REVIEW ARTICLE

Heterosis and Combining Ability in Brinjal *(Solanum melongena L.)*: A Review

Prashant Shrivastav, Muzeev Ahmad*, Satish Yadav, Rizwan Ali and Abhijeet Srivastava
DOI: 10.18811/ijpen.v10i04.04

Abstract

This review investigates the intricate dynamics of heterosis and combining ability in brinjal (*Solanum melongena* L.), elucidating their implications in breeding strategies for this economically important vegetable crop. Heterosis, or hybrid vigor, manifests in offspring displaying superior traits compared to their parents, offering increased yield potential, disease resistance, and adaptability. Understanding the genetic underpinnings of heterosis is pivotal for exploiting hybrid vigor effectively in brinjal breeding. Additionally, the concept of combining ability, reflecting the contribution of parental genotypes to desirable trait expression in offspring, is crucial for hybrid development. Various genetic and molecular mechanisms, including dominance, overdominance, epistasis, and genomic imprinting, influence heterosis and combining ability in brinjal. The review emphasizes the importance of proper parental selection, breeding methods, and environmental factors in optimizing these phenomena, proposing the integration of traditional and modern breeding approaches for enhanced brinjal productivity, quality, and resilience to biotic and abiotic stresses. The review assists brinjal breeding programs greatly through developing fundamental knowledge in heterosis and combining ability that deals with yield, disease resistance, and adaptability traits. Consequently, this review has provided a conceptualized account of how these traits have been successfully shaped by the key preconditions of parental selection, breeding techniques, and environments to provide new strategies for advancing the breeding of this important crop species.

Keywords: *Combining ability, heterosis, Growth, yield, qualitative and quantitative traits*.

Highlights:

- Enhances yield, quality, and resistance to pests and diseases in brinjal.
- Facilitates the development of hybrid varieties with desirable traits.
- Hybrid brinjal varieties often produce higher yields compared to their parental lines.
- Hybrid Vigor can confer resistance or tolerance to various pests and diseases, reducing the need for chemical interventions.
- Identifies superior parental lines for hybridization to develop high-performing hybrid varieties**.**
- Facilitates the selection of parents with complementary traits for hybridization.
- Line × Tester Analysis, Crosses diverse lines (testers) with a common elite line (line) to assess combining ability**.**
- The selection of parents with high combining ability is crucial for developing superior hybrid brinjal varieties.

International Journal of Plant and Environment (2024); **ISSN:** 2454-1117 (Print), 2455-202X (Online)

Introduction

Brinjal (*Solanum melongena L*), commonly known as eggplant or aubergine, is a significant crop within the Solanaceae family, cultivated widely across warmer regions of the world. Known for its nutritional value and diverse culinary applications, brinjal also plays a role in traditional medicine, where its fruit and other plant parts are utilized for their purported therapeutic properties. Wild relatives of brinjal can be found in regions like Malaysia and India, with prickly species such as *Solanum incanum* thriving in dry hills and other naturally occurring cultivars producing unique golden fruits. India is believed to be the center of domestication for brinjal, from where it spread to Africa, Europe, and beyond through trade and migration (Kew Royal, 2016; Burkill, 2002).

Despite its rich history and adaptability, modern brinjal breeding faces significant challenges. These include susceptibility to pests and diseases, limited genetic diversity in cultivated varieties, and the need to meet the demands of high-yield production under changing climatic conditions. Addressing these challenges requires innovative approaches such as exploiting *heterosis* (hybrid vigor), which has proven to enhance yield, quality, and stress tolerance in various crops (Legesse *et al.,* 2018). Heterosis in brinjal holds immense potential, yet its application is constrained by knowledge gaps in understanding the genetic interactions responsible for hybrid performance. Bridging these gaps is critical for

Assistant Professor, Department of Agriculture, Integral Institute of Agriculture Science and Technology (IIAST), Integral University, Lucknow

***Corresponding author:** Muzeev Ahmad, (Assistant Professor) Department of Agriculture, Integral Institute of Agriculture Science and Technology IIAST, Integral University, Lucknow, Email: prashant.vardhanshri@gmail.com

How to cite this article: Shrivastav, P., Ahmad, M., Yadav, S., Ali, R. and Srivastava, A. (2024). Heterosis and Combining Ability in Brinjal (*Solanum melongena L.*): A Review. International Journal of Plant and Environment. 10(4), 27-37.

Submitted: 11/10/2024 **Accepted:** 09/12/2024 **Published:** 31/12/2024

developing resilient, high-performing brinjal cultivars that cater to contemporary agricultural and market demands. (Deshmukh *et al.,* 2020) This research aims to address these challenges by exploring the genetic basis of heterosis and its implications for breeding strategies, thereby contributing to the development of sustainable brinjal production systems.

A relatively small plant, brinjal reaches a height of 1.5 m, because of its non-woody stem. It has simple, somewhat lobed leaves that are oval to oblong in shape and have a paler green underside than the upper surface. There are small hairs all around the stem and leaves. The flower stalks emerge singly or in little clusters from the leaf axils. Individual blooms resemble stars, have light purple tints, and short stems. Five stamens and one superior ovary are attached to the corolla tube. Its fruits are berries with many round or long seeds that might be white, orange, green, purple, or black, depending on the variety. It bears fruit all year round and is a perennial. Most people classify brinjal fruits as veggies. Thirteen, they can be prepared in many ways, including baking, grilling, frying, and pickling. (Ware 2015) They can also be flavored and served as a dip or chutney in Mediterranean and Indian cuisines. In traditional Chinese medicine, all parts of the plant are used to stop intestinal bleeding. The fruit of the plant can also be used as a counteragent for mushroom Silla. In Indochina, plant parts are utilized as a purgative. Traditional Malay medicine uses the fruit's ashes as hot, dry poultices to heal hemorrhoids. (Wee, 1992) The root is crushed and put inside the nostrils to treat ulcers. The Ambonese take the juice of the root of a wild variety of plants to ease difficult labor. Arabs believe that the fruit has high "heating" properties that in turn, cause melancholia and madness. For this reason, Malay and Indian women do not consume brinjal for the first 40 days after giving birth."

Although brinjal farming has proved viable and highly developed, breeding the crop in the modern world has its unique set of problems. These include vulnerability to pest and disease attacks, low gene variability in the modern seeds, and pressure on productivity to feed the increasing human population under a constantly changing climate. Solving these issues calls for strategies including taking advantage of heterosis, a technique that has been discovered to increase yield, quality, and or tolerance to stress in different crops.

Heterosis in brinjal could be of very high value, but its use is hampered due to a lack of information on the underlying gene-gene-phenotype relationships that determine hybrid vigor. Filling these gaps is important to produce robust, high-yielding brinjal varieties that respond to current-day agricultural and market requisites. This research tries to help to overcome these challenges by investigating the genetic mechanism of heterosis and the potential application of this study for developing more efficient breeding plans to promote sustainable production of brinjal.

Origin, Evolution and Domestication

Eggplant (*S. melongena* L) is a native to the Indian subcontinent. Most of the Solanum species, including eggplant, are characterized by flattened seeds and curved embryos. Eggplant is a berry-producing vegetable belonging to the family of Solanaceae, which has around 3000 different species distributed in across 90 genera. Out of these, Solanum is the largest, with approximately 1500 species. In a broader sense, the name 'eggplant' is commonly meant for three species of Solanum. *S. melongena* L., is a globally cultivated species of Asian origin. Likewise, scarlet (*S. aethiopicum* L.) and gboma (*S. macrocarpon* L.) as African eggplants. *S. melongena* L. is widely accepted as a primary concern because of its acreage on large scales on almost every continent. Noticeably, the wild relatives of eggplant usually have a smaller fruit size. Several forms, shapes and colors of eggplant are found across Southeast Asia, indicating that this area might be the secondary center of variation. "The data presented in Table 1 shows the area, production and productivity of vegetables in India and UP for the period of 2011-12 to 2021-22. In India, there is a slow but steady expansion of the area sown with vegetables using garden tractors from 691.5 thousand hectares in 2011-12 to 752.8 thousand hectares in 2021-22 (Fig. 1). However, production (Fig. 2) has been less volatile, bouncing between 12510 MT/Ha and 13557.8 MT/Ha, while productivity

Table 1: Trends in area, production and productivity of vegetables in India and Uttar Pradesh

Year	*India*			*Uttar Pradesh*		
	Area (000' Ha)	*Production (000'MT)*	*Productivity (MT/ Ha)*	*Area (000' Ha)*	*Production (000'MT)*	*Productivity (MT/ Ha)*
2011-12	691.5	12634.1	18.3	2.9	90.8	31.3
2012-13	722.1	13443.6	18.6	3.1	106.4	34
2013-14	711.3	13557.8	19.1	3.4	111.7	32.6
2014-15	673	12589	18.7	4.5	154.7	34.3
2015-16	663	12515	18.9	7.78	267.19	34.34
2016-17	733	12510	17.1	7.91	272.01	34.38
2017-18	730	12801	17.5	8.01	275.4	34.4
2018-19	727	12680	17.4	8.24	289.3	35.11
2019-20	744	12682	17	8.49	299.13	35.25
2020-21	749	12874	17.2	8.61	303.41	35.25
2021-22	752.8	13023.2	17.3	8.82	312.98	35.47

Source: India stat. 2022

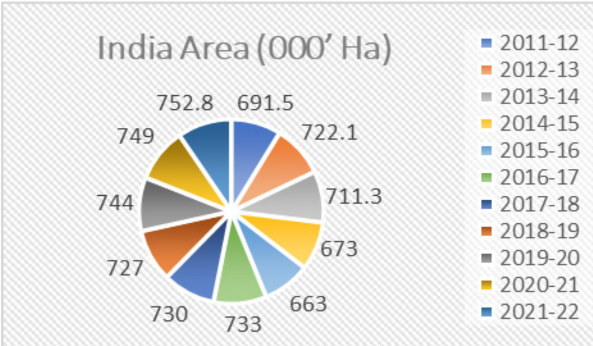


Fig. 1: Brinjal area in India

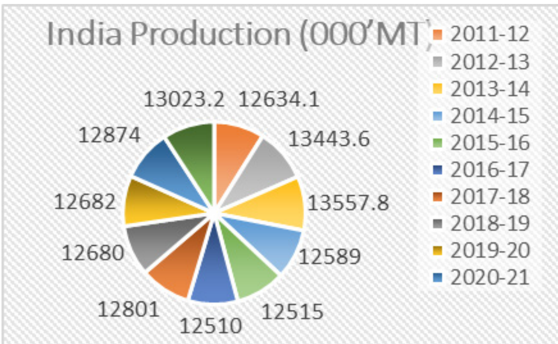


Fig. 2: Brinjal Production in India

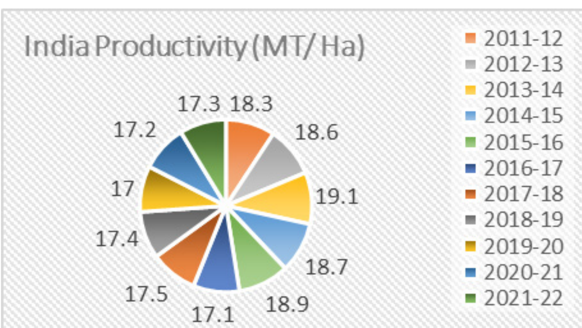


Fig. 3: Brinjal Productivity in India

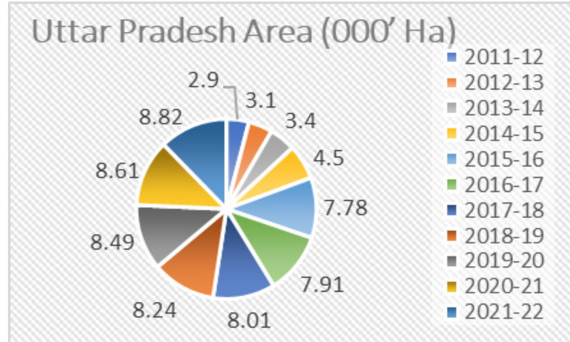


Fig. 4: Brinjal area in Uttar Pradesh

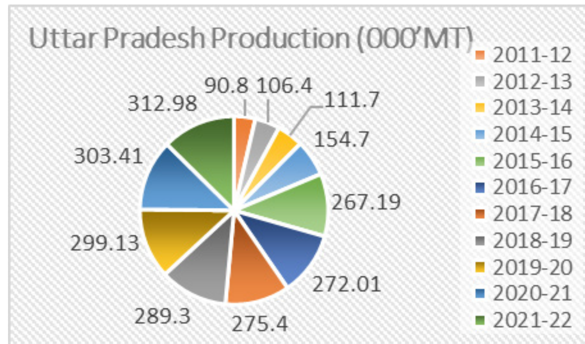


Fig. 5: Brinjal Production in Uttar Pradesh

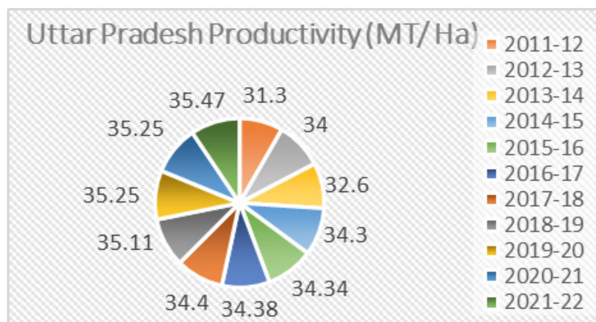


Fig. 6: Brinjal Productivity in Uttar Pradesh

(Fig. 3), as seen in Table 1, has fluctuated between 17.0 MT/Ha and 19.1 MT/Ha. The state with consistently high growth is Uttar Pradesh, which has stepped up from 2.9 thousand hectares in 2011-12 to 8.82 thousand hectares in 2021-22 (Fig. 4). In the same regard, the state has recorded an upward trend in its production (Fig. 5) and productivity (Fig. 6), with productivity reaching the highest level of 35.47 MT/Ha in 2021-22. Vavilov considered its center of origin in the Indo-Burma region. In another study, Vavilov highlighted the "Indo-Chinese center" as the center of origin of brinjal. However, according to recent studies on the domestication of eggplants, there are still several unanswered queries about this process. However, there are several shreds of evidence that suggest, that eggplant domesticated from S. insanum through multiple and independent domestication processes naturally spread in tropical Asia from the Philippines to Madagascar in several centers of domestication. (Legesse *et al.*, 2018)

It was introduced from India by early traders from Arabia and Persia to the countries of the eastern and southern shores of the Mediterranean early in the Middle Ages. It is now widely cultivated for its fruits in the tropical, subtropical and warm temperate zones, especially in southern Europe and the southern United States. In 1806, it was introduced to American gardens primarily as an ornamental curiosity and probably introduced into Europe during the Moorish invasion of Spain. It gained popularity in the 1890s as a minor vegetable. The ancestral form was very likely a spiny plant with small, bitter fruit, but selection for improved palatability and relative spinelessness resulted in the gradual emergence of an acceptable type. Brinjal has been cultivated for many centuries in India, Bangladesh, Pakistan, China, Arabia and the Philippines. There are several names by which the crop is known in India, but brinjal is the most familiar. Brinjal is also called 'eggplant' or 'aubergine'. The name eggplant is believed to derive from Gerard's description of early forms with small, white fruit resembling eggs. In the early years, eggplant was also termed 'Male Insana' and the 'Italian Melazana,' both of which translated to "made apple." "Table 2 indicates that the Compound Annual Growth Rate (CAGR) of area production and productivity of brinjal has increased in India during both the periods 2001–2010 and 2011–2022 as well as the cumulative period of 2001–2022. A comparison of the above two tables revealed that during the period I, an 8.76% increase in the area under cultivation was recorded in Uttar Pradesh as compared to 3.07% for the whole of India. During Period II, the national growth rate, however, declined to 0.78% and Uttar Pradesh's area, nevertheless, marched up to 10.64%. Concerning production, Uttar Pradesh showed good results, continuing the trend registered in the first period, with a growth rate of 11.90% in Period II, whereas the rate for the whole country was only 0.27%. Alternatively, yield trends; Uttar Pradesh yield decreases by -1.15% at Period I, while the rest of the country shows a meagre increment of 0.52% (Fig.-7). The variations highlighted in the study affirm regional differences and probable regions of interest of BRINJ in its growth and development." It was originally domesticated from the wild nightshade species thorn or bitter apple, *S. incanum*, (Abhinav and Nandan 2010 & Ali *et al.,* 2022) , probably with two independent domestications: one in South Asia and one in East Asia. (Doganlar *et al.,* 2002 & Deshmukh *et al.,* 2020) In 2021, world production of eggplants was 59 million tonnes, with China and India combined accounting for 86% of the total."

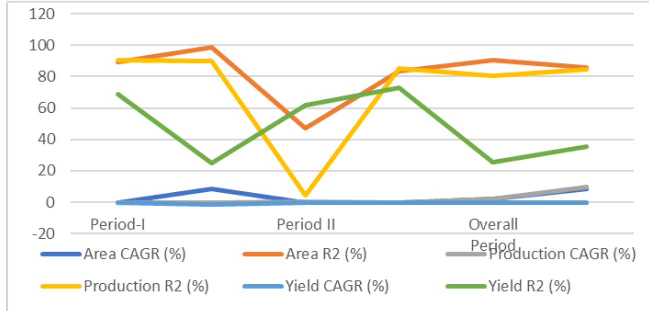


Fig. 7: Overall CAGR of Area, Production and Productivity

Importance of heterosis breeding

Heterosis breeding, also known as hybrid breeding, is importance in the improvement of vegetable crops, including the cultivation of brinjal (*S. melongena* L.). This breeding approach involves crossing genetically diverse parental lines to produce offspring, or hybrids, with superior traits compared to their parents. In vegetable crops, where productivity, quality, and resilience are key factors, heterosis breeding offers numerous benefits. Firstly, it significantly enhances yield potential, addressing the ever-increasing demand for vegetables due to population growth and changing dietary habits. High-yielding hybrids developed through heterosis breeding contribute to increased agricultural productivity and improved economic returns for growers. Brinjal, being a globally important vegetable crop, stands to gain immensely from heterosis breeding. Through the exploitation of hybrid vigor, breeders can create brinjal hybrids tailored to meet specific market requirements and environmental conditions. Improved yield, fruit quality, resistance to pests and diseases, and adaptability to various agroecological zones are among the traits that can be enhanced through heterosis breeding in brinjal. Furthermore, by developing hybrids with desirable characteristics, heterosis breeding aids in the sustainability of brinjal production by reducing the need for chemical inputs and enhancing resource use efficiency. Overall, heterosis breeding plays a vital role in ensuring the availability of high-yielding, resilient, and nutritious vegetable crops like brinjal to meet the needs of a growing global population. By harnessing the genetic diversity inherent in hybridization, breeders can continue to develop improved varieties that contribute to food security, economic prosperity, and environmental sustainability in agricultural systems FAO (2019)."

"It offers opportunities for improvement in productivity, earliness, uniformity, quality, wider adaptability and for rapid deployment of dominant genes for resistance to diseases and pests. (Chen and Li 1996) In vegetable crops, heterosis breeding has been found useful in the improvement of yield potential of self as well as cross-pollinated crops. Exploitation of heterosis for various characters has become a potential tool in the enhancement of brinjal. (Taher *et al.,* 2017) It has been substantially applied in cultivated plants. In this direction, the genetic basis of heterosis has been studied for almost a century. Two principles are farmed because the common factors for heterosis phenomenon dominance and over-dominance hypothesis. (Birchler *et al.,* 2010) In the dominance hypothesis, heterosis is appeared because the result of the complementation of the deleterious alleles that had been present in the inbred parental lines. Whereas the over-dominance hypothesis interpretation factors out that the allelic interactions unique to

Table 2: Overall CAGR of area, production and productivity of brinjal in India

		Period-I (2001-2010)		*Period II (2011-2022)*		*Overall Period (2001-2022)*	
		All India	*Uttar Pradesh*	*All India*	*Uttar Pradesh*	*All India*	*Uttar Pradesh*
Area	CAGR (%)	3.07*	8.76	0.78**	10.64*	1.94	8.53
	R^2 (%)	89.3	98.89	47.11	83.18	90.37	85.82
Production	CAGR (%)	3.60*	7.50*	0.27	11.90*	2.14	9.62
	R^2 (%)	90.2	90.02	4.39	85.33	80.65	84.88
Yield	CAGR (%)	0.52**	-1.15	-0.51*	1.14*	0.19**	1.00*
	R^2 (%)	68.51	24.96	61.69	72.63	25.79	35.53

Source: NHB

the hybrid are such that the heterozygous alleles in the hybrid aggregate carry out higher than either of the homozygous ones. (Luo *et al.,* 2001) Moreover, efforts are persevering to decode the molecular basis of heterosis correctly, however, breeders preserve to enhance inbreds. Whereas new technologies, which include gene expression profiling, are underway, efforts are being made to take advantage of heterosis phenomena. (O'Sullivan & Edwards 2003)"

"Now, single cross-hybrid corn has developed into a major industry worldwide. In the 1970s, Yuan Longping developed hybrid rice with a significant yield advantage (10–20% greater) over inbred parental varieties. Hybrid rice was accepted in China, and about half of the total area of rice in China was planted to hybrids by the early 2000s. Hybrids are also used in crops such as sorghum, sunflower, canola, and a number of vegetables. Attempts have been made to produce hybrid seeds in wheat (Dubey *et al.,* 2014). Similarly, hand emasculation is simple to carry out because of the massive length of eggplant flowers and a successful cross can produce someplace among 20-200 based on its genotype. Moreover, male sterility has been discovered; it's also facilitating the hybrid development in eggplant. Identification of desirable combiner mother and father is essential for hybrid improvement in eggplant. The combining abilities, particularly preferred combing ability (GCA) and unique combining ability (SCA) values, are essential in predicting the hybrid overall performance and suitability. (Davidar *et al.,* 2015)"

Applications of Hybrid Breeding Programs in Brinjal

In brinjal hybrids breeding, heterosis or hybrid vigor is taken advantage of in improving on desirable characters. Among them are enhanced yields arising from improved fruit size, number, and quality. The resilience to pests, for example, fruit and shoot borer and diseases for example, bacterial wilt, is enhanced, thereby reducing reliance on chemicals. The hybrids, therefore, exhibit a better ability to perform under different conditions of agro-climatic stress as compared to their non-hybrid counterparts. Taken together, these advancements lead to increased yield, better returns to the farmers, and better cultivation practices. For instance:"

Yield Improvement

It is recommended that it is genetically modified to create the 'Pusa hybrid-6,' which increases the yield by 30 to 40% to traditional varieties.

Disease Resistance

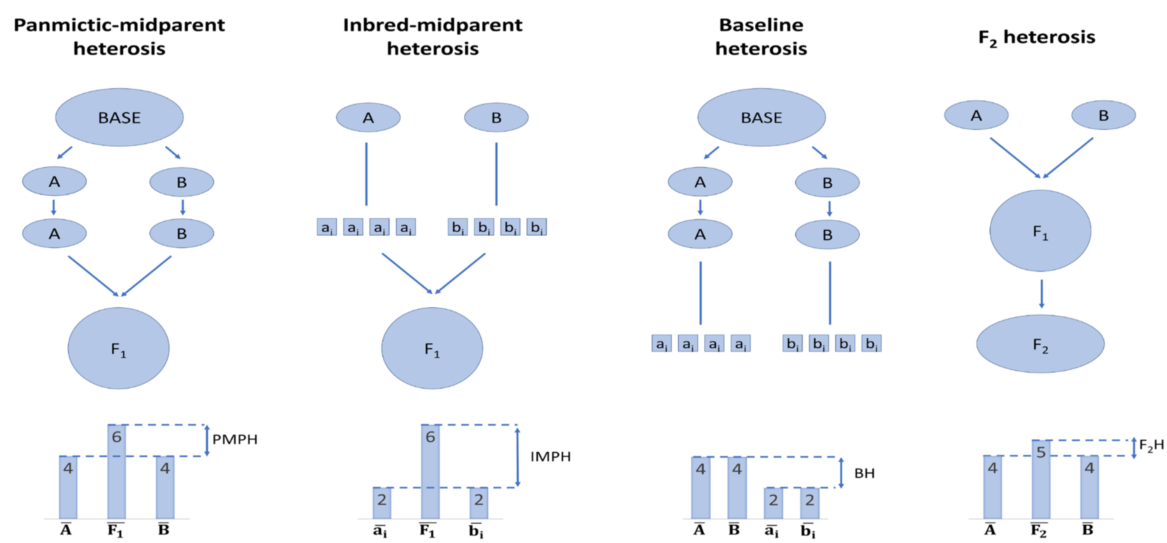
Stress on those hybrids that do not get easily affected by most prominent diseases such as bacterial wilt or fungal diseases.

Adaptability

Explain ways in which the hybrids show excellent results in abiotic stress such as drought or salinity, making it ideal for practice in difficult circumstances.

Breeding objectives

Breeding objectives in agriculture are multifaceted, encompassing goals aimed at enhancing crop performance, yield, quality, and resilience. One primary objective is to develop high-yielding crop varieties capable of meeting the increasing global demand for food. This involves selecting and breeding plants with traits such as improved biomass, harvest index, and resource use efficiency to optimize land and resource utilization while ensuring food security. Additionally, breeding efforts focus on improving crop quality by selecting traits such as nutritional content, flavor, texture, and shelf life. By incorporating consumer preferences, market demands, and



$$\overline{F_1} = (p - q - y)a + [2pq + y(p - q)]d$$
$$\overline{F_2} = (p - q - y)a + [2pq + y(p - q) - {}^1/_2\, y^2]d$$
$$PMPV = (p - q - y)a + [2pq + y(p - q) - y^2]d$$
$$IMPV = (p - q - y)a$$
$$PMPH = y^2 d$$
$$F_2H = \frac{1}{2}y^2 d$$
$$BH = 2\bar{p}\bar{q}d - \frac{1}{2}y^2 d$$
$$IMPH = 2\bar{p}\bar{q}d + \frac{1}{2}y^2 d$$

Fig. 8: Hybrid vigor and hybrid breeding

nutritional requirements into breeding programs, breeders can develop crop varieties that address dietary deficiencies and promote healthier diets while meeting consumer expectations and market standards FAO. (2019). Another critical breeding objective is the enhancement of crop resilience to biotic and abiotic stresses. This involves selecting plants with traits such as resistance to pests, diseases, and adverse environmental conditions like drought, heat, salinity, and extreme weather events. By identifying and incorporating resistance genes from wild relatives or through genetic engineering, breeders can develop crop varieties with enhanced stress tolerance, thereby reducing yield losses and increasing agricultural sustainability in the face of changing climatic conditions. Overall, aligning breeding objectives with the needs and priorities of farmers, consumers, and the agricultural industry is essential for achieving desired outcomes in crop improvement programs, ensuring food security, environmental sustainability, and economic viability FAO (2019). Breeding activities in eggplant have been targeted at the development of high-yielding, early, better quality and disease-resistant varieties. The color of the fruit and size and shape, the proportion of seeds to pulp, short cooking time and lower solanine levels are important traits in assessing quality. As brinjal is susceptible to several pests and diseases such as wilt, Phomopsis, little leaf and root-knot nematodes and to insects such as shoot and fruit borer, jassids, Epilachna beetle, etc., the development of multiple resistant varieties is a major challenge. Plants are susceptible to both low and high temperatures; therefore, attempts are being made to develop chilling or frost-tolerant and heat-tolerant varieties (Senthilnathan *et al.,* 2018; Sarwary *et al.,* 2022)."

Specific breeding objectives in eggplant in the Indian context are

1. Exploitation of heterosis for increasing production and productivity
2. Incorporation of resistance against insect pests, including borers
3. Breeding for disease resistance
4. Development of cultivars with better quality of fruits
5. Improvement of locally preferred cultivars, which are distinct

Heterosis or hybrid vigor and hybrid breeding

The heterosis or hybrid vigor may be defined as "The interpretation of increased vigor, size, fruitfulness, speed of development, resistance to pest and disease or climatic vigor of any kind manifested by cross-breed organisms as compared with corresponding inbreed as the specific rules of unlikeness in the constitution of the uniting parental gametes" (Fig. 8). Heterosis is mainly manifested in quantitative characters and expressed in the vigor of vegetative organs, in increased grain yield, etc."

Morphological characters

It refers to the number of days to the first flowering. The analysis revealed that BCB 75 × BCB 45, BCB 38 × BCB 1, and BCB 23 × BCB 42 were exceptional hybrids. According to this paper, using locally adapted cultivars as parental lines could result in hybrids with commercially exploitable heterosis. Roy *et al.,* (2010). The negative heterosis for days to first flowering in the Nilakottai Local x Annamalai hybrid was determined to be -14.08, -15.48, and -15.8% over the mid, better, and standard parent, respectively. (Kumar *et al.,*2013). In AB 7 / 2 x GJB 2, Reddy and Patel (2014a) reported a negative standard heterosis of -29.44%. Shahjahan *et al.,* (2016) report that the cross Ral 3 x BARI Begun 7 showed a significant negative better parent response for earliness (- 12.08%). According to Mistry *et al.,* (2018), for days to first flowering, the hybrids Doli-5 × KS-331 (-2.37%) and Doli-5 × KS-331 (-1.48%) had negative heterosis over better and mid parent, respectively. According to research by Vijay *et al.,* (2020), negative heterosis is preferred for qualities like Days to 50% blooming and Days to first picking. The cross combination DBR-8 × JKGEH-6012 showed the largest significant heterosis over the mid parent (-12.10%) and better parent (-17.79%)."

The Days to 50% Flowering are the topic of discussion. The heterosis over-mid-parent ranged from -7.87% (Arka Shirish x Malapur Local) to -28.08% (Arka Nidhi x Malapur Local), according to Jay *et al.,* (2013a). Between 10.34% (Arka Shirish x Kudachi B) and -19.78% (Arka Nidhi x Malapur Local), there were differences in the percentage of heterosis. The cross DBL 21 x PLR 1 over better parent showed -7.42%, according to Vidhya (2015). According to Chowdhury *et al.,* (2010), the hybrid Volanath x Nayantara showed negative heterosis over better parent -27.59%. According to Bhushan and Singh (2013), there was negative heterosis in the PB 64 x PU cross compared to standard heterosis (-23.93%), heterobeltiosis (-21.43%), and relative heterosis (-23.53%). Negative heterobeltiosis in PR x PB (-11.0%) was observed by Jay *et al.,* (2013a). Negative heterobeltiosis in FB-18 x Pant Samrat (-12.5%) was reported by Dubey *et al.,* (2014). Negative standard heterosis was found in AB 7 / 2 x GJB 2 (-22.51%) by Reddy and Patel (2014a). Better parent heterosis of -23.08% was noted by Venkatanaresh *et al.,* (2014) in the cross KS-6103 x KS-8821. The cross 1S x CO 2 (-7.52%) over-mid-parent and CO 2 x HD 2 (-11.06%) over heterobeltiosis and HD 1 x HD 2 (-13.94%) showed negative heterosis, according to Vidhya (2015). Days to first flowering and days to 50% blooming of the cross Pusa Purple Cluster × Pant Samrat showed the strongest specific combining ability effects in the desired direction, according to research by Sharma *et al.,* (2016).

"It concerns plant height. According to Ansari *et al.,* (2009), there was heterosis in the crosses CH-894 x Chinaki Local-1 (23.11%) over better parent and Chianki Local-1 x Chianki Local-2 (36.11%) over-mid-parent. The heterobeltiosis in Uttara x Nawabganj Local (35.58%) and the relative heterosis in the cross Uttara x Nawabganj Local (52.45%) were reported by Hazra *et al.,* (2010). According to Ramesh (2012), the heterosis of the cross Sedapatty x Annamalai over the mid, better, and standard parent was 44.42, 29.76, and 71.03%, respectively. Sel-5 x PPC (32.35%) had heterobeltiosis, according to Dubey *et al.,* (2014). The cross KS-6103 x KS-8821 showed improved parent heterosis of 26.28%, according to Venkatanaresh *et al.,* (2014). Heterosis for plant height was seen in the cross 1S x IC 354721 (29.08%) over-mid-parent, CO 2 x HD 2 (26.27%) over better parent, and 1S x IC 354721 (45.46%) over standard heterosis, according to Vidhya (2015). In the cross Doli-5 × GBL-1, heterosis was seen (19.12%) over the better parent and 12.8% over the mid parent, according to Mistry *et al.,* (2018). In Susmitha *et al.,* (2023) research, the hybrid showed significant standard heterosis. Plant height is determined by ICO-344674 × ICO-383119, days to first harvest is determined by ICO-344674 × Arka Kusumkar, fruit length is determined by ICO-345590, and fruit girth is determined by ICO-345590 × ICO-545862."

"It concerns the number of primary branches each plant. According to Abhinav and Nandan (2010), heterosis over better parent was seen in the cross IGBO 83 x BB 93 (41.69%). Ramesh (2012) Through recombination breeding, the hybrid L5 × T2 can be effectively employed to increase the number of branches per plant, the number of fruits per plant, and the fruit production per plant. The heterosis in the cross PB 68 x PS over relative heterosis (18.85%) and BARI x PS (27.77%) over standard heterosis was reported by Bhushan and Singh (2013). According to Mistry *et al.,* (2018), the cross Melur Local x KKM 1 showed 50.67% over heterobeltiosis and 18.01% over standard check, as well as Palamedu Local x KKM 1 (35.19%) over-mid-parent. Reddy and Patel (2014a) found that AB 8 /5 x GJB 2 (23.74%) had the usual heterosis. The cross IC 354721 x HD 1 recorded 55.0% over-mid-parent and better-parent heterosis for this trait, according to Vidhya (2015). In a study conducted by Sharma *et al.,* (2016), the highest specific combining ability effects were observed in the desired direction in the cross days to first harvesting, plant height, and percent fruit set; in the plant stem girth, number of primary branches plant–1, fruit length (cm), fruit diameter, average fruit weight, number of flowers cluster–1, cross-Pusa Purple Cluster × Arka Shirish, and number of fruits plant–1 and yield plant–1. According to Mistry *et al.,* (2018), there was a higher significant positive over better parent values for the hybrid Doli-5 × GBL-1 (120.3%) over-mid-parent and Doli-5 × KS-331 (107.5%). Studies on various characteristics under heterosis are presented by Chaudhari *et al.,* (2020). The cross JBL-08-08 x NSR-1(33.47%), AB-09-1 x NBB-1(28.21%), GBL – 1 x NSR – 1 (23.52 %), and GBL – 1 x NBB – 1 (17.25%) are the characters that are most prevalent under heterosis.

It concerns the Days until the First Harvest. In the cross CH-885 x Chianki Local-2, Ansari & Ansari (2011) found negative heterosis (-12.7%) over the mid parent and - 21.94% over the better parent. According to Chaudhari *et al.,* (2020), GOB-1 x Surti Ravaiya (-9.60%), AB 03-13 x GOB-1 (-8.60%), and the hybrid ABR 02-23 x Surti Ravaiya (-16.95%) all showed negative heterobeltiosis. According to Makani *et al.,* (2013), there was standard heterosis in GBL-1 x KS-331 (-4.44%), better parent in PPL-1 x Pusa Uttam (-12.64%), and relative heterosis over-mid-parent in Pusa Uttam x AB-07-08 (-14.71%). According to Venkatanaresh *et al.,* (2014), the KS-6103 x KS-8821 cross showed superior parent heterosis of -21.21%. Negative heterosis was seen in the cross Doli-5 × GBL-1 (-1.53%) over better parent and the cross AB 07-02 × GOB 1 (-0.56%) over-mid-parent, according to Mistry *et al.,* (2018).

Phenological Characters

It concerns the length of the fruit. The mean performance also demonstrated the hybrid BCB 75's superiority. Positive and negative heterosis were noted in the cases of fruit girth and length. Out of all the hybrids, only six displayed positive relative heterosis in fruit weight. BCB 38 × BCB 23 had the highest result (22.18%). In the hybrid BCB 75 × BCB 15, yield—the final result of several yield components—showed up to 70.62% average heterosis and 37.9% heterobeltiosis, according to Das *et al.,* (2009). According to Abhinav and Nandan (2010), heterosis over better parent was seen in the cross IGBL 67 x BB 93 (13.55%). According to Kuldeep *et al.,* (2012), the crosses HE12 × Aruna for first fruit set and BR-112 × Aruna for fruit length and diameter showed considerable heterosis over the superior parent. According to Kuldeep *et al.,* (2012), the heterosis over better parent was seen in the cross BR- 112 x Aruna (56.67%). The heterosis in the cross PB 68 x PU over relative heterosis (76.8%), heterobeltiosis (23.66%), and (73.04%) over standard heterosis was reported by Bhushan and Singh (2013). In the cross KS-5623 x KS-7512, Venkatanaresh *et al.,* (2014) found superior parent heterosis of 70.51%. According to Vidhya (2015), there was a 35.69% improvement in parent heterosis for the cross HD 1 x IC 354721. Fruit length heterosis ranged from -41.85 (PLR-1 X Doli-5) to 9.28% (PLR-1 X GOB-1) larger than Surati Ravaiya and -46.58 (PLR-1 X Doli-5) to 0.39% (PLR-1 X GOB-1), according to Kumar *et al.,* (2017). According to Mistry *et al.,* (2018), the heterosis over the better and mid-parents ranged from 6.12 to 40.49% and 15.08 to 47.08%, respectively. A cross combination of AB 07-02 × GOB revealed economic heterosis to the amount of 47.08%. Vijay *et al.,* 2020 Regarding the yield-related attributes, namely: fruit weight (DBR-8 × JB-18), fruit girth (NBJ-19 × DMU-1), and fruit length (DBR-8 × DMU-1)."

This relates to the fruit's diameter. According to Abhinav and Nandan (2010), In the cross IGBL 70 x IVBL 9, there was heterosis over the superior parent (50.96%). Chowdhury et al. (2010) found heterosis over better parent at 24.14% in the hybrid BARI Begun-8 x Volanath. Makani *et al.* (2013) reported heterosis in GP-180 x KS-331 over-mid-parent (34.58%), better parent (28.83%), and standard check (26.05%). According to Kumar *et al.* (2017), the typical heterosis was bigger than GBH-2 and varied from -19.09 (KS-224 x GOB-1) to 68.70% (GJB-3 X GBL-1) and from -25.83% (KS-224 X GOB-1) to 54.64% (GJB-3 X GBL-1) greater than Surati Ravaiya. Notable and positive heterosis across the mid-parent was observed by Mistry *et.al.,* (2018); the variation ranged from 8.30% in Doli-5 × GBL-1 to 19.15% in AB 07-02 × GOB 1.

This relates to average fruit weight. According to Hazra *et al.,* (2010), there is a relative heterosis between PPC x Pusa Anupam (40.42%) and HE 12 x Singnath (41.03%) as compared to the mid parent. According to Dharwad *et al.* (2012) state that there was 26.33% heterosis over the local check in the cross-MG x IC-909. Kuldeep *et al.* (2012) discovered that there was significant heterosis over the superior parent in the crosses Aruna × H-7 for fruit weight, Pant Samrat × S-16 for total yield per plant, and Punjab Neelam × H-7 for fruit quantity. Kuldeep *et al.* (2012) reported that the cross H-7 x Pb Neelam (35.99%) showed heterosis over the better parent. The heterobeltiosis in PR-5 x RCMBL-1 (186.34%) was reported by Jay *et al.,* (2013a). In FB-18 x Pant Samrat, heterobeltiosis was reported by Dubey *et al.,* (2014) to be 48.42%. Reddy and Patel (2014a) observed standard heterosis in JBR 6/7 x GJB 2 (17.53%). In the cross KS-7570 x KS-8821, Venkatanaresh *et al.,* (2014) found better parent heterosis (19.25%). In the cross Doli-5 × KS-331 (19.80%), Mistry *et al.,* (2018) found significantly substantial positive heterosis over better parent.

"This has to do with the number of fruits per plant. According to Chowdhury *et al.,* (2010), heterosis was observed in 105.00% of Nayantara x Khatkhatia and 253.65% of Kazla x Khatkhatia, respectively, over better parent and standard checks. NDB-18 x GP-180 over-mid-parent (168.45%), PPL-1 x GP-180 over better parent (190.34%), and GBL-1 x KS-331 over standard check (65.11%) were found to exhibit heterosis, according to Makani *et al.,* (2013). In the cross KS-5623 x KS-7512, Venkatanaresh *et al.,* (2014) discovered superior parent heterosis (67.0%). According to Vidhya (2015), heterosis was found in the following combinations: HD 1 x HD 2 (8.05%) over conventional heterosis, IC 354721 x 1S over better parent, and cross HD 2 x CO 2 (27.80%) over-mid-parent. In the cross between AB 07-02 and GOB 1, mistry *et al.,* (2018) found heterosis of 30.48 and 28.50% (AB 07-02 x GOB 1) over the mid and better parent, respectively. In Sachin *et al.,* (2022) study, it was discovered that the hybrids CMS 207 A × HRHA 5-3, CMS 852 A × RHA 271, CMS 207 A × RHA 297, CMS 234 A × 6D-1, and CMS 207 A × 6D-1 were superior in terms of oil content, heterosis, and seed yield plus its contributing feature. Given that they are dominant, hybrids with high heterotic values can be used straight away in heterosis breeding. According to research done by Naveen *et al.,* (2022), there was positive standard heterosis for fruit yield per plant (kg) in three crosses: GNRB-1 × CH-215, CH-215 × NBL-5, and GNRB-1 × NBL-5. To increase fruit yield through heterosis, indirect selection could be used for characteristics such as fruit weight, fruit diameter, and fruit count per plant. The greatest heterotic value for fruit output per plant was found in cross combinations HE-100 x H-8 (42.27%), HE-106 x BR-112 (37.54%), and HE-101 x BR-112 (36.46%), according to research by Rahul *et al.,* (2022). Among all the cross combinations, the ones that demonstrated earliness were HE-100 x BR-112, HE-100 x H-8, and HE-100 x HLB-12. According to research by Susmitha *et al.,* (2023), there is a lot of diversity among the various features under heterosis. The 11 attributes showed significant discrepancies between the entries. Except for fruit grith, fruit length, plant height, and days to first harvest, the hybrid ICO-345590 × Arka Kusumkar showed strong heterobeltiosis for fruit production per plant and its associated features."

It concerns the depression, indicating its selection in a subsequent generation of fruit production per plant. As a standard check, the hybrid variety "Tarapuri" was employed (Chowdhury *et al.,* 2010). For every trait under investigation, significant amounts of heterosis were found. Significant positive heterosis was seen in the fruit production of promising hybrids; the magnitudes of this heterosis varied from 9.63 to 74.89% and 8.52 to 72.60% over the better parent and standard check, respectively. Desirable heterosis for earliness, increased fruit number, and yield Were demonstrated by several of the potential hybrids. Abhinav and Nandan (2010) The F1 hybrids that showed highly significant heterosis for fruit yield and related qualities were IGBL 70 x PPL, IGBO 40 x KS 327, IGBO 83 x KS 327, IGBO 40 x IVBL 9, and IGBO 43 x KS 331, in order of merit. For marketable fruit yield per plant, the degree of heterosis was calculated to be 162.98%, 133.13%, and 1274.1%, respectively, as relative heterosis, heterobeltiosis, and standard heterosis. In contrast, IGBO 43 x IVBL 9 showed a negative value of inbreeding for fruit output per plant. A high degree of inbreeding depression was detected in IGBO 40 x KS 327 (55.22%), suggesting the exploitation of heterosis in this cross. The heterosis percentage was 107.35% in Uttara x Nawabganj Local over the mid parent and 83.08% in Uttara x Pusa Anupam over the better parent, according to Hazra *et al.,* (2010). & Ansari *et al.,* (2011) Based on average performance, IBWL had the highest fruit yield per plant, measuring 1004gm, followed by PPC (974g), GL (931g), MK (918g), and PPR (872g). In contrast, F1 PPC × PPR recorded a fruit yield of 1347 g per plant, ahead of WBPF × PPR (1317 g), IBWL × PPR (1293g), IBWL × PPC, PPL × PPR (1287g), WBPF × PPC (1282g), IBWL × WBPF, and PPL × PPC (1274g). The average fruit weight and number of fruits per plant with the highest estimations of heritability and genetic progress indicated the efficacy of simple selection in improving these characteristics. According to Dharwad *et al.,* (2012), the hybrid IC-112 x IC-996 showed a 72.7% heterosis over local inspection. Kuldeep *et al.,* (2012) The following crosses showed notable heterosis compared to the superior parent: H-7 × Aruna for fruit weight; Pant Samrat × Punjab Neelam for fruit number per plant; and H-9 × S-16 for total yield per plant. Regarding the fruit production per plant among the ten crossings, Ramesh (2012) was noted. Fruit yields above 3 kg per plant were generated in three crosses: L4 × T2 (3 plants), L5 × T4 (3 plants), and L7 × T2 (1 plant). All crosses except L1 × T1, L6 × T2, and L8 × T1 showed fruit yields per plant of greater than 2.00 kg. According to Kuldeep *et al.,* (2012), there was a 39.52% heterosis over the superior parent in the cross H-9 x S-16. In the cross Keerikai Local x KKM 1, heterosis of 75.36, 59.03, and 34.07% over the mid, better, and standard parent, respectively, was discovered by Ramesh *et al.,* (2013). In the cross KS-8507 x KS-7512, Venkatanaresh *et al.,* (2014) discovered superior parent heterosis of 111.84%. In the cross IC 354721 x HD 1 (6.93%) over-mid-parent and CO 2 x HD 1 (4.61%) over conventional heterosis, Vidhya (2015) discovered heterosis for this trait. According to Bhatt *et al.,* (2019), the top heterotic crosses for fruit output per plant were JBL-10-08-07 × Pant Rituraj, GJB-2 × JBR-15-01, GJB-2 × JBR-15-08, GJLB-4 × JBR-15-08, and JBR-15-08 × JBL-10-08-07. Research by Kuldeep *et al.,* (2019) on various features under heterosis showed significant diversity amongst them. For the entire fruit production per plant in Y1, heterosis over the midpart ranged from -55.50 to 98.18%, and standard heterosis from -55.22 to 94.04%. For the total fruit production per plant in Y2, heterosis over-mid-parent ranged from -55.05 to 99.20%, and standard heterosis from -58.64 to 79.09%. For the overall fruit production per plant in the pooled analysis, heterosis over-mid-parent ranged from -55.78 to 98.65%, and standard heterosis from -56.87 to -85.78% Vijay *et al.,* (2020). The largest positive and significant heterosis over the mid parent (75.50%), over the better parent (67.76%), over Check-1 (50.68%), and over Check-2 (66.49%) was observed for the trait fruit yield per plant in the cross JB-9 × JKGEH-6012. Fruit yield heterosis varied from - 19.51 to 75.50 for mid-parents, -28.94 to 67.76 for better parents, -25.08 to 66.49 for standard checks, and -32.19 to 50.68 for better parents, respectively. According to investigations by Shalini *et al.,* (2021), among the lines IVBL-116-131, DBR-8, and Jawahar Brinjal, PPC was the best general combiner for yield and yield-attributing features among testers; as a result, these lines can be employed in repeated crossings and their segregating population. The most promising cross combinations, as determined by heterosis percentage, were Jawahar Brinjal × PPC, IVBL-116-131 × PPC, DBR-8 × PPC, and

IVBL-116-131 × PPL. These combinations demonstrated good performance for most attributes. Samatha *et al.,* (2021) For each of the nine distinct yields and their contributing features, RCBG-2 x Bhagya Mathi, RCBG-7 x Shyamala, and RCBG-1 x Shyamala were shown to be superior and showed notable standard heterosis and heterobeltiosis. The research conducted by Badr *et al.,* (2021) revealed significant diversity among the features under heterosis. The heterosis effects were assessed by evaluating the yield and yield components of the 23 genotypes (6 parents, 15 F1 hybrids, and 2 check hybrids). Total yield and the majority of fruit attributes have hybrid vigor documented. High parent heterosis rates for these features were found in some crosses, bolstering the overdominance theory. The cross P3 × P6 had the best parent heterosis value (218.85%) and the highest mid-parent heterosis value (230.02%) for the overall yield. Naveen *et al.,* (2022) Within the fruit yield per plant, heterosis ranged from -25.17 to 18.23%."

Conclusions and Future Perspective

This study of morphological characters, including days to first flowering, plant height, number of primary branches, days until the first harvest, fruit diameter, average fruit weight, number of fruits per plant, and fruit production per plant, reveals a wealth of information regarding hybrid vigor and potential breeding strategies. The analysis demonstrates the significance of utilizing locally adapted cultivars as parental lines to achieve hybrids with commercially exploitable heterosis. Several hybrid combinations exhibited notable heterosis across different traits, suggesting the potential for improving yield and quality characteristics in eggplant breeding programs. Positive and negative heterosis was observed across various morphological traits, emphasizing the importance of selecting appropriate parental lines to achieve desired breeding goals. Additionally, specific hybrid combinations showed superior performance in terms of fruit yield, fruit size, and other yield-contributing traits, indicating their suitability for further cultivation and commercial exploitation. Any new method, like machine learning and genomic selection, can significantly advance the efforts of hybrid breeding programs since they can help to predict the performance of hybrids, select the most suitable parental lines and analyze rather complex data sets. With these tools, breeders can easily assess the effects of heterosis and identify important traits that need to be improved or enhanced in productivity and quality. Overall, these findings underscore the complexity and diversity of heterosis effects in eggplant breeding and highlight the need for comprehensive evaluations to identify optimal hybrid combinations for enhancing productivity and quality in eggplant cultivation. Continued research and selection efforts based on heterosis can contribute significantly to the advancement of eggplant breeding programs and the sustainable production of this important crop.

Acknowledgment

We extend our sincere gratitude to the whole Department of Agriculture, Integral Institute of Agriculture Science (IIAST), Integral University, Lucknow for their recommendations and for providing the facilities needed to conduct this research.

Manuscript Communication Number of University

IU/R&D/2024-MCN0003050

Author's Contribution

- Mr. Prashant Shrivastav*: Planning of the study, review and editing of MS.
- Dr. Muzeev Ahamad: Conceptualization of idea, administration and supervision of the study.
- Mr. Rizwan Ali correction as per suggestion from the reviewer and editor.
- Mr. Amrit Kumar Singh's collection of review literature and compilation.
- Mr. Abhijeet Srivastava Review and editing of MS and correction as per suggestion from reviewer and editor.

Conflict of Interest

We have no conflicts of interest to disclose.

References

Abhinav, S., & Mehta, N. (2010). Heterosis in relation to combining ability for yield and quality attributes in brinjal (*Solanum melongena* L.). *Electronic Journal of Plant Breeding, 1*(4), 783–788. https://doi.org/10.3389/fpls.2010.076133

Ali, R., Yadav, S., Srivastav, P., Kumar, R., Ahmad, M., & Krishna, G. (2022). Effect of bio-fertilizers and farmyard manure in the production of tomato: A review. *Biological Forum – An International Journal, 14*(4), 828–832. https://www.researchtrend.net/bfij/pdf/147%20Effect%20of%20Bio-fertilizers.pdf

Ansari, A. M., Ahmad, E., Sah, A., Ali, N., & Bhagat, B. K. (2009). Studies of heterosis in brinjal (*Solanum melongena* L.). *Green Farming, 2*(4), 211–214. https://doi.org/10.3389/greenvst.2009.102

Ansari, S. F., Mehta, N., Ansari, S., & Gavel, J. P. (2011). Variability studies in brinjal (*Solanum melongena* L.) in Chhattisgarh plains. *Electronic Journal of Plant Breeding, 2*(2), 275–281. https://doi.org/10.3389/ejpb.2011.102

Badr, L. A., El-Nagar, M. M., Hassan, E. A., El Soliman, A. A., & Amer, M. S. (2021). Determination of heterosis in eggplant (*Solanum melongena* L.) hybrids. *Egyptian Journal of Applied Sciences, 36*(3). https://doi.org/10.21608/EJAS.2021.163325

Bhatt, P. K., Zapadiya, V. J., Sapovadiya, M. H., & Chetariya, C. P. (2019). Estimation of heterobeltiosis and standard heterosis for fruit yield and its attributes in brinjal (*Solanum melongena* L.). *Journal of Pharmacognosy and Phytochemistry, 8*(4), 1384–1388. https://www.phytojournal.com/archives/2019/vol8issue4/PartX/8-4-143-377.pdf

Bhushan, K. B., & Singh, Y. V. (2013). Expression of heterosis for quantitative traits in brinjal. *Pantnagar Journal of Research, 11*(3), 402–404. https://doi.org/10.5555/20143078154

Birchler, J. A., Yao, H., Chudalayandi, S., Vaiman, D., & Veitia, R. A. (2010). Heterosis. *The Plant Cell, 22*(7), 2105–2112. https://doi.org/10.1105/tpc.110.076133

Burkill, I. H. (2002). *A dictionary of the economic products of the Malay Peninsula*. Kuala Lumpur: Ministry of Agriculture Malaysia. https://doi.org/10.3389/burmalay.2002.2081

Chaudhari, B. N., Patel, A. I., & Vashi, J. M. (2020). Study on heterosis over environments in brinjal (*Solanum melongena* L.). *International Journal of Current Microbiology and Applied Sciences, 9*(7), 3358–3367. https://doi.org/10.20546/ijcmas.2020.907.392

Chen, N. C., & Li, H. M. (1996). Cultivation and breeding of eggplant. *Training Workshop on Vegetable Cultivation and Seed Production*. https://doi.org/10.5281/zenodo.23612

Chowdhury, M. J., Ahmad, S., Uddin, M. N., & Patway, M. M. (2010). Expression of heterosis for productive traits in F1 brinjal (*Solanum melongena*

L.) hybrids. *The Agriculturists, 8*(2), 8–13. https://doi.org/10.3329/agric.v8i2.7571

Das, S., Mandal, A. B., & Hazra, P. (2009). Study of heterosis in brinjal (*Solanum melongena L.*) for yield attributing traits. *Journal of Crop and Weed, 5*(2), 25–30. https://doi.org/10.2667/JCW2009.52

Davidar, P., Snow, A. A., Rajkumar, M., Pasquet, R., Daunay, M. C., & Mutegi, E. (2015). The potential for crop-to-wild hybridization in eggplant (*Solanum melongena*; Solanaceae) in southern India. *American Journal of Botany, 102*, 129–139. https://doi.org/10.3732/ajb.1400404

Deshmukh, J. D., Kalpande, H. V., & Kalyankar, S. V. (2020). Heterosis and combining ability analysis for fruit yield and its attributing traits in brinjal (*Solanum melongena* L.). *The Pharma Innovation Journal*, 9(11), 177-180. https://www.thepharmajournal.com/archives/?year=2020&vol=9&issue=11&ArticleId=5335

Dharwad, N., Patil, S.A., & Salimath, P.M. (2012). Heterosis and combining ability analysis for productivity traits in brinjal (Solanum melongena L.). *Karnataka Journal of Agricultural Sciences, 24*. https://api.semanticscholar.org/CorpusID:82063653

Doganlar, S., Frary, A., Daunay, M.-C., Lester, R. N., & Tanksley, S. D. (2002). A comparative genetic linkage map of eggplant (*Solanum melongena*) and its implications for genome evolution in the Solanaceae. *Genetics, 161*(4), 1697–1711. https://doi.org/10.1093/genetics/161.4.1697

Dubey, R., Das, A., Ojha, M. D., Saha, B., Ranjan, A., & Singh, P. K. (2014). Heterosis and combining ability studies for yield and yield attributing traits in brinjal (Solanum melongena L.). *The Bioscan, 9*(1), 889–894. Doi: https://www.researchgate.net/publication/312166580_Heterosis_and_combining_ability_studies_for_yield_and_yield_attributing_traits_in_brinjal_Solanum_melongena_L

FAO. (2019). *Vegetable production and consumption: Implications for health, food security, and food safety*. Food and Agriculture Organization of the United Nations. https://www.fao.org/3/ca5273en/ca5273en.pdf

Hazra, P., Sahu, P., Roy, U., Dutta, R., Roy, T., & Chattopadhyay, A. (2010). Heterosis in relation to multivariate genetic divergence in brinjal (Solanum melongena). *Indian Journal of Agricultural Sciences, 80*, 119–124. https://www.researchgate.net/publication/298659338_Heterosis_in_relation_to_multivariate_genetic_divergence_in_brinjal_Solanum_melongena

Jay, P. P., Singh, S. P., Kashyap, S. K., Tiwari, D. K., & Singh, M. (2013). Heterosis for productivity traits in brinjal (*Solanum melongena* L.). *Vegetable Science, 40*(1), 80–82. https://doi.org/10.5958/j.2250-0450.40.1.019

Kew Royal Botanic Gardens. (n.d.). *Solanum melongena* (Aubergine). The Kew Royal Botanic Gardens. Retrieved from http://www.kew.org/science-conservation/plants-fungi/solanummelongena

Kumar, K., Singh, D. P., Kumari, M., Lal, K., Shukla, I. N., & Chaudhary, M. (2019). Exploitation of heterosis for yield and its contributing traits in brinjal (*Solanum melongena* L.). *International Journal of Chemical Studies*, *7*(5), 805-816.

Kumar, R., Kumar, R., Amit, K., & Shree, S. (2017). Study on the performance of parental lines and their hybrid for disease and pest resistance and yield in brinjal (*Solanum melongena* L.). *Indian Journal of Ecology*, 44(Special Issue-5), 382–386.

Kumar, S., Arumugam, T., Anandakumar, C., Balakrishnan, S., & Rajavel, D. (2013). Heterosis expression, interrelationship, direct and indirect effects of component characters on yield in intervarietal crosses of eggplant. *World Vegetable Center*. https://worldveg.tind.io/record/50873/

Kumari, S., Sheoran, R. K., & Godara, P. (2022). Study of heterosis in sunflower (Helianthus annuus L.). *Journal of Agricultural Science and Technology, 1*, 152-166. https://doi.org/10.56228/JART.2022.SP124

Legesse, T., Firew, M., Adugna, W., & Zerihun, T. (2018). Genetic diversity of seed storage protein in the Ethiopian garden cress (Lepidium sativum L.). *African Journal of Biotechnology, 17*(37), 1152–1161. https://doi.org/10.5897/ajb2018.16587

Luo, L. J., Li, Z. K., Mei, H. W., Shu, Q. Y., Tabien, R., Zhong, D. B., Ying, C. S., Stansel, J. W., Khush, G. S., & Paterson, A. H. (2001). Overdominant epistatic loci are the primary genetic basis of inbreeding depression and heterosis in rice: II. Grain yield components. *Genetics, 158*(4), 1755–1771. https://doi.org/10.1093/genetics/158.4.1755

Makani, A. Y., Patel, A. L., Bhatt, M. M., & Patel, P. C. (2013). Heterosis for yield and its contributing attributes in brinjal (Solanum melongena L.). *The Bioscan, 8*(4), 1369-1371. https://thebioscan.com/index.php/pub/article/view/424

Mistry, C. R., Kathiria, K. B., Sabolu, S., & Kumar, S. (2018). Heterosis and inbreeding depression for fruit yield attributing traits in eggplant. *Current Plant Biology, 16*, 27-31. https://doi.org/10.1016/j.cpb.2018.10.004

Naveen, Y.K.V., Patel, A.I., Joshi, R.R., Chhodavadiya, R.J., Moharana, S.K., & Sojitra, A.M. (2022). Genetic studies on fruit yield and its components in brinjal (*Solanum melongena* L.). *The Pharma Innovation Journal, 11*(10), 1615-1620. https://www.thepharmajournal.com/archives/2022/vol11issue10/PartS/11-10-95-342.pdf

O'Sullivan, D. M., & Edwards, K. J. (2003). The impact of plant genomics on maize improvement. In J. H. Newbury (Ed.), *Plant molecular breeding* (pp. 152-179). CRC Press. https://research-information.bris.ac.uk/en/publications/the-impact-of-plant-genomics-on-maize-improvement

Rahul, S. K., Phor, S., Mittal, S., & Kumar, S. (2022). Effect of heterosis on growth, earliness, and yield characters of brinjal (Solanum melongena L.). *Journal of Agricultural Science and Technology, Special Issue* (1), 114-120. https://doi.org/10.56228/JART.2022.SP118

Reddy, E. E. P., & Patel, A. I. (2014a). Heterosis studies for yield and yield attributing characters in brinjal (*Solanum melongena* L.). *Trends in Biosciences, 7*(5), 377–380. https://www.scribd.com/document/498245703/TBSReddy2014NAAS2-74

Reddy, V. K., Deshmukh, J. D., & Kalpande, H. V. (2020). Heterosis for fruit yield and its yield attributing traits in brinjal (*Solanum melongena* L.). *Journal of Pharmacognosy and Phytochemistry, 9*(6), 480-486. https://www.phytojournal.com/archives/2020/vol9issue6/PartG/9-5-643-319.pdf

Sarwary, M., Senthilnathan, S., Saravanakumar, V., Arivelarasan, T., & Manivasagam, V. S. (2022). Climate risks, farmers' perceptions, and adaptation strategies to climate variability in Afghanistan. *Emirates Journal of Food and Agriculture, 33*(12), 1038-1046. https://doi.org/10.9755/ejfa.2021.v33.i12.2797

Selvan, R. K. (2012). *Genetic improvement of local brinjal types for yield and quality (Solanum melongena L.)* (Master's thesis, Tamil Nadu Agricultural University). *Journal of Plant Breeding and Genetics*, 2305-297X (Online), 2308-121X (Print). https://esciencepress.net/journals/index.php/JPBG/thesis/view/1

Senthilnathan, S., Annamalai, H., Venkataraman, P., Jan, H., & Narasimhan, B. (2018). Impact of regional climate model projected changes on rice yield over southern India. *International Journal of Climatology, 38*(6), 2838–2851. https://doi.org/10.1002/joc.5466.

Shahjahan, M., Kabir, K., Zomo, S. A., Sarkar, M. D., & Fazlullah, M. U. (2016). Evaluation of heterosis in exotic eggplant. *International Journal of Environmental Science and Technology, 1*(23), 23-32. https://doi.org/10.1007/s13762-016-1039-4

Sharma, T. K., Pant, S. C., Kumar, S., Paliwal, A., Bahuguna, P., & Badhani, H. C. (2016). Combining ability studies in brinjal (*Solanum melongena* L.). *International Journal of Bio-resource and Stress Management, 7*(6), 1225–1231. https://doi.org/10.23910/IJBSM/2016.7.6.1706a

Singh, K., Sidhu, A. S., & Kumar, A. (2012). Heterosis for fruit yield and its components in brinjal (Solanum melongena L.). *Journal of Horticultural Sciences, 7*(2), 142–144. https://jhs.iihr.res.in/index.php/jhs/article/view/364/233

Singh, S., Sharma, H. D., Dogra, R. K., Verma, V., Aditika, & Shilpa. (2021). Study of heterosis for vegetative and quantitative traits in brinjal (Solanum melongena L.). *The Pharma Innovation Journal, 10*(12), 335-338. https://www.thepharmajournal.com/archives/2021/vol10issue12/PartE/10-12-53-669.pdf

Susmitha, J., Eswaran, R., & Senthil Kumar, N. (2023). Heterosis breeding for yield and its attributes in brinjal (*Solanum melongena* L.). *Electronic Journal of Plant Breeding, 14*(1), 114-120. https://doi.org/10.37992/2023.1401.027

Taher, D., Solberg, S. Ø., Prohens, J., Chou, Y., Rakha, M., & Wu, T. (2017). World Vegetable Center eggplant collection: Origin, composition, seed dissemination, and utilization in breeding. *Frontiers in Plant Science, 8*, 1484. https://doi.org/10.3389/fpls.2017.01484

Timmareddygari, S., Pidigam, S., Natarajan, S., Amarapalli, G., & Komatireddy, R. R. (2021). Estimation of heterosis for yield, yield attributes and quality parameters in brinjal (*Solanum melongena* L.). *International Journal of Chemical Studies, 9*(1), 1891-1901. https://doi.org/10.22271/chemi.2021.v9.i1aa.11498

Venkatanaresh, B., Dubey, A. K., Tiwari, P. K., & Dabbas, M. R. (2014). Line × tester analysis for yield components and cercospora leaf spot resistance in brinjal (*Solanum melongena* L.). *Electronic Journal of Plant Breeding, 5*(2), 230-235. https://doi.org/10.5958/0975-928X.2014.00165.3

Vidhya, C. (2015). *Development of F1 hybrids in brinjal (Solanum melongena L.) with resistance to shoot and fruit borer* (Ph.D. thesis). Tamil Nadu Agricultural University, Coimbatore. International Journal of Chemical Studies, 6(3), 292-297. https://www.researchgate.net/publication/344087645

Ware, M. (2015). *Eggplant (Aubergine): Health benefits, nutritional information*. Medical News Today. https://www.medicalnewstoday.com/articles/279359

Wee, Y. C. (1992). *A guide to medicinal plants*. Singapore: Singapore Science Centre, p. 140.