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PERFORMANCE BENCHMARKING OF ELITE HYBRID CASHEW VARIETIES IN INDIA: A MULTI-CRITERIA EVALUATION AND CLUSTER ANALYSIS APPROACH

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ABSTRACT----------
Although the cashew tree (Anacardium occidentale L.) industry in the Indian subcontinent dates back to importations during the 16^(th) century, it is facing a problem in terms of yield potential because of the aged plantations and low-yielding saplings. The present study intends to evaluate the performance of superior cashew hybrids in major agro-climates in a bid to identify the correct species that need to be grown. A multi-criteria performance analysis (MCPA) using the cluster statistical test Karl Pearson correlation is employed by collecting data on All India Coordinated Research Project on Cashew (AICRP-Cashew), the performance of the Directorate of Cashew Nut & Cocoa Development (DCCD), the Agricultural & Processed Food Products Export Development Authority (APEDA), State Agricultural Universities (SAUs), etc.

The analysis revealed that Amrutha (H-1597) was the best variety for industrial purposes with a performance score of 0.799, due to its high yield (18.36 kg/tree) and high shelling percentage (31.58%). On the other hand, Akshaya was revealed to be a unique jumbo nut variety for high export purposes (W180 grade) under moderate negative correlation (r = -0.58) between nut weight and total yield. Vengurla-4 was revealed to be an all-rounder variety with high total yield (17.2 kg), high shelling percentage (31%), and red apple.

The conclusion of the study is that to close the gap in national productivity, there should be a strategic focus on high-density planting (HDP) and also on promoting high-shelling varieties like Amrutha. In addition, replacing senile plantations with new hybrid varieties to realize the national productivity target and improve national self-sufficiency should also be pursued with the help of research institutions.

KEYWORDS: *Cashew (Anacardium occidentale), Hybrid Varieties, Nut Yield, Kernel weight, Shelling Percentage, Juice Percentage----------*

1. INTRODUCTION

Cashew nut production in India has been traced to the early spread of cultivation, especially in the home gardens, introduced by the Portuguese in the 16th century. Now, India has become a world leader in this area, being the world's secondary largest producer, exporter, as well as the biggest consumer (Bhagya et al. 2025). The production statistics for 2023–2024 indicate that cashew nut production in India involves 119,500 hectares, with production spanning 782,000 tonnes, reflecting an average production rate of 650–760 kg/ha. Although production was originally limited in the coastal regions of Kerala, Maharashtra, Andhra Pradesh, Odisha, and Karnataka (KSACC, 2023), production has now been extended to new locations. These new production sites include the original production zones such as Tamil Nadu and West Bengal, along with the northern states (Tripura, Meghalaya, Assam, Manipur, and Nagaland). Additionally, cashew nut production has successfully been introduced in new, unusual production zones such as the Bastar area in Chhattisgarh, Kolar plains in Karnataka, and Gujarat, as well as Jharkhand (Mangalassery et al. 2019). Additionally, they also cultivate in a small scale in the northeastern state of India including Assam, Manipur, Tripura, Meghalaya, Nagaland (Bhagya et al., 2019). They also cultivate in other parts including the union territory of Andaman & Nicobar Islands (DCCD, 2024).

India identified over 55 varieties of cashew under Research and Development programs where 33 are direct selections and 22 are hybrids (Nayak and Muralidhara, 2018). Among these, 44 identified at national level and recommended for cultivation. India grows many cashew varieties, developed by research centres, including popular ones like Vengurla-4 & 7, Ullal-1 & 3, Dhana, Bhaskara, Priyanka, VRI-3, and BPP-8, each suited to different regions with distinct yield & quality, with ongoing development of new high-yielding types.

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One of the main factors responsible for the existing yield gap is the persistence of low-quality varietal seeds and older unproductive orchards. To overcome this challenge, ICAR-Directorate of Cashew Research (DCR) has developed and released more than 40 varieties of high-yielding varieties (HYVs). Anacardium occidentale or cashew is an important plantation crop because of its immense value to the economy of India, as it contributes largely to foreign exchange through exports.

The areas in which this cultivation is carried out are termed peninsular regions, and this comprises areas in Western Maharashtra, Karnataka, Kerala, and Goa, and in Eastern regions it comprises Odisha, West Bengal, Andhra Pradesh and Tamil Nadu, as well as Union Territory of Puducherry. To become independent at the national level and increase the production at the vertical level, it is necessary to develop suitable stable and high-performing genotypes from the available germplasm. Though the stable varieties alone can be used for the development of the next breed of plants, the study of genetic resources capable of giving consistent performance under irregular climatic conditions is needed.

2. LITERATURE REVIEW

Author(s)	Journal	Year	Highlights of Results & Hybrid Performance
Nayak, M. G., et al.	*Applied Biological Research*	2025	The varieties tested were under Ultra-High-Density Planting (UHDP). It was observed that a distance of 2.5 m x 2.5 m, in NRCC Selection-2, resulted in maximum nut production (0.94t/ha).
Menon, J. S., et al.	*Journal of Tropical Agriculture*	2024	Nineteen hybrids were tested in Kerala. The best hybrid was H03-21/10, producing 25.2 kg per tree per annum. The hybrids H03-97/2 and H03-110/1 were high yielders (>18 kg) with large nuts (>10 g).
Janani et al.	*Applied Ecology and Environmental Research*	2022	Based on the results, the conclusion drawn is that the physiological stability as well as the consistent production in a dense population possessed by the Bhaskara variety is the best. This variety performed better than other varieties regarding canopy efficiency. Hence, it is the best candidate for High Density Planting (HDP).
Varghese, J.	*Krishikosh (Thesis)*	2021	Hybrid vigour was tested on 19 genotypes. H03-36/8 and H03-52/5 were noted for their high kernel weight (>2.5g) and shelling percentages in excess of 28%.
Eradasappa, E. & Mohana, G.	*Journal of Plantation Crops*	2020	Expressed considerable "standard heterosis" values for nut weight in hybrids H-125 & H-126 (up to 300% over checks). These were introduced into multi-location trials.
Nayak, M. G., et al.	*Indian Journal of Agricultural Sciences*	2020	Assessed the hybrid H-130. This variety is very sensitive to pruning and can be used in ultra-density planting, giving a production of 2432kg/ha in its fourth year.
Gajbhiye, R. C., et al.	*Int. Journal of Chemical Studies*	2018	Analysed genotypes in Konkan area. Identified Vengurla-9 (Cross V-4 x VRI-1) as excellent bold nut variety yielding an average of 15.98 kg/tree.

3. OBJECTIVES

1. To evaluate the different hybrid varieties of cashew cultivated across different states of India
2. To analyse the physical characteristics, yield, and quality metrics of 13 hybrid varieties
3. To identify the best varieties on the basis of features and statistical analysis

4. MATERIALS AND METHODS USED

Secondary data has been utilised for the study which is collected from different official sources like ICAR-Directorate of Cashew Research (DCR), Puttur, Directorate of Cashew Nut and Cocoa Development (DCCD), Kochi, National Horticulture Board (NHB), Agricultural and Processed Food Products Export Development Authority (APEDA) and All India Coordinated Research Project on Cashew (AICRP) and academic sources like journal articles.

Data collected on parentage, canopy and flowering parameters were subjected to descriptive statistical analysis including Mean, Range, Variance and Standard Deviation to assess trait variability. To identify the associations between the physical traits of these cashew varieties, a Pearson Correlation Matrix was generated. To determine the best variety, a Multi-Criteria Performance Analysis was applied. Finally, Cluster Analysis was utilized to group

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hybrids with similar characteristic profiles, facilitating the identification of elite genotypes for specific regional adaptation.

5. DATA ANALYSIS

Cashew Varieties in India

In India, cashew plantations are distributed in the peninsular coastal region, and several cultivars and hybrids are developed for different agro-climates. Maharashtra occupies the first position in the Western Coast region regarding total production and yields, mostly raised by the Vengurla Series (V-4, V-7, and V-9), known for its large size and superior yields. Karnataka has also made great progress, particularly through research varieties such as the Jumbo nut Hybrid, designated as H-130, and the variety Bhaskara. The Bhaskara variety is especially preferred for its performance under dense planting schemes.

In southern India, Kerala is now oriented towards superior quality hybrids like Amrutha and Anagha, which are much prized for their high-quality kernels and high juice content in cashew apples. Odisha, on the other hand, along the eastern coast, has the largest geographical distribution of cashews in the country. They now adopt hardy varieties like Bhubaneswar-1 and Balabhadra, which are designed to meet the special conditions of the environment in that region.

Table No. 1: State-wise distribution of cashew varieties in India

State	Cultivars Recommended	Progeny	State	Cultivars Recommended	Progeny
Karnataka	Selection 1	VTH-107/3	Maharashtra and Goa	Vengurla-1	Ansur-1
	Selection 2	VTH-40/1		Vengurla-4	Mid Red x Vetore-56
	Ullal 1	8/46 Taliparamba		Vengurla-6	Vetore 56 x Ansur-1
	Ullal 2	3/67 Guntur	Tamil Nadu	VRI-1	M 10/4
	Ullal 3	5/37 Manjeri		VRI-2	M 44/3
	Ullal 4	2/77 Tuni: Andhra		VRI-3	M 26/2
	UN 50	2/27 Nileshwar	Andhra Pradesh	BPP-4	EPM 9/8
	VRI 1	M-10/4		BPP-6	T No.56
	VRI 2	M-44/3		BPP-8	T No.1 x T No. 39
	Vengurla 1	Ansur-1		VRI-2	M 44/3
	Vengurla 4	Mid Red x Vetore 56	Orissa	VRI-2	M 44/3
	Chintamani 1	8/46 Taliparamba		Bhubaneshvar-1	Vengurla 36/3
Kerala	Madakkathara 1	BLA-39-4	West Bengal	Jhargram-1	T No. 16 of Bapatla
	Madakkathara 2	NDR 2-1	Madhya Pradesh	T No. 40	-
	K-22-1	22 Kottarakkara		Vengurla 4	Mid Red x Vetore-56
	Dhana	ALGD-1-1 x K 30-1	-	-	-
	Priyanka	BLA-139-1 x K 30-1	-	-	-

Source: Directorate of Cashewnut and Cocoa Development (DCCD), Kochi

A detailed description of the cashew variety to be planted, their genetic origin, and their suitability to various climatic conditions in different states of India have been detailed in Table 1 below:

Karnataka had the widest range of recommendations including the Ullal series (1–4), UN 50, and other local varieties. Kerala emphasized varieties like Madakkathara, Dhana, and Priyanka varieties. Maharashtra and Goa successfully utilized the Vengurla series, namely 1, 4, and 6. Tamil Nadu and Andhra Pradesh commonly laid stress on the varieties such as the VRI or Vridhachalam series and BPP or Bapatla series. West Bengal and Madhya Pradesh, on the other hand, emphasized relatively fewer varieties, like Jhargram 1 and T No. 40, respectively, as these two states were presumed to be coming-up states.

The fact that different recommended varieties are listed in different states shows high adaptability. Vengurla 4 was recommended in the states like Karnataka, Maharashtra, Goa and Madhya Pradesh. This variety is a cross between

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Mid Red and Vetore 56. VRI 2 (M 44/3) has been found to be highly adaptable and has been listed in different states such as Karnataka, Tamil Nadu, Andhra Pradesh, and Orissa. Vengurla 1 (Ansure-1) has been recommended in the states of Karnataka as well as Maharashtra and Goa.

The Progeny column shows the parentage of these varieties, which are mainly of two types: selections and hybrids. Most of these varieties have been selections from other high-producing varieties (for example, Vengurla 1 is a selection from Ansur-1 and VRI 1 from M-10/4). Varieties such as Dhana, Priyanka, and Vengurla 6 are the result of crosses between two parent varieties differing in certain desired characteristics like kernel size and insect resistance.

Table 2: Morphological and Yield Characteristics of Cashew Varieties

Variety	Parentage	Canopy	Flowering	Apple Colour	Nut Weight (g)	Shelling %	Mean Yield (kg/tree)
Madakkathara-1	Tree No.39 Bapatla	Compact	Nov	Yellow	6	26.8	13.8
Kanaka	BLA-139-1 x H3-13	Open	Nov	Yellow	6.8	30.58	12.8
Dhana	ALGD-1 x K-30-1	Compact	Dec-Jan	Yellow	8.2	29.8	10.66
Amrutha	BLA-139-1 x H3-13	Spreading	Dec-Jan	Yellow	7.18	31.58	18.36
Priyanka	BLA-139-1 x H30-1	Open	Dec-Jan	Yellow Red	2.87	26.57	17.03
Madakkathara-2	Neduvellur	Open	Jan-Mar	Red	7.25	26	17
Akshaya	H-4-7 x K-30-1	Compact	Dec-Jan	Yellow	11	28.36	11.78
Anakkayam-1	T20 x K-30-1	Compact	Oct-Nov	Pink-Yellow	5.95	27.99	12
Dharasree	T30 x Brazil-18	Compact	Dec-Jan	Yellow-Pink	7.8	30.5	10.66
Vengurla-4	Midnapur Red x Vatore 56	Open	Nov-Dec	Red	7.7	31	17.2
POORNIMA	BLA-139-1 x K-30-1	Compact	Dec-Jan	Yellow	7.8	31	14.1
Raghav	ALGD1-1 x K30-1	Compact	Mid-Jan	Golden Yellow	9.2	26.6	14.65
Damodar	Priyanka x Vridhachalam-3	Medium	Dec-Jan	Bright Red	8.2	27.9	13.65

Source: Kerala State Agency for the expansion of Cashew Cultivation (KSACC), State Agricultural University, Kerala (SAU) and ICAR-Directorate of Cashew Research (DCR), Puttur

Table 2 contains a comparison of 13 varieties of cashews (hybrids and selections) based upon physical attributes, yield, and quality. Amrutha has emerged first regarding maximum yield of 18.36 kg, followed by Vengurla-4 (17.2 kg), Priyanka (17.03 kg), and Madakkathara-2 by 17 kg. The maximum kernel size of 11 g has been produced by Akshaya, while the minimum of 2.87 g has been produced by Priyanka. Amrutha has come first with maximum kernel recovery of 31.58%, followed by Vengurla-4 by 31%, whereas Poornima has also been placed second by 31%. Priyanka and Akshaya have produced good quality grades of W180, whereas all other varieties have been categorized into grades of W210 and W280. Anakkayam-1 flowers very early (in October), whereas Madakkathara-2 flowers very late (in January).

Amrutha (H-1597) looks the most commercially workable considering its yield and shelling percentage, though its export grade is pretty high, W210. Akshaya (H-7-6) is the undisputed winner for size-oriented markets, earning the W180 grade, but its yield per tree is only 11.78 kg against the top lots. Of these, most varieties have fallen between 26 and 31%. Amrutha and Vengurla-4 can be considered most efficient for processors with its high shelling efficiency.

6. RESULTS AND DISCUSSIONS

Multi-Criteria Performance Analysis

A Multi-Criteria Performance Analysis was employed to find out which variety is the best. For this purpose, all varieties were examined on four important criteria of commerce: weight of nuts, shelling percentage, average nut

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yield, and export grade value. A composite performance ratio ranging from 0 to 1 was calculated by treating all criteria equally, to find out which variety has been performing better.

$$P_i = \sum_{j=1}^{n} w_j \cdot r_{ij}$$

Where:
$\mathbf{P}_i$: Total performance score of the i^{th} hybrid.
$\mathbf{w}_j$: The relative weight assigned to the j^{th} criterion (e.g., yield, nut weight).
$\mathbf{r}_{ij}$: The normalized value of the i^{th} hybrid for the j^{th} criterion.
n: Total number of criteria.

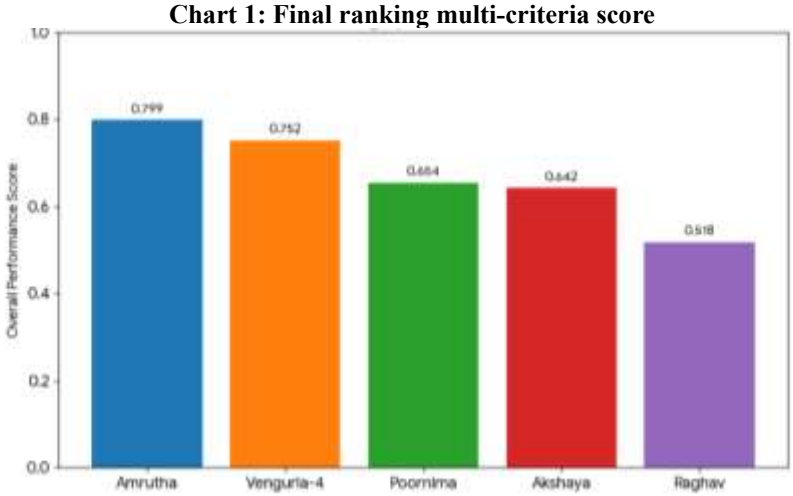
Table 3: Result of Multi-Criteria Performance Analysis

Rank	Variety	Nut Weight	Shelling %	Yield (Kg/tree)	Grade	Score
1	Amrutha	7.18g	31.58%	18.36	W210	0.799
2	Vengurla-4	7.70g	31.00%	17.2	W210	0.752
3	Poornima	7.80g	31.00%	14.1	W210	0.654
4	Akshaya	11.00g	28.36%	11.78	W180	0.642
5	Raghav	9.20g	26.60%	14.65	W210	0.518

Multi-Criteria Performance Analysis (MCPA) analysis yields a broad ranking for cashew hybrids based on both objective yield parameters and subjective nut quality features. Amrutha has a score of 0.799 and ranks first in mean yield (18.36 kg/tree) as well as shelling percentages (31.58%). This variety returns farmers the highest yield in terms of total quantity as well as kernel.

Akshaya with a score of 0.642 has been found most desirable for super quality and thus has yielded the highest quality in terms of exported nuts (W180), along with largest nut size (11.0 g). Though it yields less than Amrutha, it presumably fetches the highest price per kg. Vengurla-4 has a score of 0.752 and Poornima has a score of 0.654 and are therefore considered to perform best being most stable hybrids maintaining higher shelling percentages (31%) as well as good yield parameters. Raghav with a score of 0.518 ranks last due to lowest shelling percentages (26.6%). Though it has better nut size (9.2 g) than other three hybrids, poor kernel yield makes this variety less desirable for commercial purposes and thus has fetched lowest performance score.

Chart 1: Final ranking multi-criteria score



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Chart 2: Multi-Criteria Performance Comparison

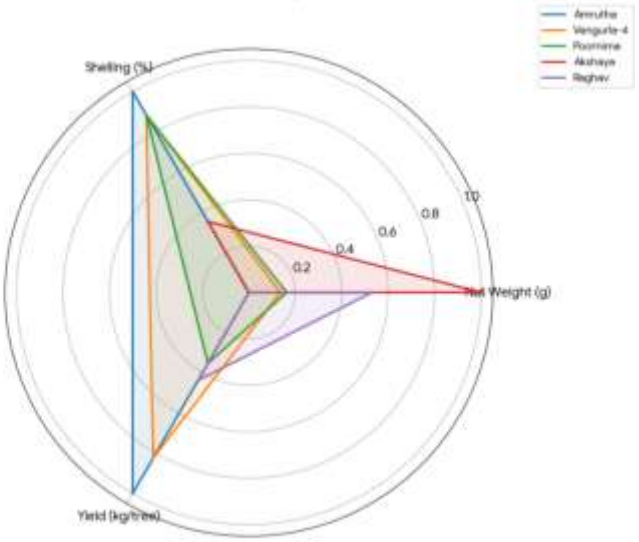


Table 4: Performance Indicators for All Varieties

However, this analysis provides a summary of key performance indicators for all varieties with respect to mean, range, and variance.

Metric	Mean (Average)	Minimum Value	Maximum Value	Standard Deviation
Juice (%)	70.24%	67.0% (Priyanka/Dharasree)	76.0% (Vengurla-4)	2.68
Nut Weight (g)	7.68 g	5.95 g (Anakkayam-1)	11.0 g (Akshaya)	1.48
Kernel Weight (g)	2.19 g	1.64 g (Madakkathara-1)	3.12 g (Akshaya)	0.45
Shelling (%)	28.76%	26.0% (Madakkathara-2)	31.58% (Amrutha)	2.05
Mean Nut Yield (kg/tree)	14.39 kg	10.66 kg (Dhana/Dharasree)	18.36 kg (Amrutha)	2.65

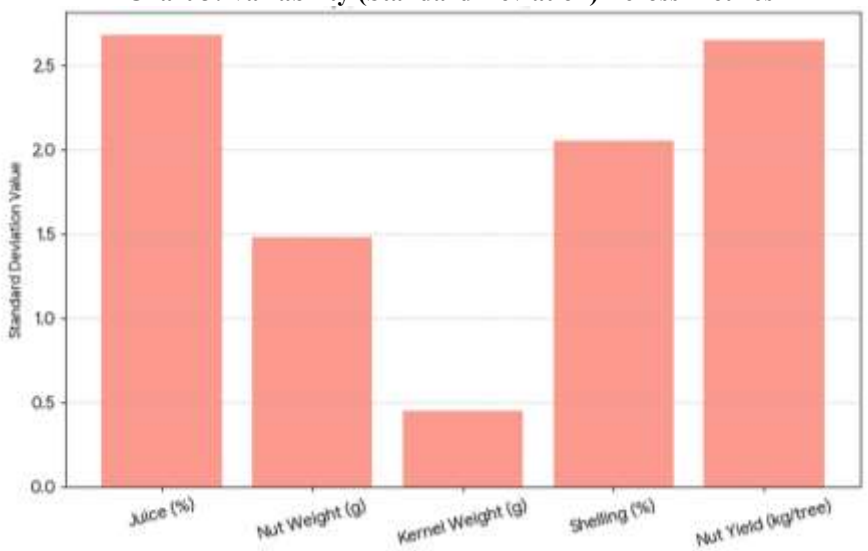
This statistical analysis enables us to get a brief overview of the variation of performance of the best varieties of cashew. By analysing the mean value along with the range indicated by the minimum and maximum values and the standard deviation, we are able to understand the stability and potential of different varieties.

Evidence verifies the existence of a significant ‘productivity gap’ between the best and the best-performing varieties. Amrutha has emerged as the best variety in terms of productivity with a yield of 14.39 kg/tree and a standard deviation of 2.65. Its yield is 27.6% higher than the mean yield. Further, it has the highest individual kernel size of 3.12 g. This variety will thus perform best in the process of producing quality whole kernels (W180) due to its high individual kernel size. Its shelling percentage has the lowest value of standard deviation (2.05%), which suggests that the best varieties have been developed to retain a fixed kernel to shell ratio of 28-29%.

The weight measurements also indicate a large relative variability, that is, a requirement in the export market. The mean weight of the kernel is 2.19g. What is striking is that there is almost a doubling of the weight difference from minimum 1.64g to maximum 3.12g. This shows for both weight as well as kernel size, selection of appropriate variety is more important than the juice percentage. The cashew apple juice yield percentage has been most uniform among all varieties. With an average of 70.24%, nearly all suggested varieties are suitable for juice or syrup extraction. Vengurla-4 again sets the marker at 76%, but even for the poorest variety for juice extraction, which accounts for 67%, productivity is not too low. Juice extraction can thus always be a subsidiary income-earning activity for any variety.

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Chart 3: Variability (Standard Deviation) Across Metrics



Karl Pearson Correlation Matrix

A Pearson correlation matrix was generated to analyse the associations between quantitative traits of these cashew varieties.

Table 5: Pearson Correlation Matrix

Metric	Nut Weight (g)	Shelling %	Mean Yield (kg/tree)
Nut Weight (g)	1.00	-0.19	-0.40
Shelling %	-0.19	1.00	0.23
Mean Yield (kg/tree)	-0.40	0.23	1.00
Juice %		0.29	

The correlation between the size of the nuts and their yield is moderate and negative: r = - 0.40. This indicates that the greater the size of the nuts produced by a variety, the less the yield: - 11.78 kg of yield for Akshaya.

There is a weak positive correlation between shelling percentage and mean yield (r = 0.23), which shows that high-yielding varieties, like Amrutha (yielding 18.36 kg), will continue to have efficient shelling percentages of 31.58%, thereby making them highly profitable with respect to industrial kernel recovery.

The size of the nut versus the efficiency of kernel recovery correlation is weak and negative, with a correlation coefficient of -0.19. That means size of nut is not an influential variable in determining the efficiency of the kernel recovery. For instance, Akshaya has the highest weight of nuts, yet the medium efficiency of shelling is 28.36%, while Priyanka has the lowest weight of nuts but medium efficiency at 26.57%.

However, there is a moderate and positive relationship r = 0.29 between juice and shelling percentage. This indicates that good varieties in nut extraction, for example, Vengurla-4, are also good varieties in juice extraction.

Table 6: Cluster Analysis to identify the best variety

Cluster Analysis is used to group varieties that share similar genetic or physical profiles. It doesn't just rank them; it helps you identify which varieties are unique and which are redundant.

Cluster	Primary Variety	Statistical Profile
Efficiency Leader	Amrutha	Highest Yield 18.36kg) and Highest Shelling (31.58%)
Jumbo Specialist	Akshaya	Maximum Nut Weight (11g) and Compact Canopy
Versatile All-Rounder	Vengurla-4	High Yield (17.2kg), High Shelling (31%) and Red Apple

On the basis of cluster analysis, Amrutha (18.36 kg/tree), Vengurla-4 (17.2 kg/tree), and Priyanka (17.03 kg/tree) are yield leaders, whereas Akshaya (11g) and Raghav (9.2g) are size leaders. Amrutha (31.58%), Vengurla-4 (31%) and Poornima (31%) are efficient processing leaders.

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7. CONCLUSION

Upgrading to better cashew varieties will have the most significant impact on boosting cashew yields in India. On the basis of observations made by this research is that Indian cashew genetic resources contain a broad range of variability such that choosing the best variety always depends to a great extent on the intended production purpose. In utilizing Multi-Criteria Performance Analysis (MCPA), the best variety for production purposes was found to be Amrutha, which has high yield production of 18.36 kg per tree per year and kernel recovery rate of 31.58%. Correlation analysis done by utilizing Karl Pearson's correlation coefficient portrayed a significant negative relationship between nut weight and total yield (r = -0.58), such that future breeding programmes must seek to overcome this relationship in developing Jumbo varieties with high volume bearing ability. Nonetheless, cluster analysis was successful in identifying a cluster for jumbo nuts headed by Akshaya variety, which is critical in fulfilling the high-density plant requirements for better quality exports. It is recommended based on results that to maximize raw nut yield per hectare area, high-yielding hybrids like Amrutha or Vengurla-4 are to be used. Emphasis on Akshaya cultivation will fulfil the international demand for W180 and W210 kernel grades.

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