REVIEW ARTICLE

MUTATION BREEDING FOR CROP IMPROVEMENT: A REVIEW

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ABSTRACT

Despite the fact that the world is at the rapid phase of agricultural modernization, but we are still concerned about food security. To meet the demand of exponential increase in population there is requirement of 70% more food by 2050. To overcome this situation we have to improve our existing crop varieties and make them genetically diverse, adaptive to climate change, input use efficient, high yielding, enhanced nutritional attributes, and better adaptable to a wide range of agro-ecosystems and should not deteriorate existing environment. Among the various methods of breeding to improve crop varieties mutation breeding (induced mutation) plays a crucial role for the development of genetic variation among themselves. Over past five decade mutation breeding is getting more popular and till now 3,362 mutant plant varieties from 240 different plant species in more than 75 countries are released. Different types of physical, chemical and combined mutagens have been used by various breeder to induce genetic variability in various crops. 2635 varieties are developed by physical mutagens, 398 varieties are developed by chemical mutagens and 37 varieties are developed by combination of physical and chemical mutagens. Continent wise, 82 varieties are developed by Africa, 2049 by Asia, 10 by Australia and Pacific, 959 by Europe, 53 by Latin America, and 209 by North America. Similarly, 1602 major cereals, 501 major legumes and 86 major oil seed mutant crop varieties are developed by mutation breeding/induced mutation. Mutation breeding improve several qualitative and quantitative characters of crop plant and is successfully applied in several cereal, grain legume, oil seed, vegetable, fruits, medicinal plant, ornamental plants and fodder crops. With the advancement of various plant breeding, genetics, and biotechnological tools mutation breeding contribute toward the increase in global food and agriculture production which ultimately overcome global hunger and improve the nutritional status of the globe.

KEYWORDS

Mutation, Mutation breeding, Induced mutation, Mutagens, Variation, Food security.

1. INTRODUCTION

As the world's population increases day by day in an exponential rate, food security is the major concern of this 21st century. By 2050 world population is expected to increase by 34% higher than today, which will reach up to 9.1 billion (FAO, 2009). To meet the demand of increasing population there is requirement of 70% more food production which obviously put a massive pressure on existing climate and agriculture production. This increase in food production must be accomplished in context of controlling unpredictable ecological and weather fluctuations (Charles et al., 2014). To overcome this situation establishment of low input agriculture in 21st century through generation of improved crop varieties that are genetically diverse, climate change resilient, input use-efficient, high yielding, enhanced nutritional attributes, and better adaptable to a range of agro-ecosystems and farming practices (FAO, 2011). Along with these practices numerous policies could be implemented to feed the world in 2050 such as careful evaluation, and reduction of excessive use of pesticides, fertilizers, antibiotics, and growth hormones in plant and animal agriculture; regulation of groundwater use, encourage efficient water handling system as pioneered (for example) by Israel and price water appropriately; expansion of the research that lead to more sustainable and ecologically

sound cropping system as opposed to immediate yield; follow carbon tax system and relies on cost effective renewable energy; e.t.c. (Ehrlich & Harte, 2015). The presence of extreme narrow genetic base of available crop varieties which is the major impediment for breeding of desirable crop varieties which are suitable for enhancing the farm productivity and establishing food security (Khursheed et al., 2019). The enhancement in the crop productivity to ensure food security is a major challenge in till this date. Global climate change is the key threat to the crop productivity and one of the major challenging task to the plant breeders and hence crop improvement programs should have focused on development of a variety which is adaptable to changing climate and should produce high yield (Raina et al., 2016) (Laskar et al., 2018). To develop such varieties variation among themselves and should have wider genetic base of desirable crops. Induced mutagenesis for creating genetic variation in the agro-economic traits which are required for meeting the demand of 21st century (Mba et al., 2012).

Variation includes the morphological, physiological, cytological and behavioural differences between species which is counted as major factor for crop improvement. Among various source of variation mutation is one of them. Hugo de Vries is considered as a father of mutation. In 1900, he used the term 'mutation' to describe inheritable phenotypic changes. A

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mutation is a change in the genome sequence of an organism (Ripley, 2013). Mutation arise in two ways; Firstly, spontaneous mutation: which occurs without treatment of the organism with an exogenous mutagen. Secondly, induced mutation: which occurs due to the treatment of a plant or plant parts such as seed, stem, cuttings, pollen and ovules with the mutagens. Purposeful utilization of the induced mutation for crop improvement is known as mutation breeding (Pathirana, 2011). Induced mutation or mutagenesis is the sudden heritable changes in the genome of an organism not caused by genetic recombination or segregation but induced by physical, chemical, or biological agents (Roychowdhury & Tah, 2013). Among the several breeding methods for creation of genetic variation in various crops, mutation breeding is one of the rational tool for creation of genetic variation.

2. DISCUSSION

The concept of induced mutation for the improvement of crop forerun to the beginning of 20th century. During the past 89 years, for the crop improvement mutation breeding plays a crucial role and also support the pace made using traditional methods of plant breeding (Amin et al., 2015). Due to emergence of induced mutation which plays a vital role in the development of crop varieties with desirable features all over the world, cultivation of different crop varieties has continued to be successful over the past five decades. Due to extensive use of induced mutants in the plant breeding programs across all over the world has led to official release of 3,362 mutant plant varieties from 240 different plant species in more than 75 countries throughout the world (FAO/IAEA, 2020). Varieties developed by mutation breeding increase the biodiversity due to presence of variation among themselves which serves as a baseline for conventional plant breeding and directly contribute toward the conservation and use of plant genetic resources.

To induce genetic variability in various crops different mutagens have been used by various breeders. Since the discovery of mutation effect of X-rays in the 1920s Lewis John Stadler has recognized induction of mutation as a potential technique for crop improvement (Shu et al., 2012). The first disease resistant mutant was reported in barley in 1942 (Usharani & Ananda Kumar, 2015). This finding lead to further work on mutagenesis and helps to develop and release different mutant of several crops. Chemical mutagens have been successfully employed in mutation breeding programs to artificially generate variations for the development of new varieties with improved traits, such as an increased yield, reduced plant height and resistance to disease (Khurshed, et al., 2015) (Tantray et al., 2017). Chemical mutagens primarily induce single point mutation so, it has been most commonly used in reverse genetic studies, and current technologies can also be easily adapted for their discovery (Jankowicz-Cieslak & Till, 2016). After fast neutron irradiation treatment germinability in three Nigerian sesame is improved (Falusi et al., 2015). Similarly, Daudu et al., (2012) found that yield of African long Pepper (*Capsicum annum var. accuminatum*) can be increased by fast neutron irradiation treatment. In case of lentil at lower concentration of methyl methanesulphonate, the genetic variability induced and 100 seed weight increases (Khurshed, 2014). During replication purines, especially guanine selectively alkylates by ethyl methanesulphonate causing a thymine base over a cytosine residue opposite to the 0-6-ethyl guanine, which results in random point mutation (Sikora et al., 2011).

In polyploid plant like bread wheat morphological mutation may occur at a high frequency (Hancock, 2012). In case of common wheat or bread wheat which is hexaploid in nature have three times higher total mutation rate than in diploid and triploid genotype (Rajarajan et al., 2014). This implies that hexaploid wheat is a source of variation for improvement of wheat crop. There is a difference in mutation frequency for the factor controlling chlorophyll development in different monosomics of *Triticum aestivum* (Lundqvist, 2014). Closer the varieties in case of genotypes, the greater is the similarity in the spectra and frequency of mutation (Gottschalk & Wolff, 2012). Mutation breeding also provide a path for improvement of vegetatively propagated crops. Vegetatively propagated crops require specialized method for the induction of mutation as it is complicated to handle as they present a wide range of targets. In recent years with the advancement in biotechnology, particularly in context of tissue culture, which provide efficient method for mutation breeding in vegetatively propagated crops (Spencer-Lopes et al., 2018). Improvement of vegetatively propagated crops include in vitro micro-propagation to raise the population for mutation induction, mutation screening, and mutation line development (Bado et al., 2015). Mutation breeding is a sustainable and ecologically sound method which plays a crucial role in increasing food production and providing sustainable nutrition to this growing world.

Table 1: Different types of mutagens and their characteristics.

Mutagens	Characteristics
X-rays	Electromagnetic radiation; ionizing, penetrate tissues from a few millimeters to many centimeters.
Gamma rays	Electromagnetic radiation, ionizing, very penetrating into tissues; sources are Co60 and Ce137.
Neutrons	Uncharged particles; penetrate tissues to many centimeters; source is U235.
Beta particles	Negatively charged electrons; ionize; shallowly penetrating; sources P32 and C14.
Alpha particles	Helium nucleus capable of heavy ionization; very shallowly penetrating.
Proton	Positively charged particles; penetrate tissues up to several centimeters.

(Raina et al., 2018)

Table 2: Number of mutant varieties developed by different mutagen treatments.

Mutagen treatment	Number of mutant varieties
Chemical	384
Physical	2610
Combined	37
Somaclonal variation	3
Total	3034

FAO/IEAE Mutant Variety Database, 2020.

Table 3: Number of mutant varieties developed by physical mutagens.

Physical mutagens	Number of mutant varieties
³² P	2
³² P and gamma rays	1
Accelerated ageing	3
Aerospace	46
Beta rays	16
Carbon ion beams	3
Chronic x-rays	1
Electrons	2
Fast neutron	4
fN	54
Gamma and x-ray recurrent	9
Gamma rays	1702
Gamma rays and fN	1
Gamma rays and microwave	3
Gamma rays and mixed neutron	1
Gamma rays and neutron	1
Gamma rays chronic	89
Gamma rays recurrent	1
Ion beams	20
Laser	26
Neutrons	24
Protons	1
Soft x-rays	6
thN	50
Tissue culture induced	1
Ultrasound	1
UV light	1
X-rays	561
X-rays or fN	5
Total	2635

FAO/IEAE Mutant Variety Database, 2020.

Table 4: Number of mutant varieties developed by chemical mutagens.

Chemical Mutagens	Number of mutant varieties
AA+DAB	1
Arsenic-q	2
BEO (Beryllium oxide)	1
Bromodeoxyuridine	1
Colchicine	46
dES	14
DES+PYM	2
Diazoacetylbutan	1
DMS	19
DMS+DAB+Dioxane	1
DMSO	1
EI	36
EMS	108
EMS+DAB	1
ENH	1
Ethyleneoxide	2
Extract of Dhatura seeds	1
MNH	6
MNU	7
NaN ₃	11
NDEU	1
NDMU	1
NENG	5
NEU	57
NEU+Dioxane	1
NEU+NMU+DES+DMS+EI	1
NMH	2
NMU	48
NMU and EI	1
NMU and NEU	2
NMU+DAB+Dioxane	2
NMU+Dioxane	3
NMU+EI+DMS	1
NTMU	1
PMS	2
Sodium azide	2
Tissue culture induced	6
Total	398

FAO/IEAE Mutant Variety Database, 2020.

Table 5: Number of officially released mutant varieties across the various continent.

Continents	Number of mutant varieties
Africa	82
Asia	2049
Australia and Pacific	10
Europe	959
Latin America	53
North America	209
Total	3362

FAO/IEAE Mutant Variety Database, 2020.

Table 7: Number of mutant varieties developed and their general improved characters.

General Improved Characters	Number of variety released
Agronomic and botanic traits	2981
Quality and nutritional traits	1173
Resistance to biotic stresses	557
Tolerance to abiotic stress	248
Yield and contributors	1029

FAO/IEAE Mutant Variety Database, 2020.

Table 8: Number of mutant varieties released in cereals, legumes and oil seed crops.

Latin name	Number of mutant variety
Cereals	
Avena sativa L. (Oat)	23
Eleusine coracana (Finger millet)	2
Hordeum vulgare L. (Barley)	311
Oryza sativa L. (Rice)	851
Secale cereal L. (Rye)	4
Sorghum bicolor L. (Sorghum)	17
Triticum aestivum L. (Bread wheat)	265
Triticum dicoccum L. (Emmer wheat)	2
Triticum turgidum ssp. durum Desf. (Durum wheat)	31
Zea mays L. (Maize)	96
Total	1602
Legumes	
Arachis hypogaea L. (Groundnut)	79
Cajanus cajan Millsp. (Pigeon pea)	7
Cicer arietinum L. (Chickpea)	27
Dolichos lablab L. (Hyacinth bean)	1
Lathyrus sativus L. (Grass pea)	3
Lens culinaris Medik. (Lentil)	18
Glycine max L. (Soyabean)	181
Phaseolus vulgaris L. (Common bean)	59
Pisum sativum L. (Pea)	34
Trifolium alexandrinum L. (Egyptian clover)	1
Trifolium incarnatum (Crimson clover)	1
Trifolium pratense (Red clover)	1
Trifolium repens (White clover)	1
Trifolium subterraneum (Subterranean clover)	1
Vicia faba L. (Faba bean)	20
Vigna aconitifolia (Jack. Marechal) (Moth bean)	1
Vigna angularis Wild. (Azuki bean)	3
Vigna mungo L. (Blackgram)	9
Vigna radiata (L.) Wil. (Mung bean)	39
Vigna unguiculata Walp. (Cowpea)	15
Total	501
Oilseeds	
Brassica campestris L. (Rapeseed)	3
Brassica juncea (L.) Czern & Coss (Indian mustard)	2
Brassica juncea L. (Mustard/ Oriental mustard)	10
Brassica napus L. (Rapeseed)	21
Carthamus tinctorius L. (Safflower)	2
Helianthus annuus L. (Sunflower)	6
Linum grandiflorum Desf. (Red flax)	1
Linum usitatissimum L. (Linseed/Flax)	11
Sesamum indicum L. (Sesame)	30
Total	86

FAO/IEAE Mutant Variety Database, 2020.

Table 6: Official release of mutant varieties across the various countries in the world.

Country	Registration date	Number of released varieties	Name of the major released crops
Albania	1996	1	Wheat
Algeria	1979	1	Soybean
Argentina	1962-1987	6	Wheat, Groundnut, Lemon, Peach, Orange
Australia	1967-2010	9	Barley, Oat, Lupin, Blue lupin, Soybean, Serradella
Austria	1959-1995	17	Barley, Durum, Apple, Faba bean
Bangladesh	1970-2018	75	Rice, Wheat, Black gram, Lentil, Mungbean, Onion, Rapeseed, Indian mustard, Chickpea, Tomato, Jute
Belgium	1967-1987	22	Barley, Potato, Red clover, Ficus, Chrysanthemum
Brazil	1974-2016	16	Wheat, Rice, Chrysanthemum, Sweet orange
Bulgaria	1972-2010	76	Maize, Wheat, Soybean, Barley, Lentil, Cotton, Green pepper, Sunflower, Peach, Pea, Tobacco
Burkina Faso	1978-1979	2	Rice
Canada	1964-2000	40	Barley, Oat, Common bean, Sweet cherry, Tobacco, Linseed, Apricot, Rose, Apple, Begonia, Rapeseed
Chile	1981-1990	2	Wheat, Barley
China	1957-2013	816	Rice, Wheat, Maize, Millet, Barley, Sorghum, Tomato, Cotton, Orange, Mandarin, Canna lilies, Chinese cabbage, Chinese garlic, Common bean, Sunflower, Pea, Dahlia, Sugarcane, Apple, Pear, Radish, Lotus, Peach, Mulberry, Tea, Foxtail millet
Congo	1972	3	Maize, Soybean
Costa Rica	1975-1996	4	Rice, Common bean, Cowpea
Cote D'Ivoire	1976-1987	25	Rice
Cuba	1990-2015	21	Rice, Soybean, Sugarcane, Tomato, Hibiscus
Czech Republic	1965-1996	18	Barley, Apple, White mustard
Denmark	1977-1990	21	Barley
Egypt	1980-2011	9	Sesame, Common bean, Safflower, Chickpea
Estonia	1981-1995	5	Barley, Potato
Finland	1960-1981	11	Wheat, Barley, Rye, Oat
France	1970-1988	39	Rice, Barley, Durum, Dahlia, Apple, Black currant, Weigela, Forsythia, Carnation, Plum
Germany	1950-2005	171	Wheat, Rye, Soybean, Barley, Chrysanthemum, Carnation, Geranium, Rose, Faba bean, Spinach
Ghana	1997	1	Cassava
Greece	1969-1970	2	Barley, Durum
Guyana	1980-1983	26	Rice
Hungary	1969-2001	10	Rice, Wheat, Maize, Soybean, Chrysanthemum
India	1950-2019	341	Rice, Barley, Sorghum, Pearl millet, Paper flower, Rose, Chrysanthemum, Hibiscus, Okra, Bougainvillea, Castor bean, Cotton, Opium poppy, Groundnut, Chickpea, Mustard, Oriental mustard, Moth bean, Mulberry, Gladiolus, Coleus, Sunflower,
Indonesia	1982-2020	51	Rice, Wheat, Mung bean, Tobacco, Soybean, Cotton, Groundnut, Sorghum, Banana
Iran	2004-2008	4	Rice
Iraq	1992-1999	24	Rice, Wheat, Barley, Sesame, Faba bean, Tobacco, Soybean
Italy	1968-1995	35	Rice, Wheat, Durum, Olive, Sweet cherry, Potato, Pea, Eggplant Green pepper, Common bean, Vetch, Almond
Japan	1961-2009	479	Rice, Wheat, Barley, Buckwheat, Soybean, Strawberry, Wasabi, Chrysanthemum, Potato, Annual baby's-breath, Rose, Azuki bean, Begonia, Carnation
Jordan	2019	1	Barley
Kenya	1985-2001	3	Wheat, Cowpea
Korea	1970-2011	40	Rice, Barley, Soybean, Sesame, Chrysanthemum
Malaysia	1995-2015	16	Rice, Groundnut, Chrysanthemum, Orchid, Banana
Mali	1998-2000	15	Rice, Sorghum
Mauritius	2015-2019	7	Tomato, Oyster mushroom
Mexico	NA	5	Wheat, Soybean
Moldova	2007-2010	7	Soybean, Lentil, Grass pea, Faba bean
Mongolia	1984-2018	6	Wheat
Myanmar	1975-2005	8	Rice, Groundnut, Tossa jute
Netherlands	1954-1988	176	Barley, Carnation, Chrysanthemum, Dahlia, Onion, Apple, Begonia, Lily, Hyacinth, Gladiolus
Nigeria	1980-1988	3	Rice
Norway	1978-1988	2	Barley
Pakistan	1970-2017	59	Rice, Wheat, Cotton, Mustard, Rapeseed, Mung bean, Chickpea, Groundnut, Mandarin, Lentil, Sesame
Peru	1995-2006	3	Barley, Amarant
Philippines	1970-2019	20	Rice, Ti plant, Dracaena, Freycinetia, Murraya, Sansevieria, Schefflera, Ribbon dracaena
Poland	1977-1995	31	Barley, Pea, Yellow lupin, Blue lupin, Faba bean, Scarlet runner, Chrysanthemum, Gerbera
Portugal	1983	1	Rice
Romania	1992	1	Rice
Russian Federation	1965-2011	216	Rice, Wheat, Maize, Hybrid maize Barley, Spring barley, Sorghum, Millet Oat, Buckwheat, Cotton
Senegal	1968	2	Rice
Serbia	1974	1	Pepper
Slovakia	1964-1995	19	Maize, Barley, Soybean, Common bean, clover, Rose
Spain	2006-2010	3	Clementine
Sri Lanka	1971-2010	4	Rice, Groundnut, Sesame, Tomato
Sudan	2007-2018	2	Groundnut, Banana
Sweden	1950-1988	26	Barley, Rapeseed, White mustard, Pea
Switzerland	1985	1	Wheat
Syrian Arab Republic	1985	1	Wheat
Taiwan	1967-1973	2	Rice
Thailand	1977-2019	24	Rice, Mung bean, Soybean, Carnation, Portulaca/moss rose, Canna lilies, Chrysanthemum, Banana
Tunisia	2007	1	Common bean
Turkey	1994-2016	11	Barley, Soybean, Potato, Chickpea, Sesame, Tobacco
Uganda	2015	3	Wheat
Ukraine	1997-2017	14	Wheat, Barley
United Kingdom	1966-1990	34	Barley, Streptocarpus
United States	1956-2006	139	Rice, Wheat, Barley, Oat, Common bean, Lettuce, Tobacco, Groundnut, Pepper mint, Rose, Carnation
Uzbekistan	1966-1991	9	Cotton
Viet Nam	1975-2017	58	Rice, Maize, Soybean, Groundnut, Chrysanthemum
Zambia	2009-2018	4	Finger millet, Cowpea
Zimbabwe	2017	1	Cowpea
Total		3362	

FAO/IEAE Mutant Variety Database, 2020.

3. CONCLUSION

Variation is among the major factor without which we cannot imagine the improvement of crop in any aspect. Among various method of breeding in crop plant mutation breeding i.e. induced mutation is one of the preeminent methods of creation of variation/genetic variation. Conventional method of breeding takes long time to improve a crop variety due to a very slow increase in genetic variation. To overcome this induced mutation play a crucial role which helps in creation of genetic variation in a short period. Over last several year's mutation breeding is getting popular and is adopted by several countries. It improves several qualitative and quantitative characters of crop plant and is successfully applied in several cereal, grain legume, oil seed, vegetable, fruits, medicinal plant, ornamental plants and fodder crops. With the advancement of various plant breeding, genetics, and biotechnological tools mutation breeding contribute toward the increase in global food and agriculture production which ultimately overcome global hunger and improve the nutritional status of the globe.

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