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Modern Plant Breeding For Sustainable Agriculture: A Review

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Abstract

More foods are required to fulfill a human need. The limitation of the farming area is leading to an intensification system in crop cultivation, so the use of chemical properties and environmental destruction cannot be denied. However, this industrial practice in the crop system has caused many adverse effects on ecological balance and human health. Many severe impacts of industrial agriculture practices have been reported, including soil erosion, groundwater contamination, loss of productivity, depletion of fossil resources, air pollution, new threats to human health and safety. Many experts agreed that sustainable agriculture seems to be an effective way to solve these issues. Modern plant breeding is now a popular approach to provide superior crop cultivars that can minimize adverse effects of agriculture practices because humans can recognize and manipulated genes through this method. Recently, the application of molecular markers in plant breeding selection has been brought enthusiasm for plant breeders. Marker-assisted selection (MAS) has been evidenced to be a beneficial technique in plant breeding. Through this approach, the selection process of parents and progenies in the breeding process could be more efficient. Plant breeding is influential in crop production achievement because this effort is connected with the adaptability and stability of the varieties in many different environmental circumstances. Plant breeding also focuses on agriculture sustainability due to its effort to produces durable disease resistance, abiotic stress tolerance, nutrients, and water-use efficiency.

Keywords: crop system, ecological balance, sustainable agriculture, modern plant breeding.

Introduction

To feed more than seven billion living people in the world, the supply of high-quality food becomes a major concern. More foods are required to fulfill the human need and farming area for the agricultural land expanding. Several studies suggest that the world will need 70 to 100% more food by 2050 (World Bank, 2008). Unfortunately, the global environmental change is now more challenging to accomplish sufficient crop production. However, many human efforts are being implemented for improving agricultural yield, including using fertilizers, pesticides, water supply, and technology support.

In the 18th century, when the industrial revolution started, agriculture belonged to one aspect affected by new technologies, mechanization, specialization, and high dependence on chemical fertilizers and pesticides. New technologies and scientific methods were applied to assist farmers in increasing agricultural products due to the human population expanding. However, these developments were beneficial for farmers and had reduced risks in farming, but they were also high-cost. These developments were also brought some adverse effects on the environment and human health. Many severe issues regarding industrial agriculture practices have been reported, including soil erosion, groundwater contamination, loss of productivity, depletion of fossil resources, air pollution, new threats to human health and safety (Reganold et al., 1990; Sonja et al., 2001). Until now, humans are still trying to find the best method to improve crop productivity without damage the environmental balance, although so many debates on how the food must be produced appropriately.

Sustainable agriculture seems to be an effective way to solve many problems in food production. In the ecological concept, sustainable agriculture means conserving the ecological balance by avoiding the exhaustion of natural resources (Oxford Dictionaries, 2014). Firstly, the definition of "sustainable agriculture" came from Wes Jackson, who has credited the term in his publication, *New Roots for Agriculture* in 1980 (Harwood, 1990; Kirschenmann, 2004 *in* Paoletti et al., 2011). The early idea of sustainable agriculture was for a farming system that imitates natural ecosystems (Jackson, 1980 *in* Paoletti et al., 2011).

Sustainable agriculture relies as much as possible on beneficial natural processes and renewable resources drawn from the farm itself. In addition, sustainable farming must results in adequate amounts of high-quality food, protect its resources and be environmentally safe and profitable (Reganold et al., 1990).

Sustainable agriculture is important because now a day climate change has become more authentic and inevitable. Weather fluctuations are spreading pests and limiting resources quickly. Sustainable agriculture is significant to protect the environment, enlarge the earth's resource base and maintain soil fertility. It also can upgrade the production of food as well as for profitable farm income. With biotechnology support, it could enhance the quality of life of humans and all organisms on earth and keep ecological balance. For example, implementing a smart breeding approach is a promising method for climate change resilience by gaining better-adapted crop varieties. However, very different genotypes might be needed to perform in the modified environments of protected agriculture. Direct selection of all desirable alleles and or gene editing will be required to deliver genotypes with the targeted alleles to provide sufficient yield and deliver nutritional food and functional traits for the new environments.

Is organic farming equal to Sustainable Agriculture?

The concept of sustainable agriculture has many operational meanings. Some argued that organic farming and sustainable agriculture have the same meaning. Nevertheless, others regard them as separate concepts that should not be equated. Sustainability is considered concerning organic farming- a growing sector in many countries (Rigby and Caceres, 2001).

Recently, the conceptual differences between organic farming and sustainable agriculture have been pointed out. Organic farming relies on farm-derived renewable resources that supply crops, livestock, and human nutrition. The organic farming method also concerns protection from pests and pathogens to keep harmony between agriculture and ecological and biological processes. In the organic farming method, foods are produced without synthetic fertilizer or pesticide and neither with genetically modified organisms (GMO) (Crespo-Herrera and Ortiz, 2015).

Organic farming is characterized by implementing an "organic system plan" that describes crop and livestock production practices. It also keeps the complex system in tracking all products from the field to the point of sale to prevent contamination of adjacent conventional fields (Singh, 2021). In addition, the organic farming system has a positive impact on the environment by enhancing soil fertility, contributing to mitigating climate change, and conserving biodiversity (Crespo-Herrera and Ortiz, 2015).

Sustainable agriculture presenting a farming method that mimics natural ecosystems. It is divided into some definitions and practices, including *agroecology*, integrated agriculture, low-input, precision agriculture, and organic agriculture. Later, "sustainable intensification" emerged as a process of producing more food from the same area of land as well as reducing the environmental impacts (Pretty, 2008). The fundamental principles of sustainable agriculture are: (i) integrate biological and ecological processes, such as nutrient cycling, nitrogen-fixing, soil regeneration, *allelopathy*, competition, predation, and parasitism into food production processes, (ii) reduce the application of those non-renewable inputs that cause harm to the environment or the human health, (iii) upgrades the farmer's knowledge and skills, thus improving their self-reliance and substituting human capital for costly external inputs, and (iv) improve farmer's capacities to work together to find solutions for agricultural and natural resource issues, such as pest, watershed, irrigation, forest and credit management. Many reports that evidenced improvement in crop production toward more sustainable agriculture were the production of corn and soybeans without using chemical fertilizers, pesticides, herbicides, and without causing soil infertility, soil erosion, and other environmental damages (Pimentel et al., 2005).

Organic farming and sustainable agriculture each have the same goals but different in the scope and plan systems. Therefore, organic farming is part of a sustainable agriculture system that concerns environmental protection by using biological and ecological processes. The two systems also aim to increase food production for human needs without bringing obstruction to ecological balance.

Several Problems in Agricultural Production Related to Abiotic and Biotic Stress

Submergence Stress

According to FAO (2109), extraordinary events related to water supply like floods and droughts have been significant threats to food security. Flooding caused by intensive and or extensive rainfall has negatively impacted livestock and seed stock loss, damage of infrastructure, machinery and tools, food shortage, disease, and loss of agricultural productivity (Saldana-Zorrilla, 2008). Submergence has adverse effects on crop plants: it can reduce seed germination and growth. Extended periods of complete submergence for seven days may cause the crop plant's ultimate death (Bailey-Serres et al. 2010; Xu et al. 2006).

In the submergence condition, plants experience multiple stresses, including low oxygen, low light, nutrients deficiency, restricts transpiration, induce energy starvation, and high risk of infections (Bailey-Serres and Voesenek, 2008; Tamang and Fukao, 2015). Increasing submergence depth and duration decreased in carbohydrate and starch's total soluble of shoot and root (Tan et al., 2010). Submergence would also impede aerobic respiration and photosynthesis and stimulate various responses to enhance survival, such as switching from aerobic to anaerobic respiration. Submergence-tolerant genotypes of rice were distinguished in metabolic studies by initial high-rate glycolysis that lessened as the stress continued (Singh et al. 2001; Xu et al. 2000). Molecular-oxygen deficiency caused altered cellular metabolism and can reduce crop productivity (Fukao and Bailey-Seres, 2008). Continues anaerobic metabolism can result in the accumulation of phytotoxic end-products (Bailey-Serres and Voesenek, 2008).

The metabolic response of flood-tolerant lowland rice cultivars and genotypes to oxygen deprivation is not easily classified as carbohydrate consuming or carbohydrate conserving. When the young plants are completely submerged, they transiently increase anaerobic respiration and then limit carbohydrate catabolism. This metabolic gymnastics is correlated with the protection of *meristematic* regions that reinitiate growth once submergence is alleviated. Therefore, the management of carbohydrate use is crucial for submergence tolerance. Carbohydrate-consuming response to hypoxia poses the danger of both depletion of carbohydrate reserves and oxidative damage (Fukao and Bailey-Serres 2004).

Drought Stress

Drought is one of the most devastating stress to the crop plant of all abiotic stresses. With the limitation of the water supply, cropland farming becomes more affected by the drought problem. Reduce and loss of yield caused by the drought stress has been reported from cropland farming in many countries worldwide. In a dry environment, it is not easy to increase crop productivity. Drought stress affected plants from morphological to molecular levels at vegetative and generative stages. Under drought stress, plants experience diminished growth regarding the cell division is limiting, and cell elongation is obstructing caused by turgor loss and impaired mitosis (Farooq et al., 2009). The root system is the most obstructed site in perceives drought stress signals in the plant (Seo et al., 2009).

Drought stress can reduce leaf size, stem extension, and root proliferation, disturb plant water relations, and reduces water-use efficiency. Physiologically, drought stress also leads to many destructive metabolisms, such as reduced CO_2 assimilation, membrane damage, the disturbed activity of various enzymes (Farooq et al., 2009). Regarding soil water deficit, there are three main mechanisms declining crop yield: (i) decreased canopy absorption of photosynthetically active radiation; (ii) declined the efficiency of radiation-use; and (iii) reduced plant's harvest index (Earl and Davis, 2003).

Water deficit in plants occurs in the limited water environment and in the saline habitat, in which a high concentration of salt can restrict plant roots from extracting water from the environment. This condition may influence water uptake by the plant as well as root hydraulic conductivity and nutrient uptake and transport (Aroca et al., 2006). For example, the inhibition of aquaporin activity leads to a decline in root hydraulic conductivity at low temperatures. In addition, the transpiration activity will be affected during this condition, depending on the temperature and humidity. Water deficit also inhibits cell elongation leading to root morphology and root hair length changes, while the *abscisic acid* (ABA) is produced by dehydrating roots (Nonami, 1998; Bibikova and Gilroy, 2003).

According to Bacelar et al. (2009), there are two mechanisms of woody plants to respond to water deficit conditions. The first is the prodigal water use strategy (for short periods only), in which plants pose high stomatal conductance, high Ci/Ca ratio, and low leaf water use efficiency (high rate of photosynthesis). This strategy enables plants to proliferate quickly. The second strategy is conservative water use, which enables the plant to use available water efficiently. This strategy is associated with high leaf water use efficiency, high capacity for drought tolerance, slow growth rate, and valuable in extended dry period conditions.

Pathogen Stress

Biotic stresses caused by pathogens and pests have been an enormous issue in crop cultivation worldwide. Blast and bacterial blight are two infectious diseases that attack many rice land farming. Blast diseases caused by *Magnaporthe oryzae* (*Pyricularia oryzae*) causing of hundreds of millions of tons of rice grain losses in many developing countries such as Asia and Africa. Rice blast causes significant crop losses, varies from 30% to 50% in different production zones depending on the physical environment, crop management, and pathogen population dynamics (Babujee & Gnanamanickam, 2000; Greer & Webster, 2001).

Bacterial blight caused by *Xanthomonas oryzae* is expanding to new rice production areas and threatens food security. This disease has leads to yield loss in rice up to 50% in some areas (Verdier et al., 2012). This disease had declined the grain yield of rice. The proper strategies and approaches are required to control and manage the disease, reduce crop loss, and prevent an epidemic (Gnanamanickam et al., 1999). The methods implemented to reduce adverse effects of the infection were using certified seeds and conducted chemical and cultural control in management (Karavina et al., 2011). While, Palti (1981) suggested four strategies in diseases management: (i) host plant resistance, (ii) cultural practices, (iii) biological control, and (iv) chemical control. Cultural control such as crop rotation, *polyculture*, manipulation of planting date plays a central role in diseases management. However, sometimes it is inadequate, impractical, or economically nonviable. Biological control also sometimes failed to lead to practical. Host plant resistance is an environmentally sound way to manage crop diseases. Approach to genetic improvement, from simple phenotypic selection until genome editing potentially produces adequate levels of diseases control. Genetic engineering (GE) potentially being a precise strategy to intensify disease resistance of crop plants sustainably, including minimizing pesticide usage (Vincelli, 2016).

Pest Stress

Plants may respond to pest stress in many ways, such as leaf curling, wilting, leaf *chlorosis* or *necrosis*, stunted growth, or in some cases, reduction of leaf area due to severe defoliation. Major pest damage mechanisms are germination reduction, stand reduction, light stealing, assimilation rate reduction, assimilation sapping, tissue consumption, and turgor reduction (Boote et al., 1983; Aggarwal et al., 2006).

The outbreak of *brown planthopper* (BPH), *Nilaparvata lugens* (Stal.) in the rice ecosystem has led to crop failure. This pest caused hopper burn, which may inflict significant yield loss of up to 70% (Krishnaiah et al., 2008; Srivastava et al., 2009). BPH is a phloem-feeding insect and one of the most economically harmful insect pests of cultivated rice. The use of insecticides is the common way to control insects, and tropical Asian countries have recently experienced *planthopper* outbreaks in record number. BPH resistance to insecticides especially *imidacloprid,* has raised the potential outbreak as farmers have applied increasing insecticide quantities to combat resistant populations (Bottrell and Schoenly, 2012).

Using genetically engineered crops is beneficial for farmers since their commercial introduction in the mid of 1990s. It can reduce time to recognize desirable traits and present a more precise alteration of a plant's trait. In addition, plant breeders can target a single plant trait without unintended characteristics in traditional breeding methods.

Plant Breeding for Sustainable Agriculture

Genetic manipulation is required in crop improvement, involving gene transfer from one source to another to gain desirable traits. Conventionally, gene transfer in flowering species was conducted by crossing or sexual hybridization. By this method, genes from the two parents were assembled into a new genetic matrix. However, besides the gene transfer, the crossing is also conducted for many other specific purposes: recombination, *heterosis*, breaking undesirable linkages, maintenance of parental lines and diversity in a gene pool, evaluation of parental lines, and genetic analysis (Acquaah, 2007). Although modern biotechnology development now led the plant breeder to transfer genes without involving the

Table 1. The list of studies in plant breeding uses DNA marker-assisted selection for obtaining desirable traits in crop production.

No.	Study topic	Plant material	Result	References
1	Marker-assisted selection for *brown planthopper* (BPH) resistance in rice (*Oryza sativa* L.)	Rice	Identification of Bph18(t) enlarges the BPH resistance gene pool to help develop improved rice cultivars and the PCR marker for the *Bph18(t)* gene was applicable for marker-assisted selection (MAS) in the rice breeding program	Jena et al. (2006)
2	Using molecular markers for genetic diversity, drought QTLs, and blast resistance genes	Rice	The presence of both drought-related QTLs and blast resistance genes can improve rice production	Anupam et al. (2017)
3	The use of molecular genetic markers (DNA markers) linked to the loci of blast resistance	Rice	The cultivation of developed varieties in production can reduce the use of chemical protective equipment and avoid pollution of grain ecosystems	Dubina et al. (2020)
4	The use of molecular markers to detect resistance genes to *Fusarium* Head Blight (FHB) in wheat	Wheat Barley	Resistant cultivars could reduce damage from FHB. Several QTL have been identified for lower FHB severity, DON content, kernel discoloration, and enhance FHB resistance in Barley	Bai and Shaner (2004)
5	Comparative analysis of conventional and marker-assisted selection methods in breeding Maize Streak Virus (MVP) in maize	Maize	Produce resistant cultivar by using MAS more effective and cheaper than using a conventional breeding method	Abalo et al. (2009)
6	Marker-assisted selection of qMrdd8 to improve maize resistance to rough dwarf disease (MRDD)	Maize	Inbred lines and hybrids could enhance resistance to MRDD	Xu et al. (2020)
7	Genetic gain and cost efficiency of marker-assisted selection of maize for improving resistance to multiple foliar pathogens	Maize	Molecular marker linked to target rQTL can facilitate pyramiding resistance to multiple diseases during early generation pedigree selection and the cost of using MAS was lower than phenotypic selection	Asea et al. (2012)
8	The using of DNA marker-assisted selection of sorghum in Sub-Saharan Africa	Sorghum	Four sorghum lines developed by the MAS breeding method were *Striga* resistant, drought-tolerant, and high yield.	Mohamed et al. (2014)
9	Introgression of QTLs implicated in resistance to sorghum downy mildew/SDM (*Peronosclerospora sorghi*) (Weston&Uppal) C.G. Shaw in maize through marker-assisted selection	Sorghum	The QTLs were successfully used in the MAS program for introgression of resistance to SDM in susceptible maize lines	Lohithaswa et al. (2015)
10	Application of molecular Marker-Assisted Selection (MAS) for disease resistance in a practical potato breeding program	Potato	The program presents advantages in applying MAS for breeding	Ortega and Lopez-Vizcon (2012)

sexual process (i.e., crossing), conventional plant breeding still being a common method to improve crop production. However, phenotypic selection by conventional breeding could take 8-10 years (Lema, 2018). Recently, the application of molecular markers in plant breeding selection has been brought enthusiasm for plant breeders. This approach was called marker-assisted selection (MAS). Marker-assisted selection has been evidenced to be a beneficial technique in plant breeding. Through this approach, the selection process of parents and progenies in the breeding process could be more efficient (Lema, 2018). DNA markers can be used to recognize the allelic variation in the genes related to desirable traits. MAS is a new part of "molecular breeding" since it could upgrade the efficiency and accuracy of conventional plant breeding (Collard and Mackill, 2008). Varieties can be grouped into genetic pools based on the genetic diversity determined from fingerprinting data. This precious information can be used for distinguishing the most suitable parental lines to be crossed.

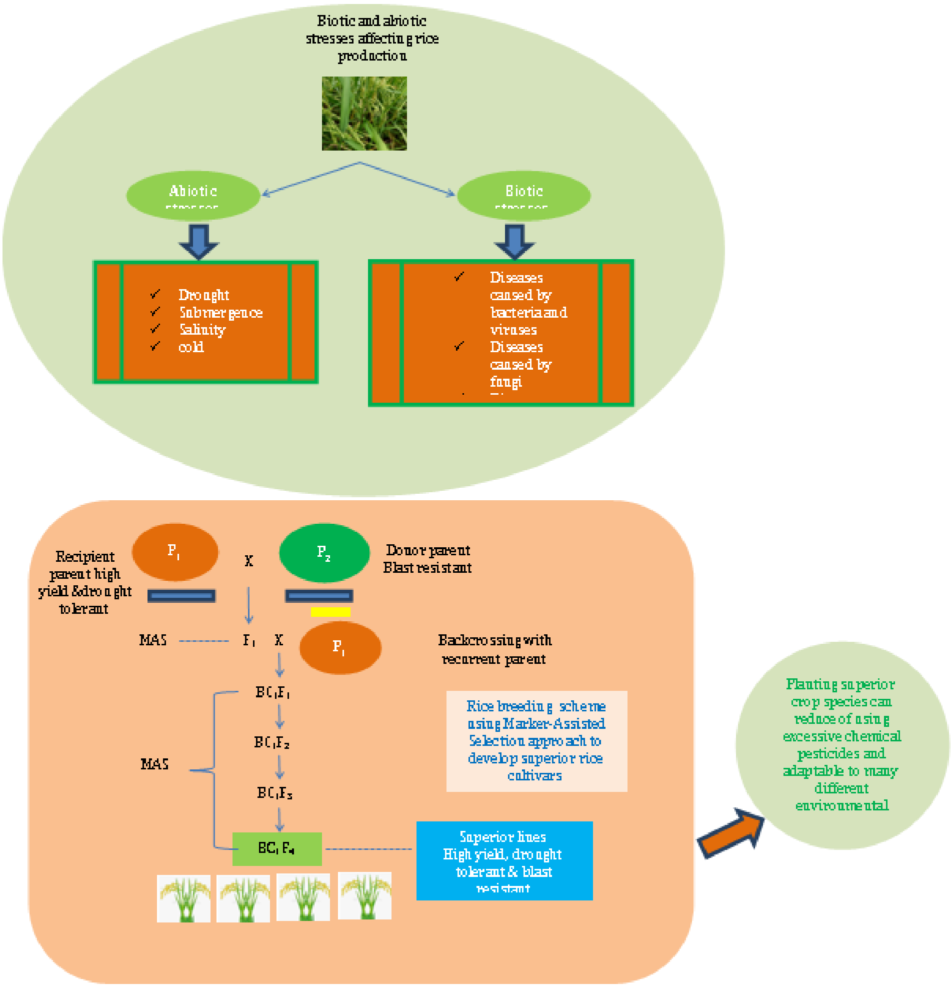

Figure 1. An overview of plant breeding implementation with molecular technology support (marker-assisted selection/MAS) to develop superior plant cultivars to minimize environmental degradation.

The investigation by using an analytical approach (computer simulation) indicated that MAS was more efficient rather than purely phenotypic selection in a large population and low heritability (Hospital et al., 1997). Furthermore, several studies recently revealed that plant breeding using DNA markers could effectively improve crop production, diseases resistance, abiotic stresses tolerance, and agronomic qualities (Table 1).

Plant breeding is necessary to enhance the crop's value by improving its yield and the nutritional quality of healthy living humans. Breeding is also necessary to make some plant products more digestible and safer to eat by reducing their toxic components and improving their texture and other qualities. Toxic substances occur in major food crops, such as alkaloids in yam, *cyanogenic glucosides* in cassava, trypsin inhibitors in pulses, and steroidal alkaloids in potatoes. Many studies evolved that modern plant breeding can improve crop quality and yield (Akos et al. 2019; Bruce et al. 2014; Prusty et al. 2018; Shamsudin et al. 2016a; Shamsudin et al. 2016b).

In another way, a plant breeding program is also valuable to bring harmony between agriculture and the environment (Brummer et al., 2011). It concerns improving crop's adaptability and resistance to abiotic and biotic stress to increase crop yields. Besides, a plant breeding program is also potentially to minimize the adverse effects of industrial agriculture practices. Plant breeding poses an influential role in crop production achievement because this effort is connected with the adaptability and stability of the varieties in many different environmental circumstances. Furthermore, plant breeding also focuses on agriculture sustainability due to its effort to produces durable-disease resistance, abiotic stress tolerance, nutrient- and water-use efficiency (Mackill et al., 1999).

Figure 1 shows the correlation between plant breeding by using a marker-assisted selection approach with sustainable agriculture. In the plant breeding program, superior cultivars with desirable traits were obtained. Planting adaptable cultivars in biotic and abiotic stresses conditions will minimize using excessive chemical pesticides and fertilizers and maximize crop cultivation management systems. Thus, a modern plant breeding system will support sustainable agriculture goals in protecting the environment, enlarging the earth's resource base, and maintaining soil fertility. It is also instrumental in producing sufficient food for humans as well as increase profitable farm income. Furthermore, implementing a modern plant breeding approach is a promising method for climate change resilience by gaining better-adapted crop varieties.

Conclusions

Plant breeding by implementing molecular markers will be necessary to achieve sustainable agriculture goals. Production of superior cultivars through modern plant breeding could minimize the adverse effects of using chemical fertilizers, pesticides, and other industrial agriculture practices. Sustainable agriculture will bring harmony between agriculture and the environment.

References

[1] Abalo, G., P. Tongoona, J. Derera, R. Edema. 2009. A comparative analysis of conventional and marker-assisted selection methods in breeding maize streak virus resistance in maize. *Crop Science*.49:509-520.

[2] Acquaah, G. 2007. *Principles of plant genetics and breeding*. Blackwell Publishing. USA.

[3] Akos, I.S., M.R. Yusop, S.I. Ismail, N. Ramlee, A.A.Z. Shamsudin, A.B. Ramli, B.S. Haliru, M. Ismai'la and S.C. Chukwu. 2019. A review on gene pyramiding of agronomic, biotic and abiotic traits in rice variety development. *Int. J. of Appl. Biology*, pp: 65-84.

[4] Aggarwal, P.K., N. Kalra, S. Chander and H. Pathak. 2006. InfoCrop A generic simulation model for assessment of crop yields, losses due to pests and environmental impact of agro-ecosystems in tropical environments 1 Model description. *Agric Syst.* 89:1–25

[5] Aroca, R., A. Ferrante, P. Vernieri and M.J. Chrispeels. 2006. Drought, abscisic acid and transpiration rate effects on the regulation of PIP aquaporin gene expression and abundance in *Phaseolus vulgaris* plants. *Ann Bot.* 98:1301–1310.

[6] Asea, G., B.S. Vivek, P.E. Lipps and R.C. Pratt. 2012. Genetic gain and cost efficiency of marker-assisted selection of maize for improved resistance to multiple foliar pathogens. *Molecular Breeding.* 29:515-527.

[7] Babujee, L.& S. Gnanamanickam. 2000. Molecular tools for characterization of rice blast pathogen (*Magnaporthe grisea*) population and molecular marker-assisted breeding. *Curr Sci.* 78: 248–57.

[8] Bacelar E.A., J.M. Moutinho-Pereira, B.C. Goncalves, J.I. Lopes and C.M. Correia. 2009. Physiological responses of different olive genotypes to drought conditions. *Acta Physiol Plant.* 31(3):611–621.

[9] Bai, G. and G. Shaner. 2004. Management and resistance in wheat and barley to *Fusarium* head blight. *Annu. Rev. Phytopathol.* 42:135-161.

[10] Bailey-Serres, J. and L.A.C.J. Voesenek. 2008. Flooding stress: acclimations and genetic diversity. *The Annu. Rev. of Plant Biology.* 59:313-339.

[11] Bibikova T. and S. Gilroy. 2003. Root hair development. *J. Plant Growth Regul.* 21:383–415.

[12] Bottrell, D. G. and K.G. Schoenly. 2012. Resurrecting the ghost of green revolutions past: the *brown planthopper* as a recurring threat to high-yielding rice production in tropical Asia. *J. Asia Pac. Entomol.* 15: 122–140.

[13] Boote, K.J., J.W. Jones, J.W. Mishore and R.D. Berger. 1983. Coupling pests to crop growth simulators to predict yield reduction. *Phytopathology.* 73:1581–1587.

[14] Brummer, E.C., W.T. Barber, S.M. Collier, T.S. Cox, R. Johnson, S.C. Murray, R.T. Olsen, R.C. Pratt and A.M. Thro. 2011. Plant breeding for harmony between agriculture and the environment: Review. *Frontiers in Eco. and the Environ.* 9(10):561-568.

[15] Collard, B.C.Y. and D.J. Mackill. 2008. Marker-assisted selection: an approach for precision plant breeding in the twenty-first century. *Philos. Trans. R. Soc. Lond. B. Biol. Sci.* 363(1491):557-572.

[16] Crespo-Herrera, L.A. and R. Ortiz. 2015. Plant breeding for organic agriculture: something new? *Agriculture and Food Security.* BMC.

[17] Earl, H.J. and R.F. Davis. 2003. Drought Stress: effect of drought stress on leaf and whole canopy radiation use efficiency and yield of maize. *Agronomy Journal.* 95: 688-696.

[18] Farooq, M., A. Wahid, N. Kobayashi, D. Fujita and S.M.A. Basra. 2009. Plant drought stress: effects, mechanisms and management. *Agronomy for Sustainable Development.* 29 (1):185-212.

[19] Fukao, T. and J. Bailey-Serres. 2008. Submergence tolerance conferred by Sub1A is mediated by SLR1 and SLRL1 restriction of *gibereline* responses in rice. *PNAS.* 105(43):16814-16819.

[20] Greer C. and R. Webster. 2001. Occurrence, distribution, epidemiology, cultivar reaction, and management of rice blast disease in California. *Plant Dis.* 85:1096–102.

[21] Hospital, F., L. Moreau, F. Lacoundre, A. Charcosset and A. Gallais. 1997. More on the efficiency of marker-assisted selection. *Theor Appl Genet.* 95:1181-1189.

[22] Jena, K.K., J.U. Jeung, J.H. Lee, H.C. Choi and D.S. Brar. 2006. High-resolution mapping of a new *brown planthopper* (BPH) resistance gene, *Bph18(t)* and marker-assisted selection for BPH

resistance in rice (*Oryza sativa* L.). *Theor. Appl. Genetics*. 112:288-297.

[23] Karavina, C., R. Mandumbu, C. Parwada and H. Tibugari. 2011. A review of the occurrence, biology and management of common bacterial blight. *J. of Agriculture Technology*. 7(6):1459-1474.

[24] Krishnaiah, N.V., V.J. Lakshmi, I.C. Pasalu, G.R. Katti and C. Padmavathi. 2008. Insecticides in rice—IPM, past, present and future. *Technical Bulletin* No. 30, Directorate of Rice Research, ICAR, Hyderabad, pp 146.

[25] Lema, M. 2018. Marker-assisted selection in comparison to conventional plant breeding: Review article. *Agric. Research and Technology*. 14(2):1-10.

[26] Lohithaswa, H.C., K. Jyothi, K.R. Sunil Kumar, Puttaramanaik and S. Hittalmani. 2015. Identification and introgression of QTLs implicated in resistance to sorghum downy mildew (*Peronosclerospora sorghi* (Weston & Uppal) C.G. Shaw) in maize through marker-assisted selection. *J. of Genetics*. 94(4):741-748.

[27] Mackill, D.J., H.T. Nguyen and J. Zhang. 1999. Use of molecular marker in plant improvement programs for rainfed lowland rice. *Field Crops Research*. 64(1-2):177-185.

[28] Mohamed, A., R. Ali, O. Elhasan, E. Suliman, C. Mugoya, C.W. Masiga, A. Elhusien and C.T. Hash. 2014. First product of DNA marker-assisted selection in sorghum released for cultivation by farmers in Sub-Saharan Africa. *J. of Plant Science and Molecular Breeding*. 3(3):1-10.

[29] Nonami, H. 1998. Plant water relations and control of cell elongation at low water potentials. *J. Plant Res*. 111:373–382.

[30] Ortega, F. and C. Lopez-Vizcon. 2012. Application of molecular marker-assisted selection for disease resistance in practical potato breeding programme. Potato Research. 55:1-13.

[31] Oxford Dictionaries. Oxford Dictionaries; 2014.

[32] Paoletti, M.G., T. Gomiero, and D. Pimentel. 2011. Introduction to the special issue: towards a more sustainable agriculture. *Critical Reviews in Plant Sciences*. 30:2-5.

[33] Pimentel, D., P. Hepperly, J. Hanson, D. Douds and R. Seidel. 2005. Environmental, energetic, and economic comparisons of organic and conventional farming systems. *Bioscience*. 55: 573–582.

[34] Pretty, J. 2008. Agricultural sustainability: Concepts, principles and evidence. *Phil. Trans. B*. 363: 447–465.

[35] Prusty, N., B. Pradhan, K. Deepa, B.C. Chattopadhyay, Patra and R.K. Sarkar. 2018. Novel rice (*Oryza sativa* L.) genotypes tolerant to combined effect of submergence and salt stress. *Indian J. of Plant Genet. and Resources*. 31(3): 260-269.

[36] Rigby, D. and D. Caceres. 2001. Organic farming and the sustainability of agricultural systems. *Agric. Systems*. 68:21-40.

[37] Saldana-Zorrilla, S.O. 2008. Stakeholders' views in reducing rural vulnerability to natural disasters in southern Mexico:hazar exposure and coping and adaptive capacity. *Glob. Environm. Change*.18:583-597.

[38] Seo, Pil Joon, F. Xiang, M. Qiao, J.Y. Park, Y.N. Lee, S.G. Kyu, Y.H. Lee, W.J. Park and C.M. Park. 2009. The MYB96 transcription factor mediates abscisic acid signaling during drought stress response in Arabidopsis. *Plant Physiol*. 151(1):275-289.

[39] Shamsudin, N.A.A., B.P.M. Swamy, W. Ratnam, M.T. Sta. Cruz, A. Raman and A. Kumar. 2016a. Marker assisted pyramiding of drought yield QTLs into a popular Malaysian rice cultivar, MR219. *BMC Genetics*. 17(1).

[40] Shamsudin, N.A.A., B.P.M. Swamy, W. Ratnam, M.T. Sta. Cruz, N. Sandhu, A.K Raman and A. Kumar. 2016b. Pyramiding of drought yield QTLs into a high quality Malaysian rice cultivar MRQ74 improves yield under reproductive stage drought. *Rice*. 9(1): 1–13.

[41] Singh, S., J.S. Sidhu, N. Huang, Y. Vikal, Z. Li, D.S. Brar,H.S. Dhaliwal and G.S. Khush. 2001. Genetic inheritance of multiple traits of blast, bacteria leaf blight resistant and drought tolerant rice lines. *Theoretical and Applied Genetics*. 102(6-7):1011-1015.

[42] Singh, M. 2021. Organic farming for sustainable agriculture. *Indian Journal of Organic Farming*. 1(1):1-8.

[43] Srivastava C., S. Chander, S.R. Sinha and R.K. Palta. 2009. Toxicity of various insecticides against Delhi and Palla population of *brown planthopper* (*Nilaparvata lugens*). Indian *J. Agric Sci*. 79:1003–1006.

[44] Tamang, B.G. and T. Fukao. 2015. Review: Plant adaptation to multiple stresses during submergence and following desubmergence. *International Journal of Molecular Sciences*. 16:30164-30180.

[45] Verdier, V., C.V. Cruz, and J. E. Leach. 2012. Controlling rice bacterial blight in Africa:needs and prospects. *Journal of Biotechnology*. 159(4):320-328.

[46] Vincelli, P. 2016. Genetic engineering and sustainable crop disease management:opportunities for case-by-case decision-making. *Sustainability*. 8:1-22.

[47] World Bank. 2008. *World Development Report 2008: Agriculture for Development*. World Bank, Washington, DC.

[48] Xu, K., X. Xu, T. Fukao, P. Canlas, R. Maghirang-Rodriguez and S. Heuer. 2006. Sub1A is an ethylene-response-factor-like gene that confers submergence tolerance to rice. *Nature*. 442(7103):705-708.

[49] Xu, Z., J. Hua, F. Wang, Z. Cheng, Q. Meng, Y. Chen, X. Han, S. Tie, C. Liu, X. Li, Z. Wang, and J. Weng. 2020. Marker-assisted selection of qMrdd8 to improve maize resistance to rough dwarf disease. Breeding Science Preview, pp 1-10.