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Cucumis melo var. *callosus*: A Hidden Genetic Resource for Future Vegetable Breeding

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Kachri (*Cucumis melo* var. *callosus*), a non-dessert melon native to north-western India's arid zones, is an underutilized vegetable with significant breeding value. Systematic germplasm exploration by ICAR-CIAH (1994–2001) assembled ~625 accessions; 68 were conserved after multi-season evaluation, revealing wide variation in fruit traits, yield and stress tolerance. Two improved varieties, AHK-119 (50–60 g fruits; 68–70 days to maturity; 95–100 q/ha) and AHK-200 (100–120 g; 65–67 days; 115–120 q/ha), were released and widely adopted by farmers in Rajasthan. Selection remains the primary breeding method, but hybridization, backcrossing and recurrent selection offer routes to combine earliness, fruit quality and pest/disease resistance. Recent generation-mean analysis in kachri × elite melon crosses revealed dominance and epistatic gene action for key fruit-quality traits, supporting heterosis breeding. Kachri also serves as a donor for cultivated melon improvement, particularly for stress tolerance and earliness. Molecular markers (RAPD, future SNPs) confirm substantial genetic diversity. Future strategies include core-collection development, multi-trait evaluation, donor-line maintenance and introgression into elite melon, integrating conventional breeding with molecular tools and, potentially, speed breeding and genome editing.

Introduction

Vegetable breeding is conventionally associated with high-value horticultural crops such as tomato (*Solanum lycopersicum*), chilli (*Capsicum annuum*), onion (*Allium cepa*), brinjal (*Solanum melongena*) and cucumber (*Cucumis sativus*) (Bal et al. 2019). However, several underutilized species harbour substantial genetic resources that remain largely unexploited outside their centres of diversity. Kachri, a non-dessert melon belonging to *Cucumis melo* var. *callosus* (syn. *C. melo* var. *agrestis*; earlier literature also used *Cucumis callosus*), exemplifies this category. A member of the Cucurbitaceae, kachri is traditionally cultivated in the hot arid and semi-arid regions of north-western India, particularly Rajasthan, where it forms an integral component of mixed farming systems. Its fruits are utilized in chutneys, pickles, salads, culinary preparations and dehydrated products, and the crop has been formally recognized by ICAR as a drought-hardy vegetable adapted to arid agro-ecologies.

From a plant-breeding perspective, the significance of kachri transcends its traditional culinary role. Its principal value lies in the extensive genetic variation retained within its landraces and semi-domesticated populations, which constitute a reservoir of alleles for traits such as earliness, stress tolerance, fruit quality and yield stability.

Genetic Diversity and Germplasm Resources

The foundation of any breeding programme is genetic variability (Bal et al. 2019; Bal et al. 2020, Bal et al. 2022), and kachri exhibits considerable diversity across morphological, horticultural and molecular dimensions. Traditional populations differ markedly in fruit size, shape, colour, maturity, fruit number per vine, yield and quality attributes. Molecular characterization using RAPD markers has further confirmed substantial polymorphism within non-dessert *Cucumis* germplasm, with studies reporting up to 60% genetic diversity among accessions and clear differentiation between kachri and related morphotypes such as *var. momordica*. Systematic exploration of kachri and allied non-dessert melon types in Rajasthan during 1994–2001 resulted in the assembly of approximately 625 accessions. Following repeated multi-season evaluation under hot arid conditions, 68 representative germplasm lines were conserved for long-term maintenance and breeding utilization. Considerable variation was documented for plant growth habit, phenology, fruit morphology, skin colour, organoleptic quality and yield components. Based on comprehensive horticultural evaluation, accessions including AHK-5, AHK-13, AHK-26, AHK-40, AHK-43, AHK-99, AHK-109, AHK-119, AHK-155, AHK-200, AHK-202, AHK-356, AHK-411, AHK-564 and AHK-572 were identified as promising donors for breeding programmes. This diversity creates opportunities for direct selection, hybridization, donor identification and pre-breeding, particularly when breeding objectives extend beyond yield to encompass resistance, adaptation, earliness and fruit-quality parameters (Bal et al. 2020, Bal et al. 2021).

Germplasm Exploration and Institutional Leadership

The development of improved kachri cultivars has its origins in systematic germplasm exploration led by the ICAR-Central Institute for Arid Horticulture (ICAR-CIAH), Bikaner. The institute has played a pivotal role in collecting, conserving, characterizing and utilizing kachri germplasm through extensive field surveys across Rajasthan. The maintained germplasm encompasses different forms of non-dessert melon, including kachri, mat-kaachr and intermediate types, and has been evaluated repeatedly for plant morphology, maturity, fruit utility, fruit size and shape, skin colour, quality, yield and overall field performance under heat-stressed arid environments (Figure 1). This work underscores a fundamental principle of genetic-resource management: germplasm conservation attains maximum value when conserved material is properly characterized and subsequently incorporated into structured breeding programmes.

From Indigenous Germplasm to Released Varieties

One of the most significant achievements in kachri improvement has been the development and release of two cultivars, AHK-119 and AHK-200, by ICAR-CIAH. AHK-119 was selected from native kachri landraces and developed for systematic cultivation and promotion of kachri as a vegetable crop in hot arid regions. ICAR reports that the variety was subsequently disseminated widely and adopted by farmers, and it is cultivated during both rainy and summer seasons. According to ICAR-CIAH documentation, AHK-119 produces small, egg-shaped fruits weighing approximately 50–60 g, reaches harvest maturity in about 68–70 days after sowing, bears approximately 22 fruits per vine and yields 95–100 q/ha. AHK-200, classified as a mat-kaachr type, produces somewhat larger fruits of approximately 100–120 g, matures in about 65–67 days and has a reported yield potential of 115–120 q/ha under the institute's described conditions. Detailed evaluation reports indicate mean yields of approximately 96.65 q/ha for AHK-119 and 109.52 q/ha for AHK-200, with both varieties characterized by early harvesting and tolerance to multiple stresses under arid production conditions. The importance of AHK-119 extends beyond its varietal release. ICAR documentation records substantial farmer adoption in hot arid and semi-arid regions, demonstrating a successful trajectory from landrace to selected genotype to improved variety to farmer adoption. Thus, kachri already provides a practical example of genetic-resource utilization rather than merely a theoretical breeding possibility.

Selection as a Breeding Strategy

Selection remains one of the most relevant and cost-effective breeding approaches for kachri, particularly given the heterogeneous nature of traditional populations. When a population contains plants differing in fruit quality, maturity, fruit number or yield, superior individuals can be identified and their progenies evaluated over successive generations (Bal et al., 2022; Bal et al. 2023, Amir et al. 2023). Repeated selection and progeny testing can gradually improve uniformity and performance (Amir et al. 2023). However, selection should not depend on single-season observations (Bal et al. 2024). Quantitative traits such as yield, fruit weight and fruit number are influenced by both genotype and environment; therefore, promising selections require evaluation over generations and, preferably, across seasons or locations (Bal et al. 2023; Aruna et al., 2024). The development of AHK-119 and AHK-200 illustrates how systematic evaluation of indigenous germplasm can ultimately produce cultivars with improved horticultural performance. The breeding pathway can be described as a sequential process in which diverse germplasm is evaluated, superior plants are selected, progenies are tested, lines are purified through repeated selection, multi-season evaluation is conducted and, finally, a variety is developed and released (Bal et al. 2024; Sharangi et al. 2025). For underutilized crops, this approach is particularly valuable because large, highly structured breeding populations may not yet be available.

Hybridization and Parent Selection

Selection alone may not provide a genotype containing all the traits required in a commercial variety (Bal et al. 2025). Hybridization becomes important when breeders aim to combine complementary traits from different accessions (Bal et al. 2024). For instance, one kachri accession may possess desirable fruit quality, another may exhibit early maturity, while a third may show promising resistance to a particular pest. Rather than selecting one accession and losing the remaining traits, breeders can attempt to combine them through crossing (Bal et al. 2025). A general breeding pathway involves crossing Parent A with Parent B to produce an F_1 generation, followed by advancement to F_2 or backcross generations, selection within segregating populations and development of advanced breeding lines. The success of such a programme depends heavily on appropriate parent selection (Bal et al. 2022). Genetic divergence can assist in identifying contrasting parents, while actual field performance determines whether those parents possess useful breeding attributes (Bal et al. 2021, Bal et al. 2022). Genetic divergence and variability studies in other vegetable crops, such as onion (Bal et al. 2020, Bal et al. 2021, Bal et al. 2022) have demonstrated the value of combining phenotypic characterization with quantitative genetic analysis for identifying suitable parents, and similar approaches could help structure future kachri breeding programmes.

Kachri as a Donor Parent for Melon Improvement

Perhaps the most promising future role of kachri is as a donor of useful traits to cultivated melon. Landraces and related non-dessert melon types may carry characteristics that are less common in elite commercial material, such as stress tolerance, earliness or specific fruit-quality attributes. These resources can therefore be used in pre-breeding to broaden the genetic base of cultivated melon. This is consistent with the wider concept of crop wild relative and related-germplasm utilization (Bal et al. 2025). Such materials may not possess the complete combination of characters required in a commercial cultivar, but a particular accession may carry one or two highly valuable traits. Pre-breeding can follow a pathway in which a donor accession is crossed with an elite cultivar, a segregating population is generated, selection is applied for the target trait and the elite horticultural background is recovered through repeated backcrossing or selection (Bal and Sharangi 2025). The utilization of crop wild relatives and related germplasm has increasingly been recognized as an important strategy for broadening the adaptive potential of vegetable crops (Bal et al. 2025). For kachri, this concept is especially relevant because its close relationship with *C. melo* creates opportunities for utilizing its genetic variation in melon improvement.

Crossing Kachri with Commercial Melon: Generation-Mean Analysis

Recent work has provided a particularly interesting example of this approach. Generation-mean analyses involving crosses between non-dessert melon types (including *C. melo* var. *callosus* and var. *momordica*) and commercial muskmelon cultivars such as Hara Madhu have elucidated the genetic architecture of key fruit-quality traits. In these studies, six generations or populations—P_1, P_2, F_1, F_2, BC_1P_1 and BC_1P_2—were evaluated over multiple seasons for traits including fruit length, fruit diameter, flesh thickness, cavity width, fruit shape, fruit weight, total soluble solids and titratable acidity. The findings indicated that an additive-dominance model alone was insufficient to explain the inheritance of several quality traits. Dominance and dominance × dominance interactions were important, while duplicate epistasis was observed for several traits, including total soluble solids, average fruit weight, flesh thickness and titratable acidity. Consequently, the authors highlighted the potential usefulness of heterosis breeding or recurrent selection for improving complex fruit-quality traits. This body of work is significant for kachri breeding because it moves the discussion from simply conserving the crop to understanding how its genetic variation can be incorporated into breeding populations and how complex traits are inherited in segregating generations derived from kachri × elite melon crosses.

Backcross Breeding for Trait Introgression

When the objective is to transfer a particular useful trait from kachri into an otherwise desirable commercial background, backcross breeding can be considered. A simplified scheme would involve crossing an elite melon with a kachri donor to produce an F_1, followed by successive backcrosses (BC_1, BC_2, BC_3) to the elite parent while selecting for the desired donor-derived characteristic. This strategy is particularly suitable when the breeder has identified a specific trait worth transferring and the elite parent already possesses most of the required commercial characteristics (Figure 2). For example, if a kachri accession demonstrates a useful level of pest resistance but has undesirable fruit characteristics, it may be more efficient to use it as a donor than to develop an entire commercial variety from that accession. The distinction is important: a donor genotype provides a useful trait; breeding converts that trait into a commercially useful genetic background.

Breeding for Pest and Disease Resistance

Kachri germplasm has also attracted attention because different accessions can vary in their response to pests and diseases. The extensive germplasm evaluations conducted under arid conditions included observations on disease incidence and fruit-fly infestation. Such screening provides an initial basis for identifying contrasting materials for subsequent resistance breeding. The same breeding principle is well established in other vegetable crops. In chilli, for example, systematic screening has been used to identify donor parents against leaf curl and anthracnose (Bal et al. 2024, Bal et al. 2025), followed by breeding efforts aimed at combining resistance with commercially important traits (Bal et al. 2026). For kachri, similar strategies could involve screening, identification of resistant accessions, confirmation under controlled or repeated conditions, hybridization, selection and advanced testing. Resistance should ideally be combined with yield, maturity, fruit quality and market acceptability rather than treated as an isolated breeding objective.

Multi-Trait Breeding Objectives

The development of an improved vegetable variety requires more than simply increasing yield (Bal and Sarangi, 2026). For kachri, breeding objectives may include early and uniform maturity; high marketable yield; desirable fruit size and shape; acceptable taste and quality; suitability for fresh consumption and processing; resistance or tolerance to important pests and diseases; adaptation to hot and water-limited environments; uniformity of fruits; and alignment with consumer and market preference. This multi-trait approach is increasingly important in vegetable breeding. Studies of genetic variability and heritability in onion have demonstrated the importance of evaluating yield together with quality characteristics, while disease-resistance breeding in chilli has emphasized combining resistance with commercially important horticultural traits (Bal et al. 2024; Bal, 2025). Kachri improvement can similarly move from single-trait selection towards balanced multi-trait breeding.

Contribution of Biotechnology

Conventional breeding is likely to remain the foundation of kachri improvement, but biotechnology can increasingly support the process. The first requirement is better genetic characterization. Molecular markers can help determine relationships among accessions, verify hybrid identity and provide a more precise picture of genetic diversity. The earlier RAPD studies established the presence of substantial molecular variation; modern SNP-based genotyping could provide much higher resolution. Marker-assisted selection could become particularly useful once reliable markers are identified for traits such as resistance, maturity or fruit quality. Molecular breeding approaches have already become important in vegetable improvement, particularly for incorporating resistance to biotic and abiotic stresses. Genomic studies in crops such as garlic have likewise demonstrated how molecular information can deepen understanding of crop diversity and facilitate future improvement. For kachri, however, biotechnology should initially be viewed as a support system for breeding rather than a substitute for field selection.

Genome Editing: A Future Possibility

Genome editing technologies such as CRISPR-Cas have considerable potential in crop improvement, but their application to kachri should presently be regarded as a future possibility rather than an established breeding pathway. Genome editing requires a sufficiently strong understanding of the genetic basis of the target trait. Therefore, before editing becomes practical, kachri breeding would benefit from a stronger foundation of germplasm characterization, phenotyping, genetic mapping, candidate-gene identification, functional validation and targeted improvement. The increasing use of RNA interference and other molecular approaches for stress improvement in crops also indicates how biotechnology may eventually complement conventional breeding (Bal,, 2025). For an underutilized crop such as kachri, however, the immediate priority remains the systematic discovery and characterization of its existing genetic resources.

Speed Breeding and Modern Breeding Pipelines

Another potential area is the application of speed breeding. The basic advantage of speed breeding is the acceleration of generation turnover, allowing breeders to reach advanced generations more rapidly than under conventional seasonal cycles (Bal and Sharangi, 2025). The approach has been described as a major shift in crop improvement because reducing generation time can shorten the overall breeding cycle. For kachri, adaptation of such approaches would require optimization of photoperiod, temperature, plant density, flowering and seed-production conditions. Once suitable protocols are established, rapid generation advancement could complement conventional selection and molecular screening. This would be particularly useful where breeders need to handle segregating populations derived from kachri × elite melon crosses.

Future Potential and Strategic Directions

The next phase of kachri improvement could bring together germplasm conservation, conventional breeding, quantitative genetics and molecular characterization. A representative core collection could first be assembled from the existing diversity. These accessions could then be evaluated systematically for yield, earliness, fruit quality, pest resistance, disease resistance, adaptation and processing potential. The most promising accessions could be used in three complementary ways. First, superior indigenous material can continue to be selected and improved for uniformity, yield, quality and market preference. The successful development of AHK-119 and AHK-200 provides an established foundation for this approach, and ICAR-CIAH continues to list these two cultivars among its kachri varieties, with AHK-119 particularly noted for commercial cultivation in rainy and summer seasons. Second, selected kachri accessions with particularly useful traits could be maintained as specialized donor lines. Their value would not necessarily depend on their direct commercial cultivation. Third, where useful traits are identified, kachri-derived material could be incorporated into cultivated melon through hybridization, backcrossing, recurrent selection and, where appropriate, marker-assisted selection. The recent generation-mean analysis involving *C. melo* var. *callosus* demonstrates that this third pathway is already receiving scientific attention, particularly for understanding the inheritance of fruit-quality traits.

Conclusion

Kachri may still be unfamiliar to many vegetable consumers, but its breeding history demonstrates that an underutilized crop can possess considerable scientific and agricultural value. The work undertaken through ICAR-CIAH has already shown what systematic germplasm utilization can achieve. Extensive collection and evaluation of indigenous material led to the identification of promising genotypes and ultimately to the development and release of AHK-119 and AHK-200. Their subsequent cultivation demonstrated that improvement of a traditional crop can translate into practical farmer adoption. The future opportunity lies in going beyond selection of improved kachri varieties. Its genetic diversity can potentially be used in pre-breeding, hybridization, backcrossing, recurrent selection and donor development, particularly for traits related to fruit quality, earliness, pest and disease resistance and adaptation. Recent crossing studies involving *C. melo* var. *callosus* further indicate that kachri-related material can contribute to the genetic analysis and improvement of complex melon traits. Molecular markers, genomic characterization and eventually genome editing may add precision to these efforts, but their greatest value will come when they are integrated with strong field-based breeding and well-characterized germplasm. Kachri therefore represents more than a forgotten vegetable of the desert. It is an example of how indigenous diversity, systematic breeding and modern genetic tools can converge to create new possibilities for crop improvement.

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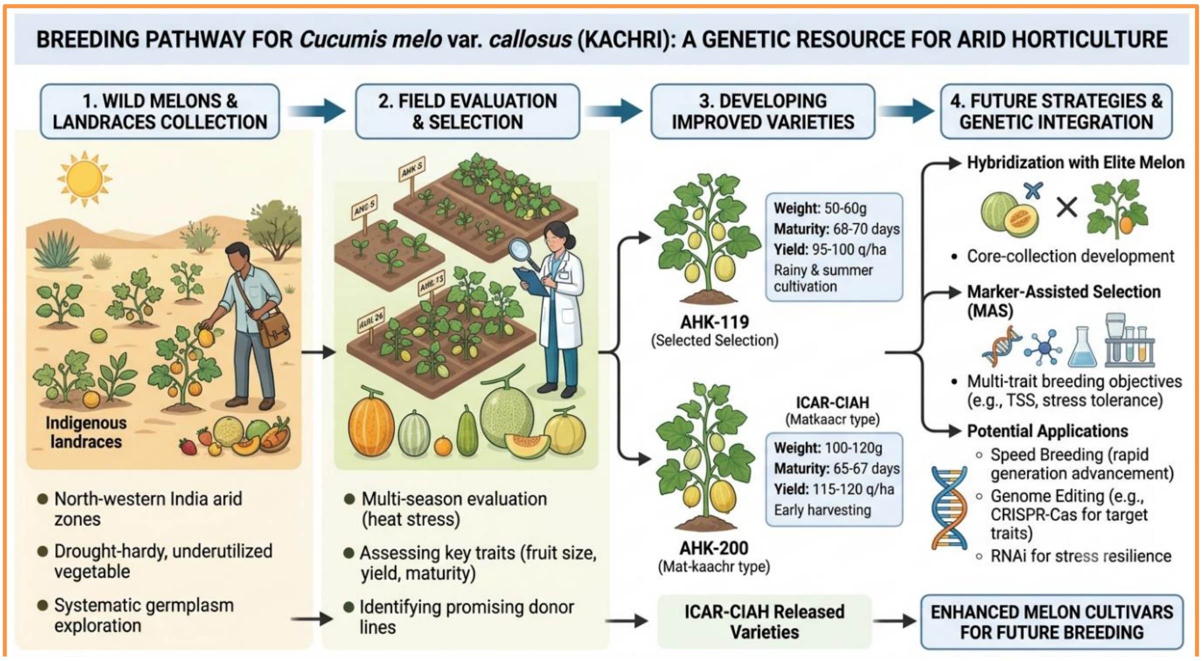

Figure 1: Germplasm Utilization and Breeding Pathway

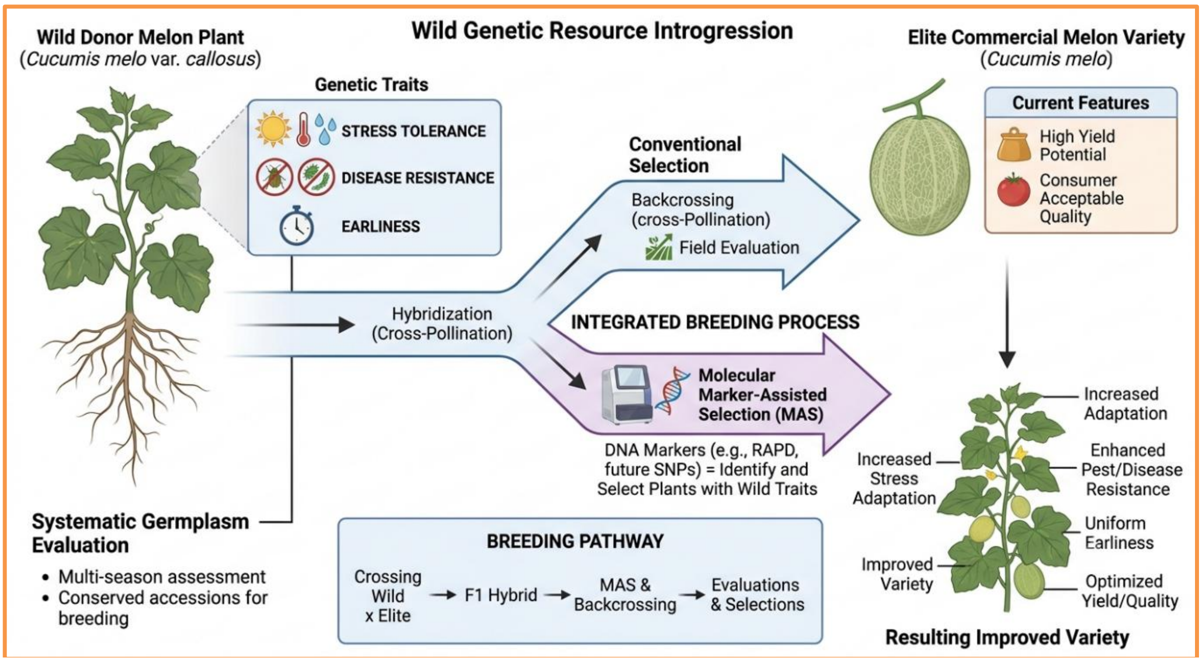

Figure 2: Trait Introgression and Multi-Trait Improvement