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Biotechnological Approaches for Stable Sex Expression in Castor

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Abstract: -

Castor (*Ricinus communis* L.) is an economically important oilseed crop valued for its high-quality oil and industrial versatility. Stable sex expression, particularly maintenance of pistillate (female) lines, is essential for hybrid seed production and yield improvement. However, instability in sex expression, frequent reversions, and environmental sensitivity present ongoing challenges. Biotechnological strategies—combining molecular, genetic, hormonal, and breeding approaches—are now central to overcoming these hurdles and securing stable pistillate lines in castor.

Keywords: Biotechnological strategies

Molecular and Genetic Strategies:

Recent advances in genomics and transcriptomics have unraveled the complexity of sex determination in castor. Studies have identified more than 3,000 differentially expressed genes (DEGs) between monoecious and pistillate lines, revealing extensive genetic involvement in sex expression. Among these, genes such as Short Chain Dehydrogenase Reductase 2a (SDR2a) and WUSCHEL have been highlighted as potentially crucial for sex regulation and reversion.

Transcriptomic and proteomic analyses show that castor floral development passes through an initial bisexual stage, after which organ-specific developmental arrest (*e.g.*, pistil or stamen abortion) determines final sex phenotype.

Marker-assisted selection (MAS) utilizes molecular markers linked to sex-determining loci to rapidly identify and propagate stable pistillate genotypes. Such precision breeding speeds the development and multiplication of lines less prone to environmental or genetic sex reversions.

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Hormonal Manipulation and Regulation

Phytohormones play a critical role in determining and stabilizing sex expression in castor. Differential expression of hormone-related genes—especially those involved in auxin, gibberellin, abscisic acid (ABA), and jasmonic acid pathways—affects floral organ development and sex fate. Transcriptomic studies reveal that higher auxin levels at critical floral stages favour femaleness, while increased gibberellin or altered ethylene signalling may induce maleness or sex reversals.

Biotechnological intervention includes the exogenous application of growth regulators (such as Ethrel/ethephon) to manipulate hormonal environment, maintaining pistillateness and minimizing the risk of sex reversion under diverse field conditions. Ethrel treatment has been specifically shown to increase pistillateness and support hybrid seed purity. Genetic engineering targeting hormone biosynthesis and signal transduction genes is being explored to create lines with built-in hormonal stability.

Cytogenetic and Mutation Breeding

Chromosomal and cytogenetic studies indicate that sex expression may also be affected by chromosome number and structure. Haploid plants are typically sterile, while trisomics produce predominantly male flowers, hinting at cytogenetic control mechanisms. Polyploidy induction and mutation breeding—using chemical mutagens or radiation—can develop novel allelic variants with reduced environmental sensitivity and more stable female expression.

Mutation breeding expands genetic diversity and facilitates the creation of lines with new regulatory or structural features that support stable sex traits. These approaches are complemented by molecular screening to select variants with high production value and sexual stability.

Male Sterility and Hybrid Production

Male sterility is a key technique for maintaining hybrid seed purity. Approaches such as cytoplasmic male sterility (CMS) and genetic male sterility (GMS) have been used in other crops and are under evaluation in castor. CMS systems, when available and stable, allow large-scale hybrid seed production without pollen contamination and the need for manual emasculation.

Recent advances aim to combine male sterility with stable pistillate lines, integrating molecular screening and hormonal regulation for practical and scalable hybrid seed production programs.

Genetic and Environmental Management

Sex expression is not only genetically controlled but highly sensitive to environmental factors. Temperature, photoperiod, nutrition, and field practices (such as pruning or planting time) can trigger sex reversions, especially in NES-type lines. Biotechnological management encompasses selecting lines with proven resilience under variable conditions, precise regulation of field microclimate, and use of genetic background less prone to instability.

Systems biology approaches—integrating genetic, proteomic, epigenetic, and environmental data—are being developed to model complex interactions and predict stability for breeding deployment.

Future and Emerging Technologies

- Emerging tools such as CRISPR/Cas 9 gene editing offer the possibility of precise modification of sex-determining genes and regulatory elements. Advanced transcriptomic and proteomic profiling will continue to clarify pathways and candidate genes for targeted manipulation.
- Integration of molecular genetics, hormone management, cytogenetics, and environmental adaptation strategies is transforming castor breeding, offering robust solutions for hybrid seed production and yield improvement. As these biotechnological approaches mature, they promise reliable and scalable options for stabilizing castor sex expression under diverse agricultural conditions. Parvathy ST et al. (2021), “Probing the floral developmental stages, bisexuality and mechanism of sexual polymorphism in castor,” Scientific Reports.

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