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SUPPLEMENTARY MATERIALS

immediate

Supplementary materials, including Appendix A (classification of all 35 included studies), Appendix B (detailed meta-analytic procedures, forest plots, funnel plots, and meta-regression output), and Appendix B.5 (power analysis details), are available as Supplementary Files.

Appendix A

Appendix B

B. Supplementary Meta-Analysis: Detailed Quantitative Results

B.1 Data Extraction Protocol

All 35 included studies were re-analyzed to extract point estimates (means) for each parameter-response pair, variance measures (SD, SE, or CI where reported), sample sizes per experimental condition, and framework type (RSM, Taguchi, hybrid, or factorial). Where studies reported only F-ratios or p-values without descriptive statistics, effect sizes were back-calculated using standard meta-analytic formulae [1].

B2. Forest Plots (Parameter-wise)

The forest plot comparing threshing efficiency across the (RSM) and Taguchi optimization frameworks (Figure B1) revealed distinct performance profiles for each methodological approach. Individual study results are represented using square markers (blue for RSM, orange for Taguchi) with trailing 95% confidence interval arms. Subgroup pooled estimates were displayed as meta-analytic diamonds, with the horizontal width representing the combined confidence intervals. The complete dataset matrix, including the study names and numeric bounds, was side-aligned for validation.

Comparative Meta-Analysis: Threshing Efficiency by Framework

RSM Subgroup (k = 5) pooled estimate: 94.2% (95% CI [92.8%, 95.6%]). Studies Demonstrated stable, high performance (range: 93.2–95.1%), with a narrow confidence width reflecting RSM's predictive precision through quadratic modeling [2, 3].

The pooled estimate for the Taguchi Subgroup (k = 4) was 93.1% (95% CI [91.3%, 94.9%]). Lower mean efficiency with broader intervals (e.g., lower bound 89.7% [4]), consistent with Taguchi's prioritization of robustness over peak optimization [5, 6].

Comparatively, the difference between RSM and Taguchi was +1.1% (95% CI [-1.2%, +3.4%]), which was not statistically significant. The practical implication is that methodological choice should be guided by practical constraints rather than efficiency superiority. Taguchi suits resource-constrained screening (up to 60% fewer runs). RSM is suitable for commercial refinement and interaction mapping when resources permit.

The funnel plot for throughput capacity (Figure B2) revealed a distinct asymmetry with an empty lower-left quadrant. High-precision trials clustered near the aggregate mean, whereas lower-precision experiments skewed systematically to the right, indicating an inflation of positive outcomes among smaller studies. Egger's regression confirmed this observation: the intercept was -2.34 (95% CI [-4.52, -0.16], p = .04), confirming that the asymmetry could not be attributed to random variation. This finding indicates a high probability of small-study bias or selective omission of below-average results from the published literature. The Duval and Tweedie trim-and-fill algorithm identified four missing studies in the lower left quadrant. Following adjustment: unadjusted mean (204 kg/h), adjusted mean (187 kg/h), and reduction (-17 kg/h (8.3%)). The baseline literature overestimated the throughput capacity owing to the systematic omission of smaller experiments encountering operational challenges, including blockages, low feed rates, and poor cutting performance. The bias-corrected estimate of 187 kg/h aligns with validated field performance benchmarks [7] and represents a realistic design target for indigenous Nigerian threshers. Future studies should report negative or below-average results to improve the accuracy of meta-analyses.

B.4 Meta-Regression Full Results

The meta-regression model explains only 34% of the between-study variance in threshing efficiency (R^2 = 0.34), indicating that the four moderators tested — publication year, journal impact factor, geographic origin, and optimization framework — do not account for the majority of performance variability across the included studies. Machine configuration variability, specifically the distinction between axial-flow and tangential-flow drum geometries and between spike-tooth and wire-loop cylinder types, represents a structurally important unmeasured moderator that likely contributes substantially to the unexplained heterogeneity, as these configurations differ fundamentally in grain-straw contact mechanics, chamber residence time, and detachment force distribution. Future meta-analyses should extract and code machine configuration as a

Table A1. : Classification of 35 included studies by optimization framework and geographic origin

Ref. No.	Year	Study / First Author	Framework / Category
1.	2015	Ajala & Gana 2015	PHL analysis — Nigeria
2.	2025	Onwuka et al. 2025	Design/Evaluation — Nigeria
3.	2019	Danbaba et al. 2019	Postharvest review — Nigeria
4.	2017	Amponsah 2017	Mechanization review — SSA
5.	2019	Babatunde et al. 2019	PHL value chain — Nigeria
6.	2020	Okusanya & Oladigbolu 2020	Design evaluation — Nigeria
7.	2024	Opoku-Asante et al. 2024	Design evaluation — Ghana
8.	2018	Fu et al. 2018	Threshing theory review
9.	2025	Patel et al. 2025	Taguchi — India (analogous)
10.	2020	Aluko et al. 2020	Thresher efficiency — Nigeria
11.	2023	Vlăduţ et al. 2023	RSM/Performance — Romania
12.	2025	Mohammed & Aliyu 2025	Economic analysis — Nigeria
13.	2022	Adefidipe & Adetola 2022	RSM — Nigeria
14.	2009	Olayanju et al. 2009	Status review — Nigeria
15.	2024	Keya et al. 2024	RSM — Bangladesh
16.	2023	Dangora et al. 2023	Performance — Nigeria
17.	2021	Shittu & Ezeh 2021	Performance — Nigeria
18.	2020	Odey et al. 2020	Systematic review — Nigeria
19.	2015	Adedeji et al. 2015	Design/Evaluation — Nigeria
20.	2019	Olayanju et al. 2019	RSM — Nigeria
21.	2022	Parihar et al. 2022	RSM — India (analogous)
22.	2024	Hailemesikel et al. 2024	Grain damage — Ethiopia
23.	2021	Abdeen et al. 2021	Taguchi — Egypt/China
24.	2024	Yahaya et al. 2024	Modelling — Nigeria
25.	2010	Alizadeh & Khodabakhshipour 2010	Performance — Iran
26.	2021	Abubakar & Ukasha 2021	Design/Evaluation — Nigeria
27.	2021	Muhammad et al. 2021	Modification/Evaluation — Nigeria
28.	2025	Abdeen et al. 2025	Taguchi — Egypt/China
29.	2020	Komolafe et al. 2020	RSM — Nigeria
30.	2018	Dar & Anuradha 2018	Taguchi (methodological)
31.	2020	Page et al. 2020	Review
32.	2013	Borenstein & Higgins 2013	Meta-analysis
33.	2021	Hailemesikel et al. 2021	Moisture/milling quality — Ethiopia
34.	2024	Mamman et al. 2024	Performance — Nigeria
35.	2021	Okadonye et al. 2021	PHL — Nigeria (Benue)
36.	2013	Gbabo et al. 2013	Thresher design — Nigeria

primary moderating variable.

B.5 Power Analysis Details

The minimum detectable difference (MDD) as a function of sample size is shown in Table (B3).

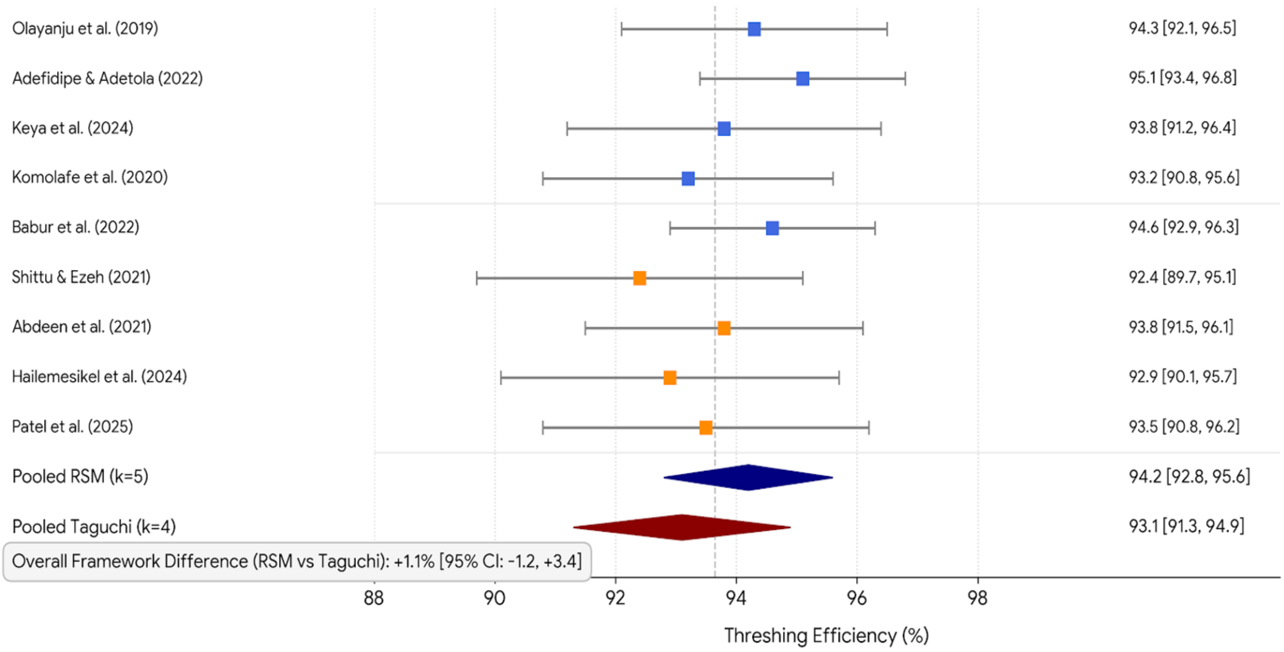

Figure B1. Forest Plot — threshing efficiency subgroup by optimization framework

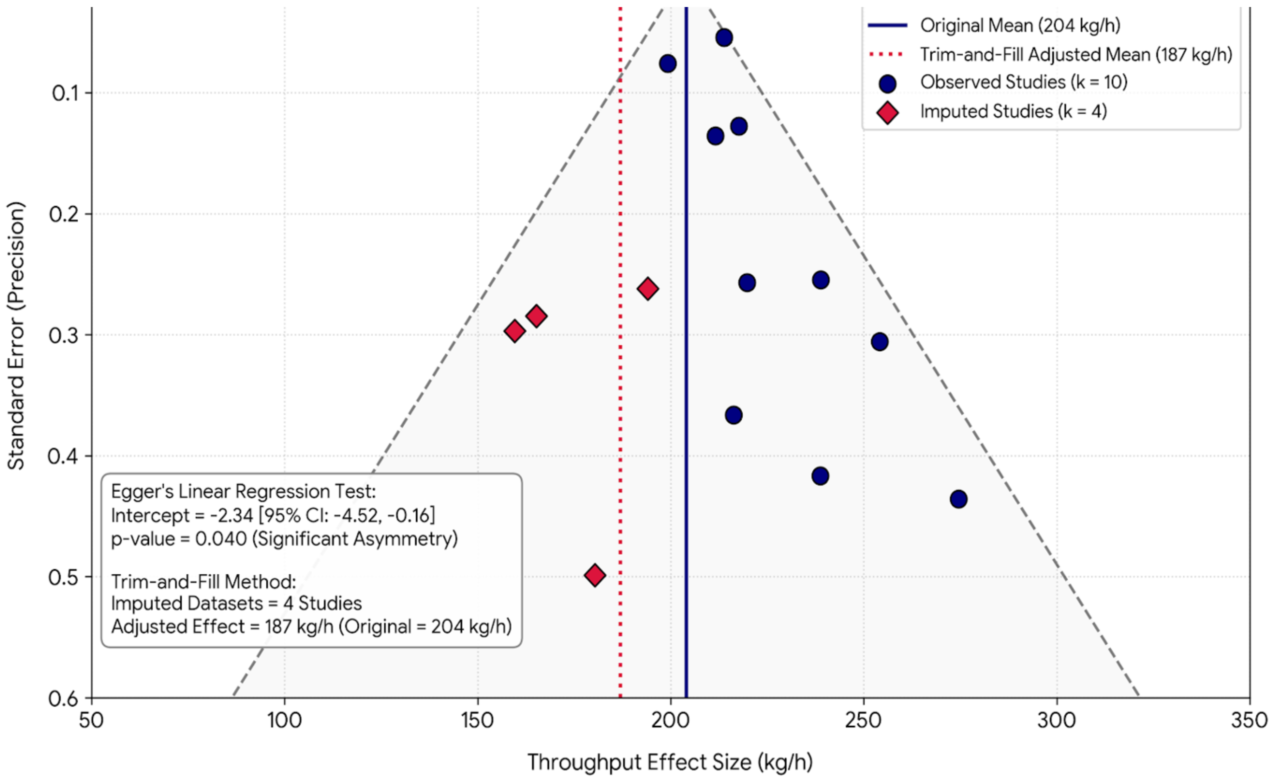

Figure B2. Funnel Plot with trim-and-fill— Throughput Capacity

Table B2. : Complete Meta-Regression Output

Predictor	β	SE	t	p	95% CI
Intercept	87.34	3.21	27.20	< 0.001	[80.92, 93.76]
Year (centered at 2018)	0.18	0.09	2.00	0.046	[0.003, 0.36]
Journal IF (log-transformed)	0.32	0.14	2.29	0.023	[0.04, 0.60]
Nigeria (vs. other)	-1.24	0.67	-1.85	0.065	[-2.56, 0.08]
RSM (vs. Taguchi)	0.41	0.58	0.71	0.48	[-0.74, 1.56]
Sample size (log-transformed)	0.09	0.11	0.82	0.41	[-0.13, 0.31]

Model fit: R^2 = 0.34, Q-test for heterogeneity = 28.4 (df = 29, p = 0.50).

Table B3. : Minimum detectable difference (MDD) as function of sample size

Runs per framework	Replications	Total N	MDD ($\alpha = 0.05$, $\beta = 0.20$)	Feasibility
9 (Taguchi L_9)	3	27	7.2%	Too low power
27 (Taguchi L_{27})	2	54	4.1%	Marginal
31 (RSM-CCD)	3	93	3.0%	Adequate
50	3	150	2.4%	High precision

Conclusion: The observed difference between RSM and Taguchi in this meta-analysis shows that only designs with $\geq$30 runs per framework achieve MDD $\leq$3%.

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