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Multi-Parent Population Breeding: An Emerging Toolbox for Rice Genetic Improvement

*Riddhi S. Karmata[1], Dhrupal P. Nakum[2] and Praful M. Sondarava[3]
[1]Ph.D. Scholar, Department of Genetics and Plant Breeding, N. M. College of Agriculture, Navsari Agricultural University, Navsari-396450, Gujarat, India
[2]Agricultural Officer, Regional Research Station, Bhachau-Kutchh-370140, Sardarkrushinagar Dantiwada Agricultural University, Gujarat, India
[3]Ph.D. Scholar, Department of Genetics and Plant Breeding, B.A. College of Agriculture, Anand Agricultural University, Anand-388110, Gujarat, India
*Corresponding Author's email: riddhisk2810@gmail.com

Rice (*Oryza sativa* L.) s one of the most important staple food crops in the world, feeding more than half of the global population.However, rice production faces yield stagnation, vulnerability to diseases and pests and environmental stresses such as drought, flooding, and soil salinity, The traditional bi-parental breeding methods have limited genetic diversity and limited mapping resolution for complex traits, Multi-parent population (MPP) breeding has emerged as a promising approach, offering new tools and methodologies to enhance the efficiency and effectiveness of rice breeding programs

In rice two main types of MPP have been developed

1. Multiparent Advanced Generation Intercrosses (MAGIC)
2. Nested Association Mapping (NAM)

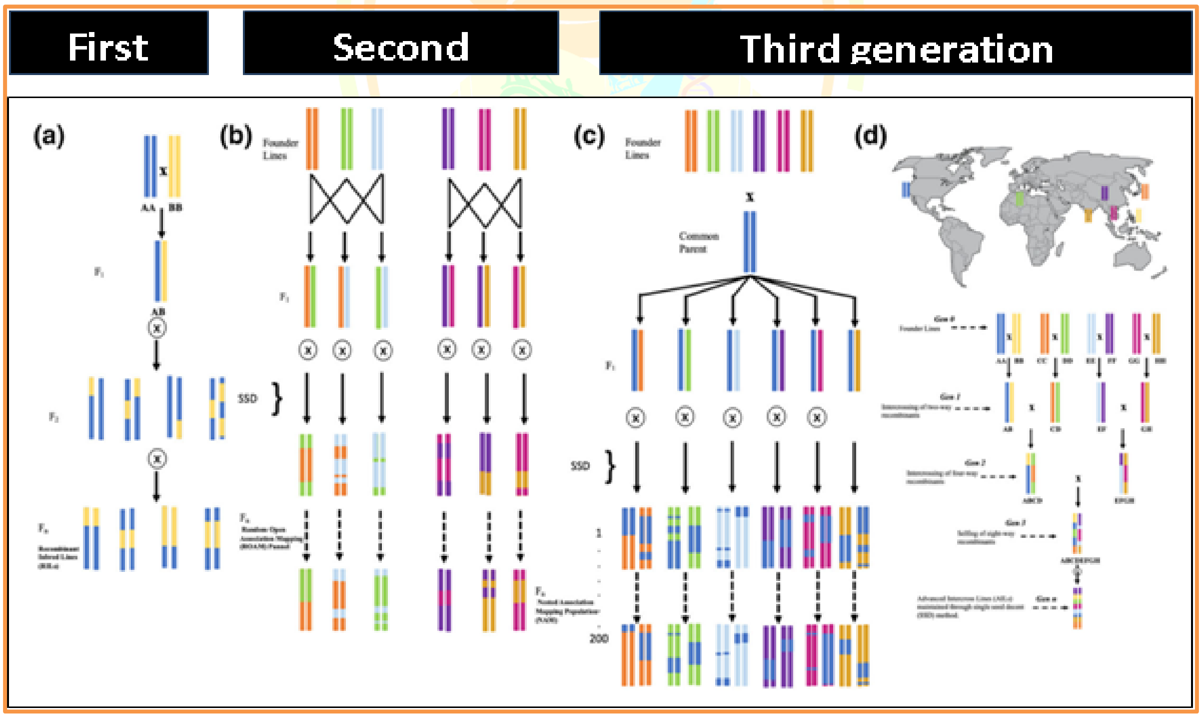


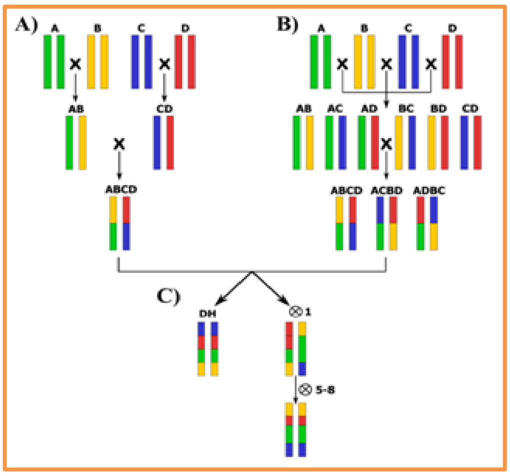
Fig. Comparison and developmental scheme of different mapping populations. (a) Bi-parental population. (b) Random open association mapping (ROAM) panel (c) Nested association mapping (NAM) population (d) Multi-parent Advanced Generation Intercross (MAGIC) population (Samantara *et al.*, 2021).

Stages of MAGIC population development design for eight founders
(A) Selection of founders based on geographic, genetic, phenotypic diversity
(B) Mixing of parents together in predefined patterns, or funnels (denoted by symbol on right)
(C) Intercrossing of individuals (generations denoted by number within crossed circle) derived from different funnels for additional generations
(D) Selfing (generations denoted by number within circular arrow) or double haploidization of individuals either directly from funnels or after advanced intercrossing to form inbred lines

Selection of Founder

- The number of founder lines selected for the development of MAGIC population in plants varies from 4 to 19 parents
- Selection criteria may be based on different prospects in crops, encompassing
    - Geographical origins of the lines
    - Genetic diversity
    - Agronomic performance
    - Disease resistance
    - Tolerance to abiotic stresses

Crop quality requirements



- Wild relative species or landraces coming from different origins that are very well adapted to their specific growing conditions
- Commercial cultivars or elite breeding lines with desirable traits
- Well characterized at the molecular and physiological levels
- Previously resequenced founders enables better design strategies to identify causal polymorphisms underlying QTLs

Cross-designs of a 4-way MAGIC population where the founders are A, B, C, and D: (A) "funnel" design; (B) "diallel" design; and (C) achievement of homozygous individuals by doubled haploids (DH) production, or by several rounds of selfing following the single-seed descent (SSD) method **(Arrones *et al*., 2020)**

The "funnel" approach

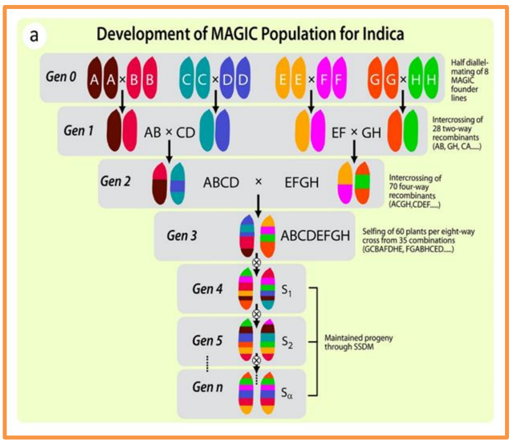
The funnel is created by several generations of inter-crossing among a number (n) of elite parental lines to obtain n/2 F1 hybrids, which are subsequently intercrossed in a set mating design to combine the genomes of all founders in the progeny lines

The "diallel" approach

Parents are crossed according to a diallel or half-diallel design

Inter-crossing the parents in multiple funnels by a half-diallel mating system (two-way crosses), followed by the inter-crossing of the resulting F1s until all the founders are represented in a single generation

In the case of eight parental lines, a total of 28 two-way, 14 four-way, and seven eight-way crosses could be performed



Crossing schemes to produce four multi-parent advanced generation inter-cross (MAGIC) populations

Development of the indica MAGIC population. The same scheme was used for the development of the japonica MAGIC population b) Development of the MAGIC plus and global MAGIC populations. The global population includes eight indica and eight japonica founder lines, which carry QTLs conferring tolerance of biotic and abiotic stresses. A, B, C, D, E, F, G and H – represent the 8 indica parents; I, J, K, L, M, N, O and P – represent the 8 japonica parents; Gen- generation; SSDM – single seed descent method ,S – selfing

Applications of Multi-parent Advanced Generation Intercross (MAGIC) population in rice

Economically Important Traits

- Abiotic stresses
- Biotic stresses
- Yield related stresses

Genetic Resource Development

- Development of NILs
- Development of elite breeding lines
- Development of multiple sets of RILs

Genetic Analysis

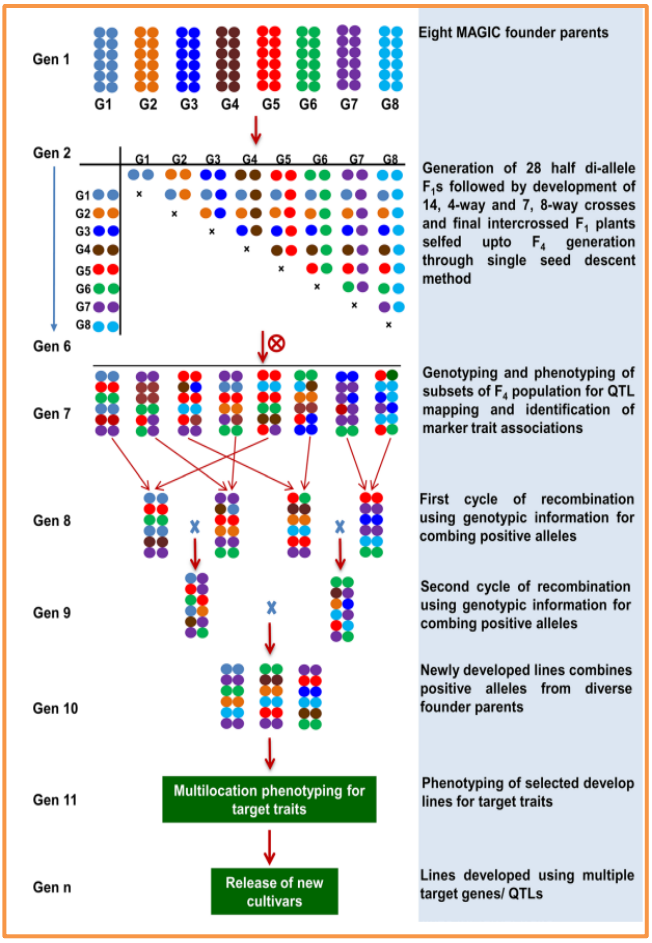
- Coarse mapping
- Fine mapping
- Gene functional analysis

Multi-Trait Analysis

- Detection of pleiotropic QTL
- Detection of closely linked QTL

Multi-parent advanced generation recurrent selection (MAGReS) approach for development of new breeding lines

- Development of MAGIC lines is followed by QTL analysis from which markers associated with the trait of interest can be identified
- MAGIC lines possessing large numbers of desired alleles are selected and combined for 2–3 additional cycles of recombination through marker-assisted recurrent selection (MARS), leading to the development of superior breeding lines
- G1, G2, G3, G4, G5, G6, G7 and G8 represent the 8 diverse founder genotypes; Gen generation



Advantages

- Shuffling the genes across different parents enable accurately ordering the genes
- Increased recombination
- Novel rearrangements of alleles and greater genetic diversity
- Fine mapping
- Epistatic and G X E interactions

Disadvantages

- Extensive segregation

- More time consuming approach
- Large scale phenotyping

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