



Gynoecious Cucumber: Genetics, Breeding Strategies and Applications in Hybrid Seed Production

*E K Naik¹, Amritendu Misra², Bharti Sinha³, S. Suresh⁴ and Nandini Sarathi⁵

¹Scientist (Horticulture), Horticultural Research Station - Mahanandi, Dr. Y.S.R. Horticultural University, Andhra Pradesh, India

²Professor, Department of Genetics and Plant Breeding, Suresh Gyan Vihar University, Jaipur, Rajasthan-302017, India

³Ph.D. Scholar, Department of Vegetable Science, College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya, Raipur, (Chhattisgarh)-492012, India

⁴Associate Professor and Head, Department of Plant Breeding and Genetics, MIT College of Agriculture and Technology, Musiri, Trichy, Tamil Nadu-621211, India

⁵Ph.D Scholar (Vegetable Science), Pt. KLS College of Horticulture and Research Station, Rajnandgaon (C.G.), Mahatma Gandhi University of Horticulture and Forestry, Durg, Chhattisgarh, India

*Corresponding Author's email: eknaik22@gmail.com

Cucumber (*Cucumis sativus* L.) is an economically important vegetable crop in which sex expression plays a major role in productivity and hybrid seed production. Among the different sex forms, gynoecious plants predominantly produce female flowers and therefore have considerable value in commercial hybrid breeding. Gynoecy can increase the proportion of pistillate flowers, facilitate efficient hybridization and contribute to earlier and more concentrated fruit production. The genetic control of cucumber sex expression involves several genes and interacting regulatory pathways, particularly those associated with ethylene biosynthesis and signalling. Recent research has strengthened understanding of the F locus, ACS genes, WIP1 and other regulators involved in female flower development. Molecular markers linked to gynoecy are increasingly useful for early identification of breeding materials, while marker-assisted backcrossing can transfer gynoecious traits into locally adapted cucumber backgrounds. A 2024 study successfully developed new gynoecious cucumber lines through marker-assisted backcrossing using foreground and background markers. Genome-editing approaches, including CRISPR/Cas technology, have further expanded opportunities to manipulate sex expression. This article discusses the genetics of gynoecy, breeding strategies, molecular approaches and practical applications of gynoecious cucumber in hybrid seed production.

Keywords: Cucumber, Gynoecy, Sex Expression, Molecular Breeding, Hybrid Seed Production

Introduction

Cucumber is one of the most widely cultivated cucurbit vegetables and is grown for fresh consumption, processing and protected cultivation. Its productivity is strongly influenced by the number, timing and distribution of male and female flowers. Unlike many conventional vegetable crops, cucumber possesses considerable diversity in sex expression, including monoecious, gynoecious, androecious, hermaphroditic and other intermediate forms. Among these types, gynoecious plants are particularly valuable because they produce predominantly or exclusively female flowers. Since female flowers develop into fruits after successful pollination or, in suitable cultivars, through parthenocarpy, a high proportion of pistillate

flowers can improve the efficiency of fruit production. The development of gynoecious lines was an important milestone in commercial cucumber hybrid breeding. Gynoecious female parents reduce the requirement for repeated removal of male flowers during hybrid seed production and make controlled crossing more efficient. Modern breeding is now moving beyond conventional selection toward marker-assisted breeding, genomic analysis and gene editing. These technologies are helping breeders understand and manipulate the genetic mechanisms underlying female flower development.

Understanding Gynoecious Sex Expression in Cucumber

Gynoecy refers to a flowering condition in which cucumber plants produce predominantly pistillate or female flowers. In contrast, monoecious plants normally produce both staminate and pistillate flowers on the same plant. The degree of gynoecy can vary between genotypes and may also change according to environmental conditions. The expression of sex in cucumber is not controlled solely by a single simple genetic mechanism. Several genes and modifiers influence the development of staminate and pistillate flowers, while environmental conditions can modify the final phenotype. Temperature, photoperiod, plant age, nutrition and hormonal balance can influence sex expression. Higher temperatures and longer days may promote male flower formation in some genetic backgrounds, whereas conditions favouring female development can increase gynoecy. This interaction between genotype and environment makes early phenotypic identification of stable gynoecious lines challenging. Molecular markers therefore provide an important complementary tool for reliable selection.

Genetic Basis of Gynoecy

The genetic basis of cucumber gynoecy has been investigated for several decades. Studies indicate that the trait may involve major genes together with modifying genes and environmental effects. The F locus is particularly important in controlling femaleness, while additional genetic factors influence the strength and stability of the gynoecious phenotype. Ethylene is one of the central hormones associated with female flower development in cucumber. Increased ethylene biosynthesis and signalling can promote pistillate flower formation, making ethylene-related genes important targets for understanding sex determination. Genes belonging to the 1-aminocyclopropane-1-carboxylate synthase (ACS) family have received particular attention. The CsACS1G region is associated with gynoecious sex expression and has been used in genetic studies and breeding programmes. The genetic network is further influenced by regulators such as CsWIP1. Research involving modification of this gene demonstrated the possibility of increasing female flower development through targeted genetic approaches.

Role of Ethylene in Female Flower Development

Ethylene is one of the most important hormonal regulators of cucumber sex expression. Increased ethylene production or enhanced ethylene sensitivity generally favours the formation of female flowers, whereas reduced ethylene activity can favour male flower production. The importance of ethylene explains why environmental conditions can alter sex expression even when the genetic background remains unchanged. Temperature, plant nutrition and developmental stage can influence ethylene metabolism and thereby affect the ratio of male to female flowers. Genes involved in ethylene biosynthesis, particularly members of the ACS family, have therefore become important targets for cucumber genetic studies. The relationship between ethylene and sex expression has been reviewed extensively in recent molecular breeding literature. Understanding this hormonal network has practical importance for hybrid seed production. Stable female flowering can reduce the need for intensive flower manipulation and improve the synchronization of flowering between parental lines.

Molecular Markers for Early Identification of Gynoecious Lines

Phenotypic screening for gynoecy can require considerable time because flower sex becomes clearly recognizable only after plant development. Molecular markers can accelerate

selection by identifying plants carrying favourable alleles at an early growth stage. Markers linked to the F locus and other genomic regions can be used in marker-assisted selection. SSR and SNP markers have been particularly useful for genetic characterization, linkage analysis and breeding populations. The development of reliable markers is especially important because gynoecious expression can be influenced by environmental conditions. A marker-based prediction can therefore complement field evaluation and improve breeding efficiency. Recent marker-assisted breeding work demonstrated the practical value of combining a foreground marker located at the F locus with background SSR markers. This approach allows breeders to select plants carrying the desired gynoecious allele while simultaneously recovering important horticultural characteristics from the recurrent parent.

Marker-Assisted Backcross Breeding

Marker-assisted backcrossing provides an effective strategy for transferring gynoecy into locally adapted cucumber cultivars. A gynoecious donor parent can be crossed with an elite monoecious cultivar, followed by repeated backcrossing and molecular selection. Foreground selection identifies plants carrying the target gynoecious allele, whereas background selection accelerates recovery of the recurrent parent's genome. Phenotypic selection can then be used for fruit size, shape, colour, maturity and other horticultural traits. A 2024 study used the BCAT marker associated with the F locus together with 52 SSR markers to transfer gynoecy into Vietnamese cucumber backgrounds. After two backcrosses and two generations of self-pollination, four new gynoecious lines were developed. This example demonstrates how molecular markers can shorten the breeding process while maintaining desirable local characteristics.

Gynoecy and Heterosis Breeding

Gynoecy has played a major role in the development of commercial cucumber hybrids. A gynoecious line can function as the female parent, while pollen is supplied by a selected male parent. Because the female parent predominantly produces pistillate flowers, hybridization can be organized more efficiently than when large numbers of male flowers need to be removed manually. Commercial cucumber breeding has therefore used gynoecious inbreds extensively. The resulting F₁ hybrids can combine gynoecy with heterosis for yield, earliness, fruit quality, disease resistance and environmental adaptation. The genetic background of the male parent remains important because hybrid performance depends on combining ability rather than gynoecy alone. Therefore, breeders evaluate gynoecious lines for both sex expression and general horticultural performance.

Gynoecious Lines in Hybrid Seed Production

Hybrid seed production involves growing the female and male parents in an appropriate spatial arrangement and ensuring effective pollen transfer. The female parent must produce sufficient pistillate flowers, while the male parent must provide viable pollen at the appropriate time. In cucumber, honey bees and other pollinating insects can transfer pollen between flowers. Commercial seed-production systems therefore require careful management of flowering synchronization, isolation, pollinator activity and parental purity. For gynoecious inbred lines used as female parents, breeders may need to induce temporary male flower production when seed multiplication of the inbred itself is required. Growth regulators such as gibberellic acid or silver nitrate have historically been used for this purpose under controlled seed-production protocols. This distinction between maintenance of a gynoecious line and commercial F₁ hybrid seed production is important for efficient breeding operations.

Table 1. Role of Gynoecious Lines in Hybrid Seed Production

Component	Function
Gynoecious female parent	Produces predominantly female flowers
Male parent	Provides viable pollen
Flower synchronization	Ensures pollen availability

Component	Function
Pollinators	Transfer pollen
Isolation	Maintains genetic purity
Fruit selection	Identifies true hybrid seed-bearing fruits
Seed extraction	Recovers mature F ₁ seed
Seed testing	Confirms quality and genetic purity

Gynoecey Combined with Parthenocarpy

The combination of gynoecey and parthenocarpy is particularly valuable for protected cultivation. Parthenocarpic cucumber can develop fruits without successful fertilization, reducing dependence on pollination under certain production systems. Recent research has advanced understanding of the molecular regulation and domestication of parthenocarpy in cucumber. When a gynoeceous genotype also possesses strong parthenocarpic ability, it can produce a high proportion of marketable fruits under suitable environmental conditions. This combination is particularly useful for greenhouse and protected cultivation where controlled pollination may be undesirable. Breeders therefore increasingly consider gynoecey, parthenocarpy, fruit quality and disease resistance as interconnected breeding objectives rather than independent traits.

Genome Editing and Future Gynoeceous Cucumber Breeding

Genome editing has introduced new possibilities for modifying cucumber sex expression with greater precision. CRISPR/Cas systems can be used to investigate genes involved in floral development and to validate their biological functions. Studies involving CsWIP1 have demonstrated that targeted modification of a sex-expression regulator can influence female flower development. This technology can complement marker-assisted breeding by allowing researchers to directly test candidate genes identified through genetic mapping and transcriptomic studies. However, genome-edited plants require detailed evaluation for stability, fertility, fruit quality, off-target changes and environmental performance. The technology is therefore best considered as part of an integrated breeding pipeline rather than a replacement for conventional breeding.

Combining Gynoecey with Modern Breeding Objectives

Modern cucumber breeding requires more than a high percentage of female flowers. Commercial cultivars must also provide good yield, uniform fruit quality, disease resistance, stress tolerance and suitability for specific production systems. Recent genetic studies have demonstrated that yield and fruit traits can involve additive, dominance and epistatic interactions. A 2024 study involving gynoeceous and monoecious parents reported significant genetic interactions for fruit weight, fruit length, fruit number and yield per plant. Therefore, gynoeceous lines must be evaluated for combining ability before being selected as parents of commercial hybrids. Integration of gynoecey with disease resistance, parthenocarpy, compact plant architecture and climate adaptation could provide valuable next-generation hybrids for both open-field and protected cultivation.

Conclusion

Gynoeceous cucumber represents an important genetic resource for modern hybrid breeding. The predominance of female flowers provides a practical foundation for efficient hybrid seed production and can contribute to early and concentrated fruit production. The genetic regulation of gynoecey involves the F locus, ethylene-related pathways, ACS genes, CsWIP1 and other interacting genetic and environmental factors. Molecular markers have strengthened breeding efficiency by enabling early identification and selection of gynoeceous plants. Marker-assisted backcrossing has demonstrated particular value for transferring gynoecey into locally adapted cucumber backgrounds while retaining desirable horticultural characteristics. The integration of gynoecey with parthenocarpy, disease resistance, high yield and protected-cultivation adaptation offers further opportunities for commercial cucumber

improvement. Genome editing provides an additional research and breeding tool for validating and modifying genes involved in sex expression.

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