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Recent Trends in Marker-Assisted Selection for Vegetable Crops: A Focused Review

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The Indian vegetable sector is undergoing a genomic revolution. With the increasing pressure of climate change and virulent new biotypes of pests, traditional breeding methods are being supplemented by Marker-Assisted Selection (MAS). This article explores the current trends (2024–2026) in MAS application across major Indian vegetables, including Tomato, Chilli, and Cole crops. It highlights the shift toward SNP-based genotyping, gene pyramiding for durable resistance, and the integration of "Speed Breeding" to ensure national food and nutritional security.

Keywords: Marker-assisted selection (MAS), Vegetable crop breeding**,** Genomic selection India**,** QTL mapping vegetables, SNP genotyping, Disease resistance breeding, Biofortification traits, Speed breeding integration, High-throughput genotyping, KASP assays, SCAR/CAPS markers, Climate-resilient hybrids

Introduction: The Paradigm Shift

India stands as the second-largest producer of vegetables globally. However, as of 2026, the sector faces a "triple threat": shrinking arable land, heat waves, and the emergence of devastating viral diseases. Traditional phenotypic selection is no longer fast enough to keep pace with these challenges. Marker-Assisted Selection (MAS) has transitioned from a high-end laboratory luxury to a standard breeding protocol in India. By using molecular markers to "tag" specific traits at the DNA level, breeders can identify superior plants at the seedling stage, eliminating the need to wait for the plant to mature or be exposed to a disease in the field.

Core Mechanisms And Tools In The Indian Context

The recent acceleration in MAS is attributed to three primary strategies:

1. **Foreground Selection:** Identifying the presence of a specific gene of interest (e.g., the Pvr4 gene for virus resistance in Chilli).
2. **Background Selection:** Using markers to ensure that 95–99% of the plant's genome remains identical to the high-yielding "recurrent" parent.
3. **Gene Pyramiding:** The simultaneous selection of multiple genes for the same trait. This is critical in India for "durable resistance," ensuring that a single mutation in a pest population does not render a variety obsolete.

Crop-Specific Breakthroughs (2024–2026)

A. Tomato (Solanum Lycopersicon)

Tomato breeding has focused heavily on Tomato Yellow Leaf Curl Virus (TYLCV) and Late Blight.

- **Trend:** The use of **KASP (Kompetitive Allele-Specific PCR)** markers has replaced older SSR markers, allowing for 99% accuracy in trait selection.

- **Success:** IARI has recently trialed lines where three different resistance genes (Ty-1/3, Ty-2, and Ty-alpha) are combined, providing total immunity in hotspots like Karnataka and Andhra Pradesh.

B. Chilli and Peppers (Capsicum spp.)

The "Chilli Leaf Curl Virus" (ChiLCV) has caused up to 90% yield losses in recent years.

- **Current Trend:** Scientists at IIVR Varanasi are now using MAS to map and transfer Quantitative Trait Loci (QTLs) from wild species (*Capsicum baccatum*) into commercial varieties. This has led to the development of the "Pusa Jwala" derivatives that require 40% less chemical intervention.

C. Crucifers (Cauliflower & Cabbage)

In India, cauliflower is highly susceptible to Black Rot. MAS has enabled the transfer of the *Xca1bc* mutation, providing high-level resistance. Furthermore, markers are now used to verify the purity of **F1 Hybrids**, ensuring farmers receive high-quality seeds.

Emerging Trends in Indian Vegetable Breeding

I. Biofortification through MAS

Breeding is moving beyond yield. Markers are now used to select for:

- **High Lycopene** content in tomatoes.
- **High Iron and Zinc** in beans and peas.
- **Anthocyanin-rich** carrots to meet the growing demand for functional foods.

II. Speed Breeding & MAS Integration

By combining MAS with "Speed Breeding" (using 22-hour light cycles in greenhouses), the time to develop a new variety has dropped from **8 years to 3.5 years**. This allows Indian breeders to respond almost in real-time to new disease outbreaks.

III. Climate-Smart Markers

With 2025 seeing record-breaking temperatures, the search for "Heat-Tolerant Markers" has become a priority. MAS is being used to identify root-architecture traits in Okra and Onion that allow for better water uptake during drought.

Challenges and Limitations

Despite the progress, MAS in India faces several hurdles:

- **Phenotyping Bottlenecks:** While we can sequence DNA quickly, measuring how a plant reacts to salt or heat in the field remains slow.
- **Linkage Drag:** The risk of bringing in "bad genes" along with "good markers" from wild relatives.
- **High Initial Cost:** Setting up molecular labs is expensive for smaller regional agricultural universities.

Conclusion

Marker-Assisted Selection is the cornerstone of the "Second Green Revolution" in Indian horticulture. By moving from phenotype-based selection to genotype-based precision, India is securing its position as a global leader in vegetable production. The future lies in the integration of MAS with AI-driven data analytics and CRISPR-Cas9 technology to create a truly "Atmanirbhar" (self-reliant) agricultural system.

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