SUPPLEMENTARY MATERIAL

Sunflower Meal in Broiler Diets: A Dose–Response Meta-Analysis of Inclusion Rate, Residual Fibre, and Bird Age

Extracted data, calculation methods and sensitivity analyses

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S1. Scope and source provenance

This supplement documents the treatment means, uncertainty assumptions and numerical results underlying the exploratory meta-analysis. Literature eligibility was restricted to publications before 1 May 2022. Retrieval was targeted, not an exhaustive systematic search, and the common days 22–42 window and analytical choices were selected during synthesis rather than prospectively registered.

The core dataset contains three independent experiments, 15 dietary treatment arms, 80 pens and 2,176 initially allocated birds. Twelve nonzero-dose contrasts are available in each phase. The same cohorts contribute starter and grower observations, so 30 phase-specific arm records do not represent 30 independent arms. The pen is the experimental unit for group-fed performance outcomes.

Table S1. Core study sources and replication.

Study	Source tables	Pens/ arm	Birds/ pen	DOI
Furlan 2001	Tables 1-3; journal pages 160-162	4	50	10.1590/S1516-35982001000100023
Tavernari 2009	Table 3, journal page 1748; grower composition Table 2	8	20	10.1590/S1516-35982009000900015
Nassiri Moghaddam 2012	Table 6, journal page 299; diet fibre Tables 2-3	4	11	10.3382/japr.2011-00396

Source locations identify the original published tables. Replication counts are not bird-level sample sizes for variance estimation.

Table S2. Meal composition as reported.

Study	Crude protein (%)	Crude fibre (%)	Dry matter (%)	Reported fibre basis
Furlan 2001	34.07	21.73	Not reported	not explicit
Tavernari 2009	28.09	22.37	89.95	reported alongside dry matter; no conversion applied
Nassiri Moghaddam 2012	30	21.2	Not reported	as-fed

No dry-matter conversion was imposed. A missing entry is not a zero. The fibre range is 21.20–22.37% on the reported bases, which are not fully harmonised.

S2. Extracted treatment means

BWG denotes body-weight gain in grams per bird over the specified phase; FI denotes feed intake in grams per bird; FCR denotes the reported feed-to-gain ratio. Actual meal inclusion is percentage of the complete diet, not percentage replacement of soybean protein. Complete-diet crude fibre is reported when recovered. The phase-specific means remain as published; no pen-level observations were available.

Table S3. Furlan 2001: days 1–21.

Meal inclusion (%)	Diet crude fibre (%)	BWG (g)	FI (g)	FCR
0	3.44	757	1126	1.488
5.05	4.17	710	1097	1.547
10.09	4.9	713	1081	1.515
15.14	5.63	722	1071	1.482
20.18	6.36	727	1126	1.549
25.23	7.09	720	1116	1.551

Each treatment arm contained 4 pens with 50 birds initially allocated per pen.

Table S4. Furlan 2001: days 22–42.

Meal inclusion (%)	Diet crude fibre (%)	BWG (g)	FI (g)	FCR
0	3.15	1655	3129	1.89
4.23	3.76	1584	3020	1.907
8.46	4.37	1636	3072	1.878
12.69	4.98	1627	3112	1.913
16.91	5.6	1612	3104	1.926
21.15	6.21	1574	3029	1.925

Each treatment arm contained 4 pens with 50 birds initially allocated per pen.

Table S5. Tavernari 2009: days 1–21.

Meal inclusion (%)	Diet crude fibre (%)	BWG (g)	FI (g)	FCR
0	Not reported	852	1185	1.392
5	Not reported	858	1175	1.369
10	Not reported	861	1162	1.349
15	Not reported	871	1158	1.331
20	Not reported	850	1141	1.344

Each treatment arm contained 8 pens with 20 birds initially allocated per pen.

Table S6. Tavernari 2009: days 22–42.

Meal inclusion (%)	Diet crude fibre (%)	BWG (g)	FI (g)	FCR
0	2.74	1799	3192	1.775
5	3.67	1818	3181	1.75
10	4.6	1831	3161	1.727
15	5.56	1830	3194	1.746
20	6.94	1825	3174	1.74

Each treatment arm contained 8 pens with 20 birds initially allocated per pen.

Table S7. Nassiri Moghaddam 2012: days 1–21.

Meal inclusion (%)	Diet crude fibre (%)	BWG (g)	FI (g)	FCR
0	2.69	465.7	879.1	1.88
7	4.05	513.5	943.8	1.83
14	5.45	528.2	955.7	1.81
21	6.85	507.3	908.3	1.79

Each treatment arm contained 4 pens with 11 birds initially allocated per pen. Published cumulative means do not consistently reconcile with phase sums; the reported phase-specific values are retained without correction.

Table S8. Nassiri Moghaddam 2012: days 22–42.

Meal inclusion (%)	Diet crude fibre (%)	BWG (g)	FI (g)	FCR
0	2.61	1180.1	2807.5	2.37
7	3.96	1282.7	2938.3	2.29
14	5.38	1382.4	3011.1	2.18
21	6.78	1275.7	2799.5	2.19

Each treatment arm contained 4 pens with 11 birds initially allocated per pen. Published cumulative means do not consistently reconcile with phase sums; the reported phase-specific values are retained without correction.

S3. Dispersion and covariance assumptions

Furlan et al. (2001) and Tavernari et al. (2009) reported coefficients of variation. Conditional on interpreting each CV as 100 times the residual standard deviation divided by the grand treatment mean, residual SD = CV × arithmetic mean of treatment means / 100, and treatment-mean SE = residual SD / square root of pens per arm. These reconstructed quantities are not observed treatment-arm standard deviations. Equal replication makes the unweighted grand treatment mean appropriate under this assumption. Nassiri Moghaddam et al. (2012) reported one SEM for each phase and outcome; it is treated as the standard error of a treatment mean.

Table S9. Reported dispersion and treatment-mean SE used in the calculations.

Study	Days	Outcome	CV (%)	Reported SEM	SE used
Furlan 2001	22–42	BWG	2.59	—	20.909933
Furlan 2001	22–42	FI	1.98	—	30.468900
Furlan 2001	22–42	FCR	1.59	—	0.015157
Tavernari 2009	22–42	BWG	3.277	—	21.093371
Tavernari 2009	22–42	FI	2.935	—	33.002349
Tavernari 2009	22–42	FCR	2.673	—	0.016516
Nassiri Moghaddam 2012	22–42	BWG	—	26.81	26.810000
Nassiri Moghaddam 2012	22–42	FI	—	48.52	48.520000
Nassiri Moghaddam 2012	22–42	FCR	—	0.044	0.044000
Furlan 2001	1–21	BWG	2.51	—	9.096658
Furlan 2001	1–21	FI	3.3	—	18.196750
Furlan 2001	1–21	FCR	2.71	—	0.020623
Tavernari 2009	1–21	BWG	3.307	—	10.036422
Tavernari 2009	1–21	FI	3.338	—	13.739437
Tavernari 2009	1–21	FCR	1.999	—	0.009591
Nassiri Moghaddam 2012	1–21	BWG	—	9.17	9.170000
Nassiri Moghaddam 2012	1–21	FI	—	27.87	27.870000
Nassiri Moghaddam 2012	1–21	FCR	—	0.051	0.051000

BWG and FI SEs are in grams; FCR SEs are on the feed-to-gain ratio scale. Dashes denote a statistic not supplied in that form. CV-derived SEs are conditional reconstructions; the SEM rows retain reported values.

For nonzero arm i, $y_i = \ln(m_i/m_0)$, where m_i and m_0 are the treatment and control means. Let s_i and s_0 denote their mean SEs. The diagonal sampling variance is $V_{ii} = s_i^2/m_i^2 + s_0^2/m_0^2$. For two different nonzero arms i and j sharing the same control, $V_{ij} = s_0^2/m_0^2$. Treatment arms are assumed independent before accounting for their shared control. The covariance matrix is computed separately for every study, phase and outcome. No covariance between starter and grower outcomes is invented.

S4. Dose-slope estimation and pooling

Within each study, x_i is the actual inclusion percentage divided by 10, so one unit represents 10 percentage points of the complete diet. The generalised least-squares projection passes through the zero-dose origin: $\text{beta} = (x'V^{-1}x)^{-1}x'V^{-1}y$, with variance $v = (x'V^{-1}x)^{-1}$. The descriptive lack-of-fit statistic is $(y - \text{beta } x)'V^{-1}(y - \text{beta } x)$, with the number of nonzero doses minus one degrees of freedom. Each study contributes one slope per outcome and phase. The transformed percentage change is $100[\exp(\text{beta}) - 1]$; it is a fitted linear projection, not necessarily an observed contrast at exactly 10% inclusion or a constant biological response across doses.

For each outcome and phase, the between-study variance tau^2 is estimated by restricted maximum likelihood. With $w_s = 1/(v_s + \text{tau}^2)$, the pooled log-scale slope is the weighted mean of study slopes. The residual scale is $q = \Sigma w_s(\text{beta}_s - \text{pooled beta})^2/(k - 1)$, and the modified Knapp–Hartung standard error is the square root of $\max(1,q)/\Sigma w_s$. Confidence limits use a Student t quantile with $k - 1$ degrees of freedom before exponentiation. The primary analyses have $k = 3$ and two degrees of freedom. Leave-one-out analyses have $k = 2$ and one degree of freedom.

For reproducibility, the REML objective minimised over nonnegative $t = \text{tau}^2$ is $\Sigma\ln(v_s + t) + \ln[\Sigma 1/(v_s + t)] + \Sigma w_s(\text{beta}_s - \text{pooled beta})^2$. The numerical search uses a golden-section minimisation over [0, U], where U is the maximum of 100 times the population variance of study slopes, 100 times the largest study sampling variance, and 0.01. After 180 iterations, the objective at the candidate is compared with the objective at zero, retaining zero if it is no larger. The t quantiles used are 4.302652729696 for two degrees of freedom and 12.706204736432 for one. Fixed-effect Cochran Q supplies $I^2 = \max[0, (Q - (k - 1))/Q] \times 100$; I^2 is set to zero if Q is zero.

Table S10. Within-study dose projections.

Days	Outcome	Study	Log slope	Slope SE	Change (%)	Normal 95% CI (%)	Lack-of-fit Q (df)
22–42	BWG	Furlan 2001	-0.013982	0.007337	-1.3885	-2.7964 to 0.0399	7.3929 (4)
22–42	BWG	Tavernari 2009	0.007004	0.007353	0.7029	-0.7379 to 2.1647	0.6314 (3)
22–42	BWG	Nassiri Moghaddam 2012	0.043144	0.013849	4.4088	1.6129 to 7.2816	18.6569 (2)
22–42	FI	Furlan 2001	-0.004661	0.005600	-0.4650	-1.5516 to 0.6335	10.2860 (4)
22–42	FI	Tavernari 2009	-0.001443	0.006556	-0.1442	-1.4190 to 1.1471	0.6274 (3)
22–42	FI	Nassiri Moghaddam 2012	0.002972	0.010988	0.2976	-1.8393 to 2.4811	13.5840 (2)
22–42	FCR	Furlan 2001	0.009450	0.004487	0.9494	0.0656 to 1.8411	3.5827 (4)
22–42	FCR	Tavernari 2009	-0.008526	0.005950	-0.8490	-1.9985 to 0.3141	2.5201 (3)
22–42	FCR	Nassiri Moghaddam 2012	-0.041271	0.012370	-4.0431	-6.3415 to -1.6882	1.5282 (2)
1–21	BWG	Furlan 2001	-0.010472	0.005881	-1.0417	-2.1757 to 0.1055	14.5711 (4)
1–21	BWG	Tavernari 2009	0.002209	0.007435	0.2212	-1.2287 to 1.6924	2.6766 (3)
1–21	BWG	Nassiri Moghaddam 2012	0.038322	0.011968	3.9066	1.4976 to 6.3728	14.3030 (2)
1–21	FI	Furlan 2001	0.001362	0.007716	0.1363	-1.3667 to 1.6621	8.2863 (4)
1–21	FI	Tavernari 2009	-0.018023	0.007469	-1.7862	-3.2134 to -0.3380	0.1528 (3)
1–21	FI	Nassiri Moghaddam 2012	0.015041	0.019799	1.5155	-2.3484 to 5.5323	4.0539 (2)
1–21	FCR	Furlan 2001	0.010656	0.006402	1.0713	-0.1889 to 2.3475	8.9074 (4)
1–21	FCR	Tavernari 2009	-0.019788	0.004447	-1.9593	-2.8101 to -1.1011	5.1434 (3)
1–21	FCR	Nassiri Moghaddam 2012	-0.022758	0.017777	-2.2501	-5.5973 to 1.2157	0.0984 (2)

All effects are per 10 percentage points of meal inclusion. Study confidence limits use a normal quantile of 1.95996398454 and differ from the modified Knapp–Hartung intervals used for pooling. Lack-of-fit statistics are descriptive; no p-values are asserted.

Table S11. Pooled dose projections and heterogeneity.

Days	Outcome	Change (%)	95% CI (%)	Tau²	Q	I² (%)	q
22–42	BWG	1.0351	-5.8022 to 8.3686	0.00066728	14.0315	85.7464	1.0442
22–42	FI	-0.2481	-1.9377 to 1.4706	0.00000000	0.4229	0.0000	0.2114
22–42	FCR	-1.1498	-7.1126 to 5.1958	0.00053522	17.6004	88.6366	1.0468
1–21	BWG	0.8478	-5.1590 to 7.2350	0.00051112	13.5117	85.1980	1.0443
1–21	FI	-0.4905	-4.1838 to 3.3451	0.00012410	4.5921	56.4472	0.9707
1–21	FCR	-0.8757	-5.6246 to 4.1122	0.00030011	15.7586	87.3085	0.9017

Three studies contribute to each row. Tau² is on the log-slope scale; q is the Knapp–Hartung residual scale before applying the lower bound of one. Starter and grower rows are statistically dependent and are not a test of age interaction.

Table S12. Random-effects study weights (%).

Days	Outcome	Furlan 2001	Tavernari 2009	Nassiri Moghaddam 2012
22–42	BWG	35.2224	35.2113	29.5662
22–42	FI	50.2641	36.6798	13.0561
22–42	FCR	35.9691	35.0066	29.0243
1–21	BWG	35.7474	34.4409	29.8116
1–21	FI	42.0749	42.9541	14.9710
1–21	FCR	38.1692	40.7001	21.1307

Weights are computed as the normalised inverse of study-slope variance plus estimated between-study variance. Rounding may prevent a row from summing to exactly 100%.

S5. Sensitivity analyses

Leave-one-out calculations omit each study in turn from the days 22–42 analysis. With only two retained studies, their t-based intervals are especially imprecise. Omission of Nassiri Moghaddam et al. (2012) also addresses sensitivity to the report with inconsistent cumulative and phase totals, although it cannot diagnose which published values are correct. No missing values or corrections are imputed.

Table S13. Leave-one-out pooled results for days 22–42.

Outcome	Study omitted	Change (%)	95% CI (%)	Tau²	I² (%)
BWG	Furlan 2001	2.3439	-18.5474 to 28.5934	0.00053010	81.1758
BWG	Tavernari 2009	1.3463	-29.4767 to 45.6409	0.00150886	92.4732
BWG	Nassiri Moghaddam 2012	-0.3488	-12.7875 to 13.8639	0.00016626	75.5009
FI	Furlan 2001	-0.0284	-6.9299 to 7.3849	0.00000000	0.0000
FI	Tavernari 2009	-0.3083	-6.4323 to 6.2166	0.00000000	0.0000
FI	Nassiri Moghaddam 2012	-0.3298	-5.5790 to 5.2112	0.00000000	0.0000
FCR	Furlan 2001	-2.2838	-20.5371 to 20.1625	0.00044191	82.4279
FCR	Tavernari 2009	-1.4495	-28.5665 to 35.9616	0.00119972	93.2696
FCR	Nassiri Moghaddam 2012	0.0887	-10.7016 to 12.1828	0.00013379	82.8132

Each row includes two independent studies and uses one degree of freedom. Percentage changes and limits are transformed from the log scale. These analyses describe sensitivity; they do not supply stable alternative feeding recommendations.

Global variance sensitivities multiply all treatment-mean sampling variances by 0.5 or 2 before slope estimation and pooling, including those from the study with reported SEM. Consequently, they assess sensitivity to overall sampling precision and are not a specific uncertainty model for CV reconstruction. All original treatment means and dose values remain unchanged.

Table S14. Global sampling-variance sensitivity for days 22–42.

Outcome	Variance multiplier	Change (%)	95% CI (%)	Tau²	I² (%)
BWG	0.5	1.1251	-5.8051 to 8.5652	0.00075115	92.8732
BWG	1 (primary)	1.0351	-5.8022 to 8.3686	0.00066728	85.7464
BWG	2	0.8482	-5.7598 to 7.9196	0.00050048	71.4928
FI	0.5	-0.2481	-1.4458 to 0.9641	0.00000000	0.0000
FI	1 (primary)	-0.2481	-1.9377 to 1.4706	0.00000000	0.0000
FI	2	-0.2481	-2.6291 to 2.1911	0.00000000	0.0000
FCR	0.5	-1.2444	-7.2854 to 5.1903	0.00059803	94.3183
FCR	1 (primary)	-1.1498	-7.1126 to 5.1958	0.00053522	88.6366
FCR	2	-0.9519	-6.7139 to 5.1660	0.00041301	77.2733

All three studies contribute to every row; intervals use two degrees of freedom. Multipliers operate on variances, not standard errors.

S6. Limits of interpretation and evidence applicability

Only three independent experiments were available for the common phase. The analysis does not establish equivalence, an optimal inclusion rate or a universal safe maximum. Nonlinear within-study responses mean that a pooled linear slope can obscure practically important differences between individual doses. The narrow range of reported meal crude fibre, differences in moisture basis and concurrent changes in diet formulation preclude an independently identified fibre effect. Within a meal batch, sunflower-derived fibre is proportional to meal inclusion. Starter results describe the same experimental cohorts and cannot be treated as independent evidence of age modification.

Source-level limitations include targeted retrieval; missing full treatment tables for potentially relevant studies; incomplete uncertainty conventions in some reports; possible overlap among reports; and changing exposure programmes. Excluding inadequately documented evidence can induce selection bias. The table below records reasons for keeping selected eligible reports outside the core model; it is not a complete screening flow or a numerical quality ranking.

Table S15. Selected eligible evidence outside the core dose model.

Report	Relevant contribution	Reason for separate treatment
Pinheiro et al. (2002)	Introduction at different ages	Cumulative outcomes and distinct exposure histories; late-phase variance cannot be recovered by subtracting SEMs.
Senkoylu & Dale (2006)	High-oil product; feed form	Mechanically extracted high-oil product; reported ± values do not identify SD versus SEM.
Raza et al. (2009)	Meal, fibre and enzyme formulations	Only whole-period performance recovered; dose and dietary fibre co-vary; numerical reporting questions remain.
L. F. Araújo et al. (2011)	Amino-acid formulation at 0/15%	Only one nonzero dose; FCR uncertainty absent and some composition entries need clarification.
Kalmendal et al. (2011)	High-fibre sunflower cake	Different product class and age window; verified performance table not recovered for pooling.
W. A. G. de Araújo et al. (2014)	Four meal doses with formulation treatments	Days 21–42; printed cells conflict with associated regression descriptions; possible overlapping report.
Horvatovic et al. (2015)	Enzymes, viscosity and staged doses	Dose changes between phases; marginal means and uncertainty convention require further clarification.
Mbukwane et al. (2022)	Enzymes and phased feeding	Eligible January publication; cumulative outcomes accompany a changing high-inclusion programme.
Gerzilov & Petrov (2022)	High-protein meal programmes	Eligible February publication; independent pen replication unestablished, FCR uncertainty absent, nonzero-meal reference.

This is an evidence-applicability table, not a complete screening flow diagram or a numerical quality ranking. A reason for exclusion from this model is not a judgement that the study has no scientific value.

Full treatment tables were not recovered for Musharaf (1991), DOI 10.1016/0377-8401(91)90051-S, or Rama Rao et al. (2006), DOI 10.1080/00071660600963511. Abstract summaries were not used to reconstruct unreported treatment means, uncertainty or replication. Further source recovery may change the synthesis and should be handled as an explicit evidence update.

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