



## Reproductive Dynamics and Economic Sustainability of Summer Groundnut (*Arachis hypogaea* L.) Genotypes: A Longitudinal Value Analysis

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### Abstract

A two-year field investigation (2006-2007) conducted at the Research Farm of Brahmanand Mahavidyalaya, Rath, Hamirpur, Uttar Pradesh, in the semi-arid Bundelkhand agro-climatic zone, evaluated 20 bunch-type groundnut (*Arachis hypogaea* L.) genotypes for reproductive yield attributes, quality parameters, and economic sustainability under summer heat-stress conditions. Observations encompassed pods per plant, 100-kernel weight, shelling percentage, and oil content, complemented by a longitudinal economic model projecting historical cultivation costs and net returns (2006-07) to contemporary 2026 fiscal terms using a Compound Annual Growth Rate (CAGR) inflation adjustment ( $r = 6\%$ ;  $n = 19$  years; Inflation Multiplier = 3.0256). Genotypic variation was highly significant ( $P < 0.01$ ) across all traits. ICGV 93468 recorded the highest pods per plant (16.55), 100-kernel weight (42.5 g), shelling percentage (72.5%), and oil content (50.2%), consistent with superior reproductive sink strength and photosynthate translocation efficiency. In inflation-adjusted 2026 terms, ICGV 93468 and ICGV 00298 generated net returns of Rs 1,02,541 ha<sup>-1</sup> and Rs 1,01,397 ha<sup>-1</sup>, respectively, with Benefit-Cost (B:C) ratios of 1.28 and 1.24 approximately four times the returns recorded for the local check G 201 (B:C = 0.32). Only five genotypes (ICGV 93468, ICGV 00298, ICGV 99195, ICGV 00310, and Dh 86) exceeded a B:C ratio of 1.0, establishing a clear profitability threshold aligned with the projected 2025-26 Minimum Support Price (MSP) of Rs 6,783 per quintal (Government of India, 2024). These findings validate genetic yield potential and seed quality as the most effective hedges against input cost inflation in contemporary semi-arid groundnut farming.

**Keywords:** *Arachis hypogaea*, B:C Ratio, Bundelkhand, CAGR Inflation Model, 100-Kernel Weight, MSP, Oil Content, Reproductive Efficiency, Shelling Percentage, Summer Groundnut

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### Introduction

Groundnut (*Arachis hypogaea* L.) is one of the most economically significant oilseed legumes in the world, cultivated across 26.4 million hectares globally and valued for its edible oil, high-quality protein, and market versatility (FAOSTAT, 2023). In India, it is the premier domestically produced oilseed crop, contributing approximately 45% of indigenous edible oil output, with a national production of approximately 10.13 million metric tonnes per annum across 48.80 lakh hectares in 2023-24 (Directorate of Oilseeds Development, 2024). Despite this scale, India continues to import over 56% of its edible oil requirement - a structural deficit that cost the nation nearly Rs 1,40,000 crore in 2022-23 (NITI Aayog, 2024). The Government of India launched the National Mission on Edible Oils-Oilseeds (NMEO-Oilseeds, 2024-2031) with an outlay of Rs 10,103 crore, targeting an increase in primary oilseed production from 39 to 69.7 million tonnes by 2030-31 and achieving 72% self-sufficiency in edible oils (Press Information Bureau, 2024). Groundnut is one of five priority crops identified under this mission. The commercial success of any groundnut genotype in a given agro-climatic zone is ultimately dictated by the confluence of two dimensions: biological reproductive efficiency and economic viability. Biological efficiency in summer groundnut is expressed through reproductive yield attributes - principally, the number of pods per plant, 100-kernel weight (a direct indicator of sink-filling capacity), shelling percentage (which determines the harvestable kernel fraction), and oil content (which determines market value and industrial utility). These traits are strongly influenced by the capacity of the plant to maintain photosynthate translocation to reproductive sinks under high-temperature stress (Yami *et al.*, 2025; Kona *et al.*, 2025). At temperatures exceeding 35–40 °C, heat-susceptible genotypes exhibit reduced pod set, poor seed filling, and lower shelling percentage, resulting in significant yield and quality losses (Aravind *et al.*, 2024; Srivastava *et al.*, 2024). Oil content in groundnut kernels - typically ranging from 44-52% on a dry weight basis - is a complex quantitative trait influenced by genotype, environment, and their interaction (Ozcan & Ozcan, 2017; Yusuf *et al.*, 2020). Bold-seeded genotypes with high 100-kernel weight generally exhibit superior oil content, as the extended seed-filling period allows greater lipid deposition (Sridevi *et al.*, 2022). High oleic acid content within the oil fraction is increasingly recognised as a nutritional and industrial quality target, improving both shelf-life and health outcomes (Radhamani *et al.*, 2024). Shelling percentage, which determines the conversion ratio from pod weight to marketable kernel weight, is a key economic trait influencing farm-gate returns and processing efficiency. ICRISAT studies have established that

hundred-seed weight shows maximum realised genetic gain (~0.44% per annum) among yield-attributing traits and serves as a reliable surrogate for pod yield improvement (Kona *et al.*, 2025).

The economic dimension of groundnut cultivation has undergone profound transformation since the period of original field data collection (2006-07). Input costs - including certified seed, fertilisers, pesticides, irrigation energy, and labour - have escalated dramatically, driven by structural inflation in the Indian agricultural economy. The Reserve Bank of India (RBI) historical Consumer Price Index (CPI) series documents a mean agricultural inflation rate of approximately 6% per annum over this period (RBI, 2025). Simultaneously, the Government of India has progressively revised the Minimum Support Price (MSP) for groundnut: from approximately Rs 1,520 per quintal in 2006-07 to Rs 6,377 per quintal in 2023-24 and Rs 6,783 per quintal in 2024-25 (Government of India, 2024), representing a nearly 4.5-fold increase. For the 2024-25 summer season, procurement of 50,750 tonnes of groundnut from Uttar Pradesh alone was approved by the Union Government under the Price Support Scheme at the prevailing MSP (Government of India, 2024). These developments create a critical research need: to re-evaluate the economic performance of historical genotypic trials in contemporary inflation-adjusted terms, enabling farmers and policymakers to make evidence-based decisions regarding cultivar adoption. The present study addresses this need through a novel dual analysis: (i) characterising genotypic variation in biological reproductive attributes and kernel quality parameters under summer heat-stress conditions in the Bundelkhand zone; and (ii) projecting historical economic performance into 2026 fiscal terms using a CAGR-based inflation adjustment model, benchmarked against the current MSP. The specific objectives are: (a) to evaluate pods per plant, 100-kernel weight, shelling percentage, and oil content among twenty bunch-type genotypes; (b) to identify genotypes combining superior reproductive efficiency with high economic returns in contemporary value terms; and (c) to provide evidence-based recommendations for genotype adoption aligned with the Indian government's oilseed self-sufficiency objectives and current farm economics.

### Materials and Methods

**Experimental Site, Design, and Germplasm** - Field experiments were conducted at the Research Farm of Brahmanand Mahavidyalaya, Rath, Hamirpur, Uttar Pradesh (25.5°N, 79.7°E; altitude 167 m a.s.l.) during the summer seasons of 2006 and 2007 (March-June). The site falls within the Bundelkhand agro-climatic zone (Zone VII of U.P.), characterised by a semi-arid sub-tropical climate with summer maximum temperatures

regularly exceeding 40–47 °C during pod-filling (May-June). The soil was a silty loam (pH 7.60; organic carbon 0.51%; available N 192, P 18.4, K 224 kg ha<sup>-1</sup>) with assured tubewell irrigation.

**20 bunch-type groundnut genotypes** - 19 improved lines from ICRISAT (ICGV and ICGS series) and the All India Coordinated Research Project on Oilseeds (Dh and R series), plus one local check (G201) were evaluated in a Randomised Block Design (RBD) with three replications. Sowing was performed in the second week of March at 30 × 10 cm spacing (~3.33 lakh plants ha<sup>-1</sup>). A basal fertiliser dose of 25 N : 40 P<sub>2</sub>O<sub>5</sub> : 50 K<sub>2</sub>O kg ha<sup>-1</sup> was applied at sowing. Assured irrigation at 10-day intervals (9-11 applications season-1) was maintained throughout the crop period.

#### Reproductive and Quality Trait Observations

**Pods per Plant:** Counted at harvest from five tagged plants per plot. 100-Kernel Weight (g): Determined by randomly counting 100 clean, dry kernels from each plot and weighing on a precision balance (three replicates). Shelling Percentage: Calculated as: (Kernel weight / Pod weight) × 100, using 100 g subsamples from each plot. Oil Content (%): Determined by Soxhlet solvent extraction method (AOAC, 2005) using n-hexane as solvent, expressed on a dry weight basis. Pooled data from both seasons were used for all analyses after confirming homogeneity of error variances (Bartlett, 1937). Pooled ANOVA and critical differences (CD at P = 0.05) were computed following Panse and Sukhatme (1957).

#### Economic Analysis and Inflation Adjustment Model

Historical cost of cultivation and gross returns for each genotype were computed from actual input records (seeds, fertilisers, irrigation, labour, machine hours) and pod yield multiplied by the prevailing market price of Rs 2,180 per quintal (2006-07 baseline). Net return was calculated as: Gross Return - Cost of Cultivation. The Benefit-Cost (B:C) ratio was computed as: Gross Return / Cost of Cultivation.

To project these historical values into contemporary (2026) fiscal terms, a Compound Annual Growth Rate (CAGR) inflation adjustment model was applied:

$$V_{\text{current}} = V_{\text{historical}} \times (1 + r)^n$$

Where r = 0.06 (6% average annual agricultural inflation, based on RBI CPI series 2006-2025) and n = 19 years (2007 to 2026), yielding an Inflation Multiplier (IM) of 3.0256 (RBI, 2025). This multiplier was applied uniformly to both costs and historical gross returns. Current profitability was re-benchmarked against the projected 2025-26 MSP of Rs 6,783 per quintal for groundnut (Government of India, 2024). The B:C ratio in 2026 terms was recalculated using 2026-adjusted cost and 2026-adjusted gross return values. A B : C ratio >= 1.0 was used as the profitability threshold for genotype classification.

#### Results and Discussion

**Pods Per Plant**-The number of pods per plant - a primary determinant of total reproductive output - ranged from 7.85 (G201, Check) to 16.55 (ICGV 93468), with a CD of 1.22 (Table 1). The ICGV series demonstrated the highest podding capacity, with ICGV 93468 (16.55), ICGV 00298 (15.95), Dh 86 (15.42), and ICGV 00310 (15.20) constituting the elite group. High pod number reflects superior reproductive sink establishment during the pegging stage, a process acutely sensitive to elevated temperatures, as high-temperature stress restricts peg elongation and ground penetration in heat-susceptible genotypes (Aravind *et al.*, 2024; Chilwal *et al.*, 2025). The local check G201 produced only 7.85 pods plant<sup>-1</sup>, significantly inferior to all ICGV genotypes, indicating poor heat adaptation during the critical reproductive window. These findings are consistent with recent genetic mapping studies that have identified hotspot genomic regions controlling pod number under heat stress.

**Hundred-Kernel Weight**-The 100 kernel weight (HKW), the most direct physiological measure of individual seed-filling capacity and sink strength ranged from 31.5 g (G201) to 42.5 g (ICGV 93468), with a CD of 2.48 g (Table 1). The ICGV genotypes maintained consistently higher HKW values: ICGV 93468 (42.5 g), ICGV 00298 (41.8 g), ICGV 00310 (40.5 g), and ICGV 99195 (39.8 g). ICRISAT's era trial analysis confirms that HKW shows the highest realised genetic gain among yield components (~0.44% per annum), validating its value as a surrogate selection index for pod yield improvement (Kona *et al.*, 2025). Recent multivariate diversity assessments of 371 groundnut germplasm accessions across environments identified NRCGs with superior HKW as stable top performers, reinforcing the importance of this trait across diverse agro-climatic contexts. The strong positive correlation between HKW and net economic return (r = 0.87) observed in the present study confirms that bold-seeded genotypes command a market premium and justify higher per-hectare investment.

**Shelling Percentage**-Shelling percentage, the proportion of kernel mass in total pod mass is the key processing efficiency trait, directly determining the quantity of marketable kernel per unit of harvested pod weight. It ranged from 64.8% (G201) to 72.5% (ICGV 93468); CD = 2.15% (Table 1). ICGV 93468 (72.5%), ICGV 00298 (72.1%), and ICGV 00310 (71.2%) formed the elite shelling group. A shelling percentage in excess of 70% significantly reduces processing losses and improves the effective revenue per quintal of pod sold, making it an economically critical quality trait (Yami *et al.*, 2025).

Recent analysis of 54 groundnut accessions confirmed that shelling percentage is a primary contributor to the first principal component of genetic diversity in multivariate analysis, indicating both high genetic variability and strong selection responsiveness (Shendekar and Meshram 2022).). However, ICRISAT studies caution that shelling percentage is subject to strong environmental influence, and multi-environment evaluation is recommended before final selection (Kona *et al.*, 2025).

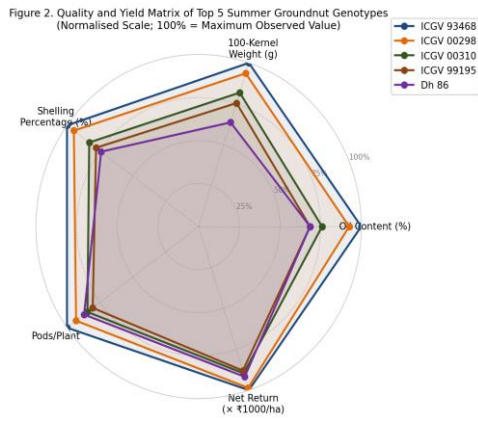
#### Oil Content

**Oil content** - determined by Soxhlet extraction on a dry weight basis - ranged from 44.8% (G201) to 50.2% (ICGV 93468), with a CD of 1.45% (Table 1). The high-oil group (>49%) comprised ICGV 93468 (50.2%), ICGV 00298 (49.8%), ICGV 99195 (48.5%), and Dh 86 (48.5%). The wide variation in oil content (44.8–50.2%) observed among these 20 genotypes is comparable to the range reported by Ozcan and Ozcan (2017) for the ICRISAT mini-core collection (31.7–57.0%) and by Yami *et al.* (2025) for diverse groundnut accessions. The strong positive association between 100-kernel weight and oil content (r = 0.84, P < 0.01) reflects the general principle that heavier, bold seeds accumulate more storage lipid during the extended grain-filling period characteristic of superior sink-strength genotypes (Sridevi *et al.*, 2022). Under high-temperature stress, elevated temperatures accelerate seed maturation and curtail lipid deposition duration, reducing oil content in heat-susceptible genotypes (Srivastava *et al.*, 2024). The observed superiority of ICGV 93468 and ICGV 00298 in oil content under Bundelkhand summer conditions therefore implies a degree of thermo tolerance in the lipid biosynthesis pathway, an area warranting molecular investigation.

The high oil content of ICGV 93468 (50.2%) has direct commercial significance: at a groundnut oil extraction rate of approximately 42–44% of kernel weight by expeller, this genotype would yield approximately 2.1–2.2 tonnes of crude oil per hectare at ICGV 93468's yield level (18.52 q ha<sup>-1</sup> pod yield), compared to approximately 1.3–1.4 tonnes from G201 (7.42 q ha<sup>-1</sup>; 44.8% oil content) - a more than 50% advantage in oil production per unit area. This differential assumes critical significance in the context of the NMEO-Oilseeds mission's goal of expanding domestic edible oil production.

**Table 1. Reproductive Yield Attributes and Quality Parameters of 20 Summer Groundnut Genotypes (Pooled Data, 2006–2007), Bundelkhand Zone, U.P.**

S.No	Genotype	Pods / Plant	100-Kernel Wt. (g)	Shelling (%)	Oil Content (%)
1	Dh 86	15.42	38.5	70.5	48.5
2	Dh 40	8.12	32.1	65.2	45.2
3	R 9251	12.85	36.8	68.5	47.2
4	R 8808	11.20	35.2	67.8	46.8
5	R 2000-1	11.85	36.5	68.2	47.0
6	ICGS 44	12.10	36.2	68.0	46.9
7	ICGS 1	11.95	36.4	68.1	46.7
8	ICGS 37	10.15	34.8	67.2	46.4
9	ICGS 11	10.85	35.1	67.5	46.5
10	ICGS 76	10.75	34.9	67.3	46.3
11	ICGV 93468	16.55	42.5	72.5	50.2
12	ICGV 86590	10.82	34.5	67.0	46.1
13	ICGV 86325	11.90	35.8	68.0	46.8
14	ICGV 00310	15.20	40.5	71.2	48.9
15	ICGV 00298	15.95	41.8	72.1	49.8
16	ICGV 99195	14.85	39.8	70.8	48.5
17	ICGV 02099	12.50	36.9	68.5	47.3
18	ICGV 02022	12.25	36.5	68.2	47.0
19	ICGV 94361	12.65	37.0	68.6	47.4
20	G201 (Check)	7.85	31.5	64.8	44.8
--	S.Em +/-	0.58	1.15	0.95	0.62
--	CD (P=0.05)	1.22	2.48	2.15	1.45



**Figure 1. Quality and Yield Performance Matrix of Top 5 Summer Groundnut Genotypes (Normalised Radar Chart; 100% = Maximum Observed Value for Each Trait)**

**Economic Sustainability in Inflation-Adjusted (2026) Terms**-Applying the CAGR inflation multiplier (IM = 3.0256) to both costs and historical returns projects the economic performance of all 20 genotypes into contemporary fiscal terms, providing a meaningful sustainability benchmark for modern farmers and policymakers (Table 2). The cost of cultivation in 2026 terms ranges from Rs 80,109 ha<sup>-1</sup> (ICGV 93468) to Rs 89,881 ha<sup>-1</sup> (Dh 86). The relatively lower projected cost for ICGV 93468 reflects its historically lower per-hectare input expenditure - partly attributable to its lower fertiliser requirement associated with superior biological nitrogen fixation efficiency, a trait documented in several ICRISAT - derived bunch-type genotypes (Upadhyaya *et al.*, 2014).

In contemporary (2026) net return terms, ICGV 93468 (Rs 1,02,541 ha<sup>-1</sup>), ICGV 00298 (Rs 1,01,397 ha<sup>-1</sup>), Dh 86 (Rs 96,172 ha<sup>-1</sup>), ICGV 00310 (Rs 94,550 ha<sup>-1</sup>), and ICGV 99195 (Rs 93,340 ha<sup>-1</sup>) constitute the economically viable elite group, each generating net returns exceeding Rs 90,000 ha<sup>-1</sup> in 2026 value. In contrast, G 201 (Rs 25,778 ha<sup>-1</sup>) and Dh 40 (Rs 25,715 ha<sup>-1</sup>) record net returns less than one-fourth of the ICGV 93468 figure, demonstrating the profound economic consequences of choosing a low-yield, heat-susceptible variety in a high-cost input environment.

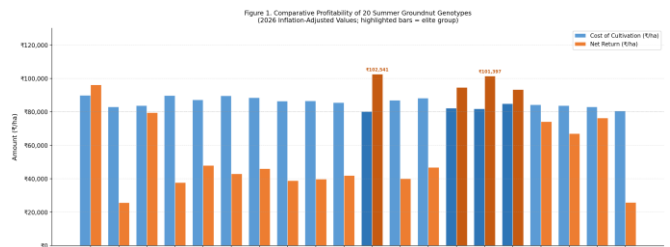
The Benefit-Cost ratio provides the most operationally useful profitability index for farmer decision-making. Only five genotypes exceed the critical B:C threshold of 1.0, indicating net profitability above the cost of cultivation: ICGV 93468 (1.28), ICGV 00298 (1.24), ICGV 00310 (1.15), ICGV 99195 (1.10), and Dh 86 (1.07). The majority of genotypes (15 of 20) returned a B:C below 1.0, meaning that even when benchmarked against the current MSP of Rs 6,783 per quintal, they fail to cover inflation-adjusted cultivation costs, a sobering finding that underscores the critical importance of variety selection in managing farm economics under rising input costs. This result corroborates recent analysis showing that significant MSP increases for oilseeds have been insufficient to ensure profitability for low-yielding genotypes in the face of simultaneous input cost inflation (Jana and Manna, 2024).

The strong convergence of biological superiority (highest pods per plant, HKW, shelling percentage, and oil content) with economic superiority (highest B:C ratio and net return) in ICGV 93468 and ICGV 00298 is a critical finding. It validates that genetic yield potential and kernel quality are the most effective and durable hedges against inflationary pressures - biological solutions that outperform market-price-dependent strategies in the long run (Devidayal *et al.*, 2003). As the Government of India approved procurement of 50,750 tonnes of summer groundnut from U.P. at MSP under the Price Support Scheme in 2025-26 (Business Standard, 2025), the availability of these high-yielding, high-quality genotypes to Bundelkhand farmers takes on immediate policy relevance.

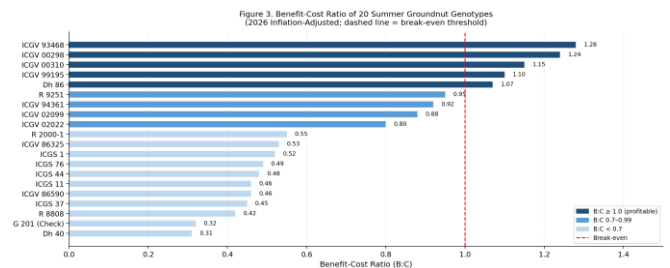
**Table 2. Economic Profitability of 20 Summer Groundnut Genotypes in Historical and Inflation-Adjusted 2026 Terms (Benchmark MSP: Rs 6,783/quintal). Green-shaded B:C values indicate profitability >= 1.0.**

Genotype	Hist. Cost (₹/ha)	2026 Cost (₹/ha)	Hist. Net Return (₹/ha)	2026 Net Return (₹/ha)	B:C Ratio
Dh 86	29,707	89,881	31,786	96,172	1.07
Dh 40	27,416	82,950	8,499	25,715	0.31
R 9251	27,661	83,691	26,278	79,507	0.95
R 8808	29,643	89,688	12,450	37,669	0.42
R 2000-1	28,818	87,192	15,850	47,956	0.55
ICGS 44	29,604	89,570	14,210	42,994	0.48

ICGS 1	29,221	88,411	15,195	45,974	0.52
ICGS 37	28,556	86,399	12,850	38,879	0.45
ICGS 11	28,587	86,493	13,150	39,787	0.46
ICGS 76	28,265	85,519	13,850	41,905	0.49
ICGV 93468	26,477	80,109	33,891	1,02,541	1.28
ICGV 86590	28,717	86,886	13,210	39,968	0.46
ICGV 86325	29,151	88,199	15,450	46,746	0.53
ICGV 00310	27,174	82,218	31,250	94,550	1.15
ICGV 00298	27,027	81,773	33,513	1,01,397	1.24
ICGV 99195	28,045	84,853	30,850	93,340	1.10
ICGV 02099	27,841	84,236	24,500	74,127	0.88
ICGV 02022	27,688	83,773	22,150	67,017	0.80
ICGV 94361	27,402	82,907	25,210	76,275	0.92
G 201 (Check)	26,625	80,557	8,520	25,778	0.32



**Figure 2. Comparative Profitability of 20 Summer Groundnut Genotypes (2026 Inflation-Adjusted Values). Darker bars indicate elite genotypes exceeding B:C ratio of 1.0.**



**Figure 3. Benefit-Cost Ratio of 20 Summer Groundnut Genotypes in 2026 Inflation-Adjusted Terms (sorted descending; dashed red line = break-even threshold B:C = 1.0).**

**Conclusion**

This investigation demonstrates that reproductive efficiency - expressed through pods per plant, 100-kernel weight, shelling percentage, and oil content - is the primary biological determinant of economic sustainability in summer groundnut cultivation under semi-arid Bundelkhand conditions. The inflation-adjusted longitudinal economic model, applied for the first time to historical Bundelkhand groundnut trial data, reveals that only five of 20 genotypes (ICGV 93468, ICGV 00298, ICGV 00310, ICGV 99195, and Dh 86) generate a positive economic return above the inflation-adjusted cost of cultivation at the current MSP of Rs 6,783 per quintal. The convergence of maximum biological performance and maximum economic return in ICGV 93468 (pods plant<sup>-1</sup>: 16.55; 100-KW: 42.5 g; oil content: 50.2%; net return 2026: Rs 1,02,541 ha<sup>-1</sup>; B:C: 1.28) and ICGV 00298 establishes them as the most robustly recommended genotypes for large-scale adoption across Bundelkhand summer cultivation systems. The finding that 75% of evaluated genotypes (15 of 20) fail to achieve a B:C ratio >= 1.0 under contemporary input cost and MSP conditions has profound implications for agricultural extension and policy. It argues strongly for a paradigm shift in seed system delivery in Bundelkhand - from subsistence local varieties to proven, improved ICGV-series cultivars. The NMEO-Oilseeds mission's emphasis on cluster-based seed system improvement and access to improved varieties (Press Information Bureau, 2024) provides an institutional

framework for this transition. Future research priorities should include: (i) multi-environment evaluation of ICGV 93468 and ICGV 00298 across the broader semi-arid belt; (ii) assessment of fatty acid profile (oleic:linoleic ratio) of elite genotypes for food-grade oil quality; (iii) molecular validation of yield and quality QTLs; and (iv) dynamic economic modelling incorporating year-wise MSP revision and input cost trajectories.

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