modified intake: conventional DDG/DDGS increased dry-matter intake by 0.28 kg/d (0.08 to 0.49), whereas fibre-plus-solubles fractions did not (P = 0.046 for the difference), and conventional co-products carried the carcass gain (+ 7.8 kg). In tropical *Bos indicus* cattle, DDG/DDGS can replace grain and protein sources without loss of growth and with a moderate-certainty gain in carcass weight, whereas fibre-separated fractions should be evaluated and priced on their own energy value.

Introduction

Corn ethanol has moved from a marginal activity to a structural part of Brazil's biofuel sector, and every litre distilled leaves behind distillers' grains (DDG/DDGS), a co-product rich in rumen-undegradable protein, fibre and, depending on oil extraction, fat. Dried forms are storable and economical to haul, and the product has spread quickly through tropical feedlots, where it displaces flint corn, citrus pulp and cottonseed, and through pasture supplements, where it replaces cottonseed meal and soybean meal (Alhadas et al. 2021; da Rosa e Silva et al. 2022; Virgínio Júnior et al. 2026).

The feeding value of DDG/DDGS is not a fixed quantity. Removal of starch during fermentation concentrates protein, fibre and fat roughly threefold relative to the parent grain, and the de-oiling now common in Brazilian plants lowers ether extract towards that of corn (Alhadas et al. 2021). Newer fractionation processes add further variation by separating high-protein products from fibre-plus-solubles streams, whose energy and protein contents differ markedly (Antunes et al. 2025; Ormond et al. 2025). Two compositional ceilings also constrain use: dietary sulfur should be held below about 0.46% and ether extract below roughly 110 g/kg (Torres et al. 2022). The same nominal inclusion can therefore deliver different amounts of energy and metabolizable protein depending on the co-product and on the ingredients it replaces.

Most of what is known about the animal response was learned in temperate, dent-corn, *Bos taurus* systems, where DDG/DDGS fed in place of grain has generally maintained or improved gain and feed

efficiency (Klopfenstein et al. 2008). The most complete quantitative synthesis pooled genetic types and feeding systems and predated most Brazilian flint-corn trials (Torres et al. 2022), and a recent narrative review covered temperate and tropical feedlots together without a quantitative synthesis for zebu cattle (Virgínio Júnior et al. 2026). Recommendations for zebu cattle in tropical diets are therefore still extrapolated from temperate taurine data. Whether those coefficients carry over to *Bos indicus* production, and whether the new fibre-rich fractions behave like conventional DDG/DDGS, are open questions with practical weight for the expanding corn-ethanol regions of central Brazil.

The present review therefore aimed to assemble the controlled trials of DDG/DDGS in tropical *Bos indicus* cattle, to estimate pooled effects and dose–responses for intake, growth, feed efficiency and carcass traits, to test whether responses differ between conventional DDG/DDGS and fibre-plus-solubles fractions, and to grade the certainty of the evidence. We hypothesized that, where DDG/DDGS substitutes for grain and protein sources, growth would be largely unchanged while carcass traits would respond, and that responses would be weaker for fibre-plus-solubles fractions.

Materials and methods

Protocol, eligibility and information sources

The review was conducted and reported under the PRISMA 2020 statement (checklist in Online Resource 6), and the protocol was registered on the Open Science Framework (OSF; https://osf.io/s35wf). Eligible reports were controlled experiments in growing or finishing tropical *Bos indicus* cattle (Nellore, zebu and *Bos indicus*-influenced crossbreds) that compared diets or supplements differing in DDG/DDGS (dried, wet or modified, conventional or fractionated, at any inclusion level or as a replacement for grain or protein sources) against a concurrent within-study control without DDG/DDGS, and reported intake, growth, feed efficiency or carcass traits with extractable means, a variance estimate and replication. Excluded were studies in *Bos taurus* or dairy cattle, small ruminants or suckling calves; metabolism or digestibility studies without performance outcomes (including Latin-square designs with cannulated animals); designs without a DDG-free control; and carry-over designs in which DDG/DDGS was fed in a previous phase. Peer-reviewed articles and theses with complete data were eligible for the main analysis; conference abstracts, which lack variance estimates, were reserved for sensitivity analysis. Departing from the registered protocol, one MSc dissertation with complete data (Benez 2024) was retained in the main analysis; its influence is shown in the leave-one-group-out analysis. Two further amendments to the registration are reported: the search was extended to four native databases on 19 October 2026, and co-product class was added as a moderator once fractionated co-products appeared among the eligible trials.

Web of Science Core Collection, Scopus, PubMed and SciELO were searched on 19 October 2026 for 2000–2026, with the string (“distillers grain*” OR “distillers dried grain*” OR “dried distillers*” OR “wet distillers*” OR “modified distillers*” OR DDGS OR DDG OR WDGS OR MDGS OR “ethanol co-product*” OR “ethanol by-product*” OR “high-protein distillers*” OR “fiber plus solubles”) AND (cattle OR bovine OR

beef OR steer* OR bull* OR heifer* OR Nellore OR Nelore OR zebu OR “Bos indicus” OR Brahman OR Guzerat OR Gyr OR crossbred*) AND (performance OR “average daily gain” OR carcass OR “feed efficiency” OR “feed intake” OR “dry matter intake” OR “hot carcass weight” OR dressing), adapted to each database and combined with a tropical filter (tropical OR Brazil* OR Nellore OR Nelore OR zebu OR “Bos indicus” OR Brahman OR Guzerat OR Gyr). SciELO was searched with an equivalent Portuguese–English string. Theses and the reference lists of included studies and reviews were also screened. Full search strings, dates, record counts and exported records are given in Online Resource 1.

Records were deduplicated and screened by title and abstract, and potentially eligible reports were assessed in full by one reviewer (A.W.P.F.). Eligibility decisions and all extracted values were checked by a second reviewer (G.B.N.) against the full texts and source tables, including column headers; disagreements were resolved by discussion. Companion reports of the same trial were linked and counted once.

Data extraction

Data were extracted at the level of treatment arms, one row per arm and outcome, with the control arm flagged once per study, which avoids the unit-of-analysis error that arises when the same control is entered repeatedly. Means, variance measures and replication were recorded with genotype, production system, design, co-product type, inclusion level and trial length. When only a pooled standard error was reported, the standard deviation was recovered as the standard error of the mean (SEM) times the square root of the experimental-unit count (pen, paddock or animal); for factorial designs, the SEM of the reported cell means was used. Arms receiving no DDG/DDGS and no conventional protein supplement (mineral-only arms in two pasture trials) and energy-only supplement arms were not contrasts of interest and were excluded. Co-products were classified as conventional (DDG, DDGS, low-fat or de-oiled DDG/DDGS, wet distillers grains), fibre-plus-solubles fractions (dry or wet fibre plus solubles, wet distillers bran plus solubles) or high-protein distillers grains. The final dataset held 15 studies and their arm-level records (Online Resource 3); screening decisions are listed in Online Resource 2.

Synthesis

For each outcome, the contrast was the mean difference (MD) between each DDG/DDGS arm and its within-study control, with sampling variance $SD_t^2/n_t + SD_c^2/n_c$, pooled by random effects (DerSimonian–Laird). Because several arms share one control and several research groups contributed more than one study, pooled estimates were re-estimated with cluster-robust variance (RVE; CR2 small-sample correction with Satterthwaite degrees of freedom), clustering contrasts by research group. RVE tests are unreliable when the degrees of freedom fall below about four (Tipton 2015), as occurred for most outcomes, so RVE intervals are reported as a conservative check and leave-one-group-out analysis was used as the main robustness test. As further checks of estimator choice and of the dependence created by shared controls, each outcome was refitted by restricted maximum likelihood with the Knapp–

Hartung adjustment, and by a multilevel model with research group, study and contrast as nested random effects and with the sampling covariance induced by shared controls specified explicitly. Dose–response was estimated by random-effects meta-regression of the MD on inclusion (per 10 percentage points of diet dry matter, DM), restricted to trials in which inclusion was expressed on a DM basis; in protein-replacement trials the dose is the proportion of protein meal replaced and was not combined with DM inclusion. Pre-specified moderators were design (feedlot vs. protein replacement) and co-product class (conventional vs. fibre-plus-solubles; the single high-protein arm was excluded from this test). Heterogeneity was summarized by I^2. Sensitivity analyses excluded crossbred cattle and added two reports not eligible for the main analysis: the conference abstract of Nardi et al. (2026), which reported means and replication but no variance, entered with pen-level standard deviations imputed over a plausible range (5–15 kg for carcass weight; 0.08–0.15 kg/d for daily gain), and the trial of Iraola et al. (2013), which compared DDGS supplementation against unsupplemented grazing. Analyses used R 4.3 with metafor and clubSandwich; code, extraction sheet and search records are openly available at Zenodo (Freitas and Balieiro Neto 2026) and as Online Resource 5. A generative AI assistant (Claude, Anthropic) was used to support literature searching and screening, data tabulation, and the writing of R and Python scripts for the analyses and figures; all screening decisions, extracted values, model outputs and plotted values were verified by the authors, who take full responsibility for the content.

Risk of bias and certainty of evidence

Each study was appraised with a SYRCLE/Cochrane-adapted instrument covering sequence generation, baseline balance, allocation concealment, blinding of outcome assessment, incomplete outcome data, selective reporting and appropriateness of the unit of analysis. Certainty of each pooled outcome was rated with GRADE, starting at high for controlled trials and downgrading for risk of bias, inconsistency, imprecision, indirectness and, where it could be judged, publication bias. GRADE ratings express confidence in each pooled estimate across the body of evidence rather than the methodological quality of individual studies alone.

Results

Study selection and characteristics

The searches returned 156 records (Web of Science 68, Scopus 38, PubMed 41, SciELO 9), of which 95 were unique (Fig. 1). After title and abstract screening, 32 reports were assessed in full; 18 were excluded, mostly because they were metabolism, digestibility or Latin-square studies, companion reports of an included trial, or lacked a DDG-free control or a concurrent DDG treatment. Fourteen studies from the databases and one dissertation were included (Table 1). Nine were feedlot or confinement trials: five inclusion gradients (Ferreira et al. 2020; Alhadas et al. 2021; Lima Junior et al. 2022; da Rosa e Silva et al. 2022; Benez 2024), two replacement comparisons (Rodríguez et al. 2013; Reis et al. 2020) and two co-product-type comparisons (Antunes et al. 2025; Ormond et al. 2025); six were protein-replacement

trials, mostly in pasture supplements (Araujo et al. 2021; Ferrari et al. 2021; Hoffmann et al. 2021a, b; de Faria et al. 2024, 2025). Thirteen studies used Nellore or other zebu cattle and two used *Bos indicus*-influenced crossbreds (F1 Angus × Nellore; Holstein × Zebu). Three studies tested fibre-plus-solubles fractions (Lima Junior et al. 2022; Antunes et al. 2025; Ormond et al. 2025). Hot carcass weight was reported by seven studies.

Table 1
Characteristics of the 15 included studies

Study	System	Genotype	Design	Co-product and level	Days	Outcomes
Alhadas et al. (2021)	Feedlot	Nellore	Inclusion gradient	Low-fat DDG, 0–45% DM	126	ADG, DMI, FBW, G:F
Antunes et al. (2025)	Feedlot	Nellore	Co-product type	HP-DDG 10%; DFS, WFS 30% DM	102	HCW, dressing, REA
Araujo et al. (2021)	Pasture	Nellore	Protein replacement	DDG, 0–100% of CSM	105	ADG, DMI
Benez (2024)	Feedlot	Nellore	Inclusion gradient	DDGS, 0–40% DM	100	ADG, DMI, FBW, HCW, dressing
da Rosa e Silva et al. (2022)	Feedlot	Nellore	Inclusion gradient	DDG, 0–30% DM	135	ADG, DMI, FBW, G:F, HCW, dressing
de Faria et al. (2024)	Pasture (dry season)	Nellore	Protein replacement	DDGS vs. SBM	Jul–Sep	ADG, FBW
de Faria et al. (2025)	Pasture (rainy season)	*Bos indicus*	Protein replacement (2 × 2)	DDGS vs. SBM	Oct–Jan	ADG, FBW, FE
Ferrari et al. (2021)	Pasture	Nellore	Protein replacement	DDG vs. SBM supplement	112	ADG, FBW
Ferreira et al. (2020)	Feedlot	F1 Angus × Nellore	Inclusion gradient	De-oiled WDG, 0–45% DM	129	ADG, DMI, FBW, G:F, HCW, REA
Hoffmann et al. (2021a)	Pasture	Nellore	Protein replacement	DDG, 0–100% of CSM	112	ADG
Hoffmann et al. (2021b)	Pasture and feedlot	Nellore	Protein replacement	DDG, 0–100% of CSM	117	ADG, FBW, HCW, carcass yield
Lima Junior et	Feedlot	Nellore	Inclusion gradient	WDBS, 0–45% DM	76	ADG, DMI, FBW, G:F,

DM, dry matter; CSM, cottonseed meal; SBM, soybean meal; HP-DDG, high-protein distillers grains; DFS/WFS, dry/wet fibre plus solubles; WDBS, wet distillers bran plus solubles; WDG, wet distillers grains; ADG, average daily gain; DMI, dry-matter intake; FBW, final body weight; G:F, gain:feed; FE, feed efficiency; HCW, hot carcass weight; REA, ribeye area; NR, not reported. Days include adaptation where reported

Study	System	Genotype	Design	Co-product and level	Days	Outcomes
al. (2022)						HCW, dressing
Ormond et al. (2025)	Feedlot (growing)	Nellore	Co-product type	DFS or DDGS, 30% DM	75	ADG, DMI, FBW
Reis et al. (2020)	Feedlot	Nellore	Replacement	Low-fat DDGS, 21% DM	84	ADG, DMI, FBW, G:F, HCW, REA
Rodríguez et al. (2013)	Confinement (Cuba)	Holstein × Zebu	Concentrate replacement	DDGS, ~ 34% DM	NR	ADG, DMI, FBW

DM, dry matter; CSM, cottonseed meal; SBM, soybean meal; HP-DDG, high-protein distillers grains; DFS/WFS, dry/wet fibre plus solubles; WDBS, wet distillers bran plus solubles; WDG, wet distillers grains; ADG, average daily gain; DMI, dry-matter intake; FBW, final body weight; G:F, gain:feed; FE, feed efficiency; HCW, hot carcass weight; REA, ribeye area; NR, not reported. Days include adaptation where reported

Pooled effects

Hot carcass weight increased by 7.2 kg (95% CI 4.7 to 9.7; $P < 0.001$; seven studies, 19 contrasts) with low heterogeneity ($I^2 = 17\%$; Table 2), equivalent to about 2.4% of the mean control carcass weight (295 kg; range 238 to 340 kg across studies). Ribeye area increased by 2.4 cm² (0.7 to 4.1; three studies), and dressing by 0.66 percentage points, although the latter rested on four studies with high heterogeneity ($I^2 = 76\%$). Growth did not change: average daily gain differed from the controls by + 0.023 kg/d (− 0.011 to 0.057; 14 studies) and final body weight by + 1.2 kg (− 2.9 to 5.4; $I^2 = 9\%$), and gain:feed was unaffected. Dry-matter intake tended to increase (+ 0.18 kg/d; −0.00 to 0.36; $P = 0.055$) with high heterogeneity ($I^2 = 78\%$). The heterogeneity in daily gain ($I^2 = 58\%$) was attributable mainly to one trial with a large positive response (Reis et al. 2020); without it the estimate was + 0.005 kg/d ($I^2 = 16\%$). Conservative cluster-robust intervals were wider for all outcomes and rested on fewer than four degrees of freedom for most.

Table 2
Pooled mean differences (DDG/DDGS minus control) in tropical *Bos indicus* cattle

Outcome	Studies (contrasts)	RE mean difference (95% CI)	RVE 95% CI; df	I^2 (%)	Slope per 10% DM (95% CI)	GRADE
HCW (kg)	7 (19)	+ 7.2 (4.7, 9.7)	(− 8.4, 22.7); 1.2	17	+ 1.6 (− 0.5, 3.6)	Moderate
REA (cm^2)	3 (7)	+ 2.4 (0.7, 4.1)	(− 0.2, 5.0); 1.5	0	+ 0.2 (− 1.6, 1.9)	Low
Dressing (pp)	4 (13)	+ 0.66 (0.31, 1.00)	(− 1.27, 2.58); 1.0	76	+ 0.20 (− 0.04, 0.44)	Low
ADG (kg/d)	14 (29)	+ 0.023 (− 0.011, 0.057)	(− 0.050, 0.097); 3.6	58	−0.028 (− 0.072, 0.016)	Moderate
FBW (kg)	12 (25)	+ 1.2 (− 2.9, 5.4)	(− 7.0, 9.5); 4.4	9	−4.0 (− 8.6, 0.6)	Moderate
DMI (kg/d)	9 (22)	+ 0.18 (− 0.00, 0.36)	(− 0.48, 0.83); 3.0	78	−0.11 (− 0.29, 0.06)	Low
Gain:feed	5 (13)	+ 0.003 (− 0.004, 0.010)	(− 0.012, 0.017); 3.3	51	−0.001 (− 0.008, 0.005)	Low

RE, random effects (DerSimonian–Laird); RVE, cluster-robust variance (CR2, clusters = research groups); df < 4 indicates unreliable robust tests (Tipton 2015). Slope estimated in trials with inclusion on a dry-matter basis. HCW, hot carcass weight; REA, ribeye area; pp, percentage points; ADG, average daily gain; FBW, final body weight; DMI, dry-matter intake

Dose–response, design and co-product type

Across trials with inclusion on a DM basis, the estimated slope for carcass weight was + 1.6 kg per 10 percentage points of inclusion and was not significant (− 0.5 to 3.6; P = 0.14; Fig. 2), and daily gain showed no trend (− 0.028 kg/d per 10 points; −0.072 to 0.016; Fig. 3). The growth null held in both designs: daily gain differed from control by + 0.036 kg/d (− 0.010 to 0.083) in feedlot trials and by + 0.003 kg/d (− 0.031 to 0.036) in protein-replacement trials (P = 0.37 for the difference).

Co-product type modified the intake response (Fig. 4). Conventional DDG/DDGS increased dry-matter intake by 0.28 kg/d (0.08 to 0.49; eight studies), whereas fibre-plus-solubles fractions did not (− 0.27 kg/d; −0.98 to 0.44; two studies), a difference of − 0.53 kg/d (− 1.04 to − 0.01; P = 0.046). Carcass weight followed the same direction, increasing by 7.8 kg (4.7 to 11.0) with conventional co-products and by 3.1 kg (− 7.1 to 13.2) with fibre-plus-solubles fractions, but the difference was not significant (P = 0.41) because only two studies with fibre-plus-solubles reported carcass data. Daily gain did not differ between classes (P = 0.46).

Sensitivity analyses

Removing one research group at a time left the carcass-weight effect between 6.8 and 11.0 kg, every interval excluding zero; removing the largest group, which contributed three studies including the dissertation, raised it to 11.0 kg. Alternative estimators gave the same conclusion: restricted maximum likelihood with the Knapp–Hartung adjustment gave + 7.3 kg (4.5 to 10.1), the multilevel model accounting for shared controls gave + 8.7 kg (2.9 to 14.5; P = 0.005), and the 95% prediction interval for carcass weight (0.6 to 13.9 kg) lay entirely above zero. In da Rosa e Silva et al. (2022), reported carcass weight equalled final body weight multiplied by the same dressing proportion (0.534) in every treatment, so its carcass contrasts reproduce final-weight differences; removing that group gave 6.9 kg (4.4 to 9.4). Excluding crossbred cattle did not change the estimates (carcass weight + 7.2 kg; daily gain + 0.021 kg/d). Adding the conference abstract of Nardi et al. (2026), in which 236 Nellore bulls (18 pens per treatment) fed fibre-separated DDGS at 20 or 40% of DM in place of flint corn had linearly lower intake, gain and carcass weight (− 14.7 kg at 40%), reduced the pooled carcass effect to 4.7–5.1 kg, with lower confidence limits between 0.6 and 1.3 kg and I^2 of 57–88%; point estimates remained positive under every imputed variance, so the effect weakened but did not reverse, and daily gain remained null (+ 0.009 kg/d). In the trial with an unsupplemented grazing control (Iraola et al. 2013), DDGS supplementation at 1.5 and 2.5 kg/d increased daily gain from 0.32 to 0.36 and 0.42 kg/d, a supplementation response not comparable with the substitution contrasts pooled here.

Risk of bias and certainty

Sequence generation, baseline balance, completeness of data and selective reporting were generally at low risk, whereas allocation concealment and blinding of outcome assessment were seldom described and were judged unclear, as is common in livestock feeding trials. Carcass data were collected at commercial abattoirs, and the unit of analysis (pen, paddock or animal) was respected. Under GRADE, certainty was moderate for hot carcass weight, average daily gain and final body weight, each downgraded once for unclear allocation concealment and blinding; the carcass effect was consistent across studies and research groups, and the heterogeneity in daily gain was explained by a single trial. Certainty was low for intake (inconsistency, partly explained by co-product type), dressing (inconsistency and few studies), and gain:feed and ribeye area (imprecision). The domain-level appraisal and GRADE table are given in Online Resource 4.

Discussion

Three results carry this synthesis. First, in tropical *Bos indicus* cattle DDG/DDGS replaced grain and protein sources without changing daily gain or final body weight, in feedlot and pasture designs alike. Second, carcass weight increased by about 7 kg, an effect of moderate certainty that was consistent across seven studies and robust to the removal of any research group, to alternative estimators, to the exclusion of crossbred cattle and to the exclusion of a trial whose carcass data appear derived from live weight. Third, the response depended on co-product type: conventional DDG/DDGS increased intake and

carried the carcass gain, whereas fibre-plus-solubles fractions did not increase intake and produced a smaller, non-significant carcass response.

The carcass-without-growth pattern differs from temperate systems, where DDG/DDGS fed in place of grain has tended to maintain or improve gain and efficiency (Klopfenstein et al. 2008). Dietary context is the most economical explanation. In most tropical trials the co-product replaced flint corn, citrus pulp, cottonseed or protein meals in diets formulated to similar energy and protein (Alhadas et al. 2021; da Rosa e Silva et al. 2022; de Faria et al. 2025), so it substituted for, rather than added to, the energy supply, and faster live-weight gain is not expected. The additional undegradable protein and nutrient density of DDG/DDGS may instead be expressed at the carcass, consistent with the greater metabolizable-protein supply measured as inclusion rose (Alhadas et al. 2021) and with the increases in ribeye area and dressing found here. Because most trials were designed as substitution rather than supplementation comparisons, greater carcass weight without a detectable change in live-weight gain is more plausibly explained by differences in nutrient partitioning and in the carcass proportion of live weight than by a greater energy supply, although the modest intake increase with conventional co-products means that some contribution of energy intake cannot be excluded. Because carcass and live-weight outcomes come from partly different studies, the implied gain in dressing should be read cautiously.

The co-product effect is the most practically relevant result. Fractionation produces a high-protein stream and a fibre-plus-solubles stream whose energy density is lower than that of conventional DDGS, and in the three trials that tested such fractions intake did not rise, gain was unchanged and carcass gains were small or absent (Lima Junior et al. 2022; Antunes et al. 2025; Ormond et al. 2025). A large recent trial with fibre-separated DDGS replacing flint corn at up to 40% of DM went further, reporting lower intake, gain and carcass weight (Nardi et al. 2026); added to the analysis under plausible variance assumptions, it reduced but did not reverse the pooled carcass effect. Together with the de-oiling of modern DDG (Alhadas et al. 2021) and the sulfur and ether-extract ceilings (Torres et al. 2022), this indicates that the benefit depends on the energy and protein density of the co-product and of the diet it enters. The present synthesis therefore refines the genotype-averaged estimates of Torres et al. (2022) and the qualitative account of Virgínio Júnior et al. (2026) for zebu cattle: carcass gains are expected with conventional and de-oiled DDG/DDGS at moderate inclusion in energy-matched diets but should not be extrapolated to fibre-rich fractions or to high inclusion in energy-diluted diets.

For the tropical corn-ethanol frontier the message is practical. Conventional DDG/DDGS can replace grain and protein sources in feedlot diets, and protein meals in pasture supplements, without penalizing growth and with a likely gain in carcass weight, which supports its use where its price relative to corn and protein meals is favourable. Fibre-plus-solubles products should be priced and formulated on their own energy value rather than as equivalents of conventional DDGS. Confirmatory trials should report carcass outcomes with variance estimates, characterize the co-product (fractionation, oil and sulfur content) and compare fractions directly at matched dietary energy.

Limitations

The evidence base comprises 15 studies, and carcass outcomes rest on seven, so the dressing, ribeye-area and gain:feed estimates and the co-product contrast for carcass weight are best treated as hypothesis-generating. With few clusters, cluster-robust tests had fewer than four degrees of freedom for most outcomes, and robustness was judged from leave-one-group-out analysis and alternative estimators. The width of the cluster-robust intervals therefore reflects mainly the small number of independent research groups rather than inconsistency among effects: for carcass weight, heterogeneity was low (I^2 = 17%), every leave-one-group-out estimate excluded zero and the multilevel estimate was significant. Screening and extraction were performed by one reviewer and checked, rather than duplicated independently, by a second reviewer. Reporting was uneven: allocation concealment and blinding were rarely described, one trial did not give exact per-treatment replication, and in another carcass weights appear to have been derived from final body weight. Inclusion was expressed on a DM basis in feedlot trials but as the proportion of protein meal replaced in protein-replacement trials, so the dose–response applies only to the former. Two studies used crossbred cattle, although their exclusion did not change the results. Finally, with fewer than ten studies for most outcomes, small-study and publication-bias tests were uninformative.

Conclusions

In tropical *Bos indicus* beef cattle, DDG/DDGS replaced grain and protein sources without changing growth performance and increased hot carcass weight by about 7 kg, with moderate certainty. The response was driven by conventional DDG/DDGS, which also increased intake, whereas fibre-plus-solubles fractions did not increase intake and gave smaller, uncertain carcass gains. DDG/DDGS is a sound substitute feedstuff for tropical diets as co-product supply grows, provided that co-product type and inclusion preserve dietary energy; the response to fractionated co-products is the priority for confirmatory research.

Declarations

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Competing interests: 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.

Statement of animal rights / Ethics approval: This study is a systematic review and meta-analysis of previously published data. No animals were used by the authors, and ethics committee approval was not required.

Consent to participate and consent to publish: Not applicable.

Data availability: The extraction dataset, analysis code (R; metafor and clubSandwich), search strings and exported records are openly available at Zenodo (Freitas and Balieiro Neto 2026; https://doi.org/10.5281/zenodo.23481688).

Author contributions: A.W.P. Freitas: conceptualization, methodology, data curation, formal analysis, software, investigation, visualization, writing – original draft, writing – review and editing. G. Balieiro Neto: validation, data curation (verification of eligibility decisions and extracted data), writing – review and editing.

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