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Review article

A COMPREHENSIVE REVIEW ON MOLECULAR BASIS OF SALINITY TOLERANCE AND HETEROTIC EFFECTS IN RICE (*ORYZA SATIVA* L.) UNDER SALINE SOILS

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MOLECULAR BASIS OF SALINITY TOLERANCE

Recent developments in quantitative genetics making use of molecular markers made it possible for the determination of the map position and the relative contribution of the different loci to the observed trait variation. An important application of this knowledge is *via* Marker Assisted Selection (MAS), where molecular markers linked to the loci determining variation for the trait can be used to select the most favorable genotypes without a need to determine mineral levels by relatively complex and expensive assays in all breeding generations.

Molecular studies have revealed that salt tolerance is controlled by interactions between several independently regulated but temporally and spatially coordinated processes (Kawasaki *et al.* 2001; Ozturk *et al.* 2002; Seki *et al.* 2002). Using F_2 population derived from a salt tolerant japonica rice mutant, M-20 and the sensitive original variety 77-170A, Zhang *et al.* (1995) mapped a major gene for salt tolerance on chromosome seven. QTL analysis of salt tolerance has been conducted by several researchers (Lin *et al.* 2004, Koyama *et al.* 2001 and Prasad *et al.* 2000) and they identified seven QTLs for seedling traits associated with salt stress and mapped these to five different chromosomes. Koyama *et al.* (2001) reported the chromosomal location of ion transport and selectivity traits that are compatible with agronomic needs and showed that QTL for Na^+ and K^+ transport are likely to act through the control of root development and structure and the regulation of membrane localized transport compartmentalization. Gregorio *et al.* (2002) have mapped a major QTL designated *saltol* on chromosome one (flanked by SSR markers RM 23 and RM 140) using a population generated from a cross between salt sensitive IR 29 and salt tolerant Pokkali. This QTL accounted for more than 70 per cent of the variation in salt uptake (Bonilla *et al.* 2002) and is now being mapped to within 1 cm distance using a large set of near isogenic lines (NILs). Pokkali was the source of positive alleles for this major QTL (Bonilla *et al.* 2002), which accounted for high K^+ and low Na^+ adsorptions and low Na^+ to K^+ ratio under salinity stress (Gregorio *et al.*,2002 *and* Lisa *et al.*, 2004). Lin *et al.* (2004) have identified a major QTL for high shoot K^+ content under salinity stress in the same region of chromosome one. Ren *et al.* (2005) have made a break through in mapping *SKC1* in chromosome one, which maintains K^+ homeostasis in the salt tolerant variety Nona Bokra under salt stress, using finely mapped BC_2F_2 population, the *SKC1* locus was cloned. Lee *et al.* (2007) identified two QTLs (*qST1* and *qST3*) conferring salt tolerance at young seedling stage and were mapped on chromosome one and three, using a population of recombinant inbred lines of the 164 genotypes derived from a cross between Milyang 23 (*indica*) and Gihobyeo (*japonica*) in rice.

Heterosis in rice under saline conditions

Heterosis is a universal phenomenon and exploitation of heterosis is a quick and convenient way of combining desirable characters and hence, assumes greater significance in the development of hybrids. Hybrids have become an integral part of agriculture to boost productivity as they would respond very well to higher fertilizer levels. The phenomenon of heterosis in rice was first reported by Jones (1926). Shull (1948) explained that heterosis is the genetic expression of the beneficial effects of hybridization. Heterosis is expressed as percentage increase or decrease of F_1 hybrid over the mid parental value. The superiority of F_1 hybrid over the better parent is known as heterobeltiosis. Shull (1952) explained the heterosis concept in maize. Heterosis is defined as the increased vigour or decreased vigour of F_1 population over the mid parent (relative heterosis), better parent (heterobeltiosis) or a standard parent (standard heterosis) with respect to any character in the direction of breeders desire (Mandal *et al*., 1990). To know the potential of hybrids, studies on magnitude and direction of heterosis is very important.

The non-allelic interaction might be the cause of heterosis rather than the special relation between the genes at the same locus (Jinks and Jones, 1958). Falconer (1996) explained heterosis as complementary to inbreeding depression. Heterosis is directly proportional to Σdy2 where'd' is the degree of dominance component of gene action and 'y' is the difference in the gene frequencies of the parents involved as the cross. The success of heterosis breeding depends on the amount of genetic diversity present in the material. Genetically speaking, heterosis refers to the significant increase or decrease in the F_1 value over the mid parent value. However, from the plant breeding point of view, increase over better parent and / or the popular commercial variety is more relevant.

Sajjad (1986) observed lack of heterotic expression for number of primary branches panicle^{-1} and panicle fertility percentage under saline environment. For plant height heterobeltiosis ranged from -13.80 to 12.40 and from -40.80 to 54.68 for productive tillers plant^{-1}.He observed maximum heterosis of 7.8, 44.2, 19.7 and 154.4 per cent for the traits *viz.,* ear length, filled grains ear^{-1}, 100-grain weight and single plant yield respectively.

In a different study on salt tolerance, Sajjad and Awan (1989) observed that the F_1's showed heterosis over Basmati 370 for all the yield attributing traits studied. Heterobeltiosis was observed only for plant height. In a separate study, Young and Virmani (1990) produced 70 crosses (10 lines x 7 testers) and observed that, hybrids flowered earlier and were taller than the parents. Similarly, in an evaluation trial with 16 varieties and 72 F_1s for seven yield components, Sarawgi and Srivastava (1991) showed high heterosis for grain yield in the cross IR 52 x Samridhi.

From the evaluated data for eight quantitative traits in a cross developed from three parents *viz.,* IR 36, IR 50 and CO-29, Vivekanandan *et al.* (1992) observed heterosis and heterobeltiosis for number of productive tillers, grains panicle^{-1} and grain yield in the cross TKM 9 x CO-29. Similarly, heterosis for yield components was evaluated in 35 hybrids under normal and saline environments by Edwin (1995). He observed that the hybrids exhibited differential response over environments for various traits. The maximum heterosis for grain yield over better parent was 38.94 and 17.27 recorded by IR 64 x IR 54717-C10-94-3-2-3-2 under two normal environments. The same combination showed negative expression for heterosis under saline environment. The same combination also recorded high magnitude of heterosis for number of productive tillers plant^{-1} which was the primary yield contributing character under stressed condition.

In a study of heterosis and heterobeltiosis for yield and yield components in a 6 x 6 diallel, Sharma and Roy (1996) reported heterobeltiosis in all the crosses for flowering and maturity and more than 30 per cent heterotic expression for yield. The crosses, IR 64 x Culture 1 (63 per cent) and Maibi x CRM49 (1.5 per cent) were found as highly heterotic for grain yield. Yolanda and Vijendra Das (1996) in their study with 36 hybrids revealed heterotic vigour for panicles plant^{-1} and grain yield plant^{-1} in hybrid IR 62829A x CO 37. Highly significant heterosis for grain yield was found in two of 36 hybrids and highly positive standard heterosis was observed in V20A x IR 64 for 100-grain weight.

In a study on selected seven crosses, Ganesan *et al.* (1997) reported negative heterobeltiosis for days to panicle emergence and positive heterobeltiosis for panicles plant^{-1} and grain yield plant^{-1}. Similarly, Rogbell *et al*. (1998) reported that TNRH 16 derived from moderately salt tolerant parents (IR 58025 A x C 20 R) recorded a standard heterosis of 23 per cent over the salt tolerant variety (CO- 43) for grain yield.

Lakshmi Narayanan (2000) reported that the hybrid combination IR 64 x CO-43 performed well under normal and saline conditions for the trait grain yield plant^{-1} based on *per se*, *sca* effects and standard heterosis. The hybrid showed a maximum standard heterosis of 44.39% under normal condition and 55.49 and 52.35% under saline environment of Karaikal and Trichy respectively.Thirumeni and Subramanian (2000) evaluated eight parents and 16 hybrids under coastal salinity for heterosis for nine yield related traits. The hybrid SSRC 920 x TRY 1 was found to be superior for productive tillers plant^{-1}, spikelet sterility, Na^+ : K^+ and grain yield plant^{-1}. A maximum negative heterosis of -23.13 per cent for earliness was exhibited by SSRC 92076 x TKM9 indicating the possibility of developing early hybrids.

Babu *et al.* (2002) reported that the hybrid TS 29 x BTS 24 was the best as it recorded high standard heterosis than BTS 24 and CORH-2 for productive tillers plant^{-1}, leaf proline content and Na^+/K^+ ratio besides single plant yield. In a study undertaken at CSSRI, significant heterosis over the mid parent and better parents was observed for almost all the characters studied (Mishra *et al.* 2003). They stated that out of 15 F_1's, Pokkali x IR 28 (79.87), CSR-10 x IR 28 (67.18), CSR 13 x IR 28 (54.58) and CSR-1 x IR 28 (48.56) exhibited positive heterotic response over the mid parent and the hybrid Pokkali x IR 28 (49.31) over the better parent in alkali soil, whereas CSR-13 x IR 28 (35.17) and CSR-10 x CSR-13 (26.72) over the mid-parent and only one cross (CSR-10 x CSR-13, 24.53) over the better parent in saline soil exhibited better heterotic effects.

Yadav *et al.* (2003) evaluated 30 hybrids derived from crossing three lines with 10 testers for nature and magnitude of heterosis over better parent for characters *viz.,* days to 50 per cent flowering and maturity, plant height, flag leaf length, productive tillers plant^{-1}, panicle length, grains panicle^{-1}, grain yield plant^{-1} and harvest index.

Bhandarkar *et al.* (2005) reported that the per cent heterosis over better parent for grain yield ranged from 13.79 to 70.98, the maximum being recorded in the hybrid INRC 140 x Madhuri A-9 and all the eight crosses studied exhibited superiority over their respective parents for grain yield plant^{-1}. Similarly, Krishnaveni *et al.* (2005) conducted an experiment with 23 crosses and found highly significant positive average heterosis and heterobeltiosis for grain yield in four crosses and the heterosis and heterobeltiosis were ranged from -60.2 to 297.9 per cent and -65.1 to 235.2 per cent, respectively.

Saravanan *et al.* (2006) studied heterosis in 28 hybrids and found that crosses between high x high and high x low *gca* parents exhibited greater heterosis. The parents CRAC 2221-67 and Jaya were promising for grain yield plant^{-1} and number of grains panicle^{-1}. None of the crosses was heterotic to all the traits simultaneously.

Singh *et al.* (2006) studied 36 hybrids for the extent of heterosis and heterobeltiosis for ten characters. The crosses *viz.,* IR 580 25A x NDR 6054, PMS 1A x NDR 3026, IR 58025A x NDR 3013 and IR58025A x MDR 2022 were identified as the potential hybrids exhibiting >60 per cent heterosis for grain yield.

Usha Kumari *et al.* (2006) studied 42 different hybrids of rice and revealed that the hybrid BP 176 (G) x ASD 18 had the highest standard heterosis for single plant yield. Similarly, Faiz *et al.* (2006) studied two CMS lines, IR69616A and IR70369A in crosses with 60001 (a fine grain aromatic advances line) and Basmati 385 (a commercial Basmati variety) and noticed that highest positive heterosis over better parents was observed for grain yield (41.83 per cent), number of productive tillers plant^{-1} (11.04 per cent) and number of filled grains panicle^{-1} (7.39 per cent) in the cross of IR69616A x Basmati 385. Muhammad Rashid (2007) noticed that highest significant heterosis (61.9 per cent) was observed in the cross Super Basmati x DM-107-4 for yield plant^{-1}. The female Super Basmati, male DM-25 and DM-107-4 were observed to be good general combiners for most of the characters. The crosses, Basmati-370 x DM-25 and Super Basmati x DM-107-4 were observed as good specific combiners for yield plant^{-1}.

Venkatesan *et al.* (2008) observed the lower estimates of heterosis for physical characters when compared to yield and yield components. Nine hybrids manifested positive and significant heterosis over mid-parent, better parent and standard check for grain yield plant^{-1}, of which AD 95157 x IR 50, MDU 5 x IR 50, AD 95157 x ADT 43, MDU 5 x ADT 36, AD 95157 x ADT 36 and AD 95137 x ADT 36 were top rankers. On considering both yield and physical traits together the crosses MDU 5 x IR 50, MDU 5 x ADT 36, AD 95157 x ADT 36, AD 95157 x ADT 43, AD 95157 x IR 50 and AD 95137 x ADT 36 could be isolated for possessing desirable average heterosis, mid-parental heterosis and standard heterosis for yield and grain traits.

Twenty rice hybrids developed through a line x tester crossing programme involving five high yielding lines and four superior grain quality testers were evaluated for yield and quality characters by Roy *et al.* (2009). The cross combinations IET 5656 x Kalonunia, IET 8002 x Dudheswar, IET 5656 x Dudheswar and IR 62 x Samba Mahsuri were identified as good heterotic crosses for yield and grain quality characters.

Rahimi *et al.* (2010) evaluated 15 F_1 hybrids and their parents generated by half diallel cross for combining ability and heterosis. They recorded both additive and non-additive gene effects in the inheritance of the traits. They observed the cross Dorfak x Domsefid with highest heterosis for grain yield and 1000-grain weight.

Vaithiyalingan and Nadarajan (2010) studied 42 inter and intra sub-specific hybrids and noticed that the mean heterosis per cent are in the order of *indica* x *japonica* F_1> tropical *japonica* x *indica* F_1 > *indica* x *indica* F_1 > tropical *japonica* x *japonica* F_1. The combinations with significant standard heterosis over local variety MDU 5 for grain yield along with important yield components recommended for heterosis breeding were Dular x IET 16114 (*indica* x *japonica*), IR 65601-120-3-5 x ADT 43, IR 67323-46-2-1 x ADT 43 (tropical *japonica* x *indica*) and IR 66158-38-3-2-1 x Odaebayeo (tropical *japonica* x *japonica*).

Tiwari *et al.* (2011) studied line x tester mating design involving three CMS lines and 20 elite restorers to identify the best heterotic combination. The results indicated that the heterobeltiosis for grain yield was manifested in 43 hybrids ranging from 11.63 to 113.04 per cent and in 46 hybrids over standard variety (Sarjoo-52) ranging from 10.48 to 71.56 per cent. The best cross combination in order of merit for grain yield and other yield components were IR 58025A x IR 48749-53-2-2-2R, NMS 4A x IR 633-76-1R, IR 58025A x IR 54853-43-1-3R, IR 58025A x IR 19058-107-1R and PMS 10A x IR 54853-43-1-3R.

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