The Role of Induced Mutations in World Food Security

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Abstract

Physical availability and economic accessibility of food are the most important criteria of food security. Induced mutations have played a great role in increasing world food security, since new food crop varieties embedded with various induced mutations have contributed to the significant increase of crop production at locations people could directly access. In this paper, the worldwide use of new varieties, derived directly or indirectly from induced mutants, was reviewed. Some highlights are: rice in China, Thailand, Vietnam, and the USA; barley in European countries and Peru, durum wheat in Bulgaria and Italy, wheat in China, soybean in China and Vietnam, as well as other food legumes in India and Pakistan. An exact estimate of the area covered by commercially released mutant cultivars in a large number of countries is not readily available, but the limited information gathered clearly indicates that they have played a very significant role in solving food and nutritional security problems in many countries.

Introduction

Ever since the epoch-making discoveries made by Muller[1] and Stadler [2] eighty years ago, a large amount of genetic variability has been induced by various mutagens and contributed to modern plant breeding. The use of induced mutations over the past five decades has played a major role in the development of superior plant varieties all over the world (**Fig. 1a**). Among the mutant varieties, the majority are food crops (**Fig. 1b**).

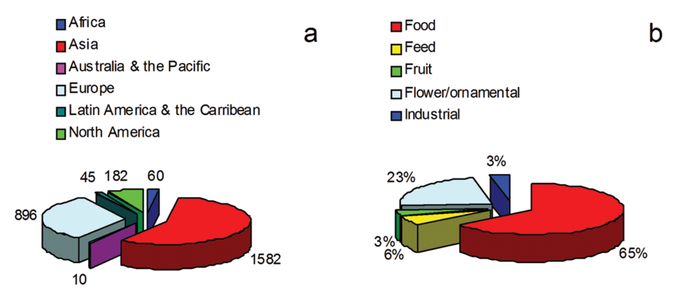

Figure 1 Plant varieties derived from induced mutants. a) The number of mutant varieties in different continents and b) proportion of various plant types Source: FAO/IAEA Database of mutant varieties and genetic stock, http://mvgs.iaea.org, 17 November, 2008.

Food security has been variously defined in economic jargon, but the most widely accepted definition is the one by the World Bank [3] – "access by all people at all times to enough food for an active, healthy life". Likewise, the World Food Summit at Rome in 1996 also known as Rome Declaration on World Food Security [4] on food plan action observed that, "Food security at the individual, household, national and global level exists where all people at all times have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life". In both definitions, emphasis has been given to physical availability and economic accessibility of food to the people. The mutant varieties are often grown by farmers in their fields, and any increase of food production resulted from the cultivation of the mutant varieties could be translated into increased food security, since this should be accessible for the people in need.

A detailed review on the global impact of mutation-derived varieties developed and released in major crops all over the world has been published by Ahloowalia, *et al.* [5]. Several papers presented in this symposium have also elaborated the contribution of induced mutations to food security in either a particular country or a particular crop. Herewith, we present the overall role of induced mutations worldwide, by continent and country, with emphasis on those countries not already discussed in papers which are included in this book.

ASIA

According to the FAO/IAEA database [6], more than half of the mutant derived varieties were developed in Asia (**Fig. 1**); China, India, and Japan are the three countries that released the largest number of mutant varieties in the world. Some important achievements are summarized here.

China

In China, the mutant rice variety 'Zhefu 802' deriving from var. 'Simei No. 2', , induced by Gamma-rays, has a short growing period (105 to 108 days), high yield potential even under poor management and infertile conditions, wide adaptability, high resistance to rice blast, and tolerance to cold [5]. Therefore, it was the most extensively planted conventional rice variety between 1986 and 1994. Its cumulative planted area reached 10.6 million ha during that period [7]. Two other mutant rice varieties, Yuanfengzao (1970's) and Yangdao # 6 (2000's), developed and released before and after Zhefu 802, are further mutant varieties that had been grown on annual scales up to one million ha (Ministry of Agriculture, China, unpublished data). Using a pollen irradiation technique, two new high-quality, high-yield, and early maturity mutant varieties – Jiahezazhan and Jiafuzhan, resistant to blast and plant-hopper, as well as endued with a wide adaptability - were developed and are now planted annually on 363,000 ha in Fujian province of China [8].

China has also been successful in breeding soybean varieties using mutation techniques. For example, the mutant soybean varieties developed by the Genetics Institute of the Chinese Academy of Sciences possess different excellent traits such as high yield, good grain quality, disease/insect resistance, or drought/salt tolerance. The total area planted with these varieties was more than $1x10^7$ ha. [9]. The "Henong series" soybean mutant cultivars, developed and released by the Soybean

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Institute of Heilongjiang Academy of Agricultural Sciences, as well as another variety, Tiefeng18, were grown on an area of more than 2.33x10^6 ha and 4x10^6 ha respectively (Ministry of Agriculture, China, unpublished data).

China has developed and released a large number of high yielding groundnut mutant varieties during the last few decades. The cumulative cultivated area of the more than 35 mutant cultivars released accounts for about 20% of the total area under groundnut in China [10].

Table 1. Number of released mutant varieties in 57 crop species in India

SN	Latin name	Common name	No. of varieties
1	*Ablemoschus esculentus* L. Moench	Okra	2
2	*Arachis hypogaea* L.	Groundnut	18
3	*Bougainvillea spectabilis* Wild	Bougainvillea	13
4	*Brassica juncea* L.	Mustard	9
5	*Cajanus cajan* L. Millsp.	Pigeonpea	5
6	*Capsicum annum* L.	Green pepper	1
7	*Carica papaya* L.	Papaya	1
8	*Chrysanthemum* sp.	Chrysanthemum	49
9	*Cicer arietinum* L.	Chickpea	8
10	*Corchorus capsularis* L.	White jute	2
11	*Corchorus olitorius* L.	Tossa jute	3
12	*Curcuma domestica* Val.	Turmeric	2
13	*Cymbopogon winterianus* Jowitt.	Citronella	9
14	*Cyamopsis tetragonoloba* L.	Cluster bean	1
15	*Dahlia* sp.	Dahlia	11
16	*Dolichos lablab* L.	Hyacinth bean	2
17	*Eleusine coracana* L.	Finger millet	7
18	*Gladiolus* L.	Gladiolus	2
19	*Glycine max* L. Merr.	Soybean	7
20	*Gossypium arborium* L.	Desi cotton	1
21	*Gossypium hirsutum* L.	American cotton	8
22	*Helianthus annus* L.	Sunflower	1
23	*Hibiscus sinensis* L.	Hibiscus	2
24	*Hordeum vulgare* L.	Barley	13
25	*Hyocyamus niger*	Indian henbane	1
26	*Lantana depressa* L.	Wild sage	3
27	*Lens culinaris* L. Medik.	Lentil	3
28	*Luffa acutangula* Roxb.	Ridged gourd	1
29	*Lycopersicon esculentum* M.	Tomato	4
30	*Matricario cammomilla*	Germen chamomile	1
31	*Mentha spicata*	Spearmint	1
32	*Momordica charantia* L.	Bitter gourd	1
33	*Morus alba* L.	Mulberry	1
34	*Nicotiana tabacum* L.	Tobacco	1
35	*Oryza sativa* L.	Rice	42
36	*Papaver somaniferum* L.	Opium poppy	2
37	*Pennisetium typhoides* L.	Pearl millet	5
38	*Phaseolus vulgaris* L.	French bean	1
39	*Pisum sativum* L.	Pea	1
40	*Plantago ovata* L.	Isabgol	2
41	*Polyanthus tuberosa* L.	Tuberose	2
42	*Portulaca grandiflora* L.	Portulaca	11
43	*Ricinus communis* L.	Castor	4
44	*Rosa* sp.	Rose	16
45	*Sachharum officinarum* L.	Sugarcane	9
46	*Sesamum indicum* L.	Sesame	5
47	*Setaria italica* L.	Foxtail millet	1
48	*Solanum khasianum* Clarke	Khasianum	1
49	*Solanum melongena* L.	Brinjal	1
50	*Solenostemon rotundifolius*	Coleus	1
51	*Trichosanthus anguina* L.	Snake gourd	1
52	*Trifolium alexandrium* L.	Egyptian clover	1
53	*Triticum aestivum* L.	Wheat	4
54	*Vigna aconitifolia* Jacq. M.	Moth bean	5
55	*Vigna mungo* L. Hepper	Blackgram	9
56	*Vigna radiata* L. Wiczeck	Mungbean	15
57	*Vigna unguiculata* L. Walp.	Cowpea	10
		Total	**343**

India

In India, sustained efforts for crop improvement through induced mutations were initiated during the second half of the 1950s, although the world's very first mutant variety of cotton, MA-9 induced by X-rays, endued with drought tolerance, was released in 1948 by India [11]. The Indian Agricultural Research Institute (IARI) in New Delhi; Bhabha Atomic Research Center (BARC) in Mumbai, Tamil Nadu Agricultural University (TNAU) in Coimbatore, and the National Botanical Research Institute (NBRI) in Lucknow, are some of the major research centers actively engaged in mutation breeding for several crops and have contributed substantially to the development and release of a large number of mutant varieties. Kharkwal, *et al.* [11] in 2004 listed a total of 309 mutant cultivars of crops, belonging to 56 plant species that were approved and/or released in India by the end of the twentieth century. An updated list of 343 mutant cultivars released in India is given in **Table 1**. The largest number of mutant cultivars have been produced in ornamentals (119), followed closely by legumes (85) and cereals (74).

The mutant cultivars have contributed immensely in augmenting the efforts of Indian plant breeders in achieving the target of food self-sufficiency and strong economic growth. Mutation breeding has thus significantly contributed to the increased production of rice, groundnut, chickpea, mungbean, urdbean, and castor in the Indian sub-continent. While authentic information on the area covered under these cultivars is unfortunately lacking in general, some data is available as summarized below.

The mungbean varieties Co-4, Pant Mung-2, and TAP-7, though released in the early 1980s, are still being grown widely around the country. The variety TARM-1, resistant to powdery mildew and YMV diseases, is the first of its kind to be released for *rabi*/rice fallow cultivation. Four of the nine mutant varieties of blackgram (urdbean) released in India have been developed at the Bhabha Atomic Research Centre (BARC) in Mumbai. One of these mutant varieties, TAU-1, has become the most popular variety in Maharashtra State, occupying an area of about 500,000 hectares (over 95% of the total area under urdbean cultivation in Maharashtra). Since 1990, the Maharashtra State Seed Corporation, Akola, has distributed about 200,000 quintals of certified seeds of TAU-1 to the farmers, which has resulted in an additional production of about 129,000 quintals of urdbean annually in Maharashtra. The notional income generated by additional production amounts to Rs. 300 crores (about 60 million US dollars) annually [11].

Several high-yielding rice mutants were released under the 'PNR' series; some of these were also early in maturity and had short height [12]. Among these, two early ripening and aromatic mutation-derived rice varieties, 'PNR-381' and 'PNR-102', were very popular with farmers in Haryana and Uttar Pradesh States. No data is available on the actual area planted with these varieties. However, based on the rate of fresh seed replacement by farmers and the distribution of breeder seed, foundation seed, and certified seed, as well as on the basis of data obtained from IARI, the value of rice (paddy) production would be 1,748 million US dollars per year [5].

Chickpea: The four high yielding and Ascochyta blight and wilt disease resistant chickpea mutant varieties Pusa – 408 (Ajay), Pusa – 413 (Atul), Pusa – 417 (Girnar), and Pusa – 547, developed at I.A.R.I., New Delhi, and released by the Indian government for commercial cultivation, are the first examples of direct use of induced micro-mutants in a legume crop in the world. Beside high yield performance under late sown crop, chickpea mutant variety Pusa – 547, released in 2006 for farmers' cultivation, has attractive bold seeds, thin testa, and good cooking quality [11, 13, 14, 15].

The success of mutant varieties released is also evident from the large quantities of breeder seed of several mutant varieties at the national level (**Table 2**).

The release of 'TG' (Trombay groundnut) cultivars of groundnut in

India has contributed millions of dollars to the Indian economy. Detailed information on the great success of mutation breeding of groundnut and legumes, as well as their contribution to food security in India, can be found in another paper in this book [16].

Table 2. Breeder seed (BS) production of mutant varieties in India (2003–2008)

S.No.	Crop	Mutant variety	BS (kg)	Period
1	Groundnut	TAG-24	427,500	5 yr
2	Groundnut	TG-26	78,600	5 yr
3	Groundnut	TPG-41	37,100	2 yr
4	Barley	RD-2035	53,600	4 yr
5	Soybean	NRC-7	50,200	5 yr
6	Chickpea	Pusa-547	9,100	1 yr

Japan

More than 200 direct-use mutant varieties generated through gamma irradiation, chemical mutagenesis, and somaclonal variations, have been registered in Japan [17]. About 61% of these were developed through mutation induction by Gamma-ray irradiation at the Institute of Radiation Breeding. In 2005, two direct-use cultivars and 97 indirect-use cultivars made up for approximately 12.4% of the total cultivated area in Japan. More information about mutant varieties and their contribution to food production in Japan is available in Nakagawa's paper in this book [17].

Thailand

The contribution of induced mutation to food production in Thailand is best reflected by the work on rice. Two aromatic *indica* type varieties of rice, 'RD6' and 'RD15', released in 1977 and 1978 respectively, were derived from gamma irradiated progeny of the popular rice variety 'Khao Dawk Mali 105' ('KDML 105'). RD6 has glutinous endosperm and retained all other grain traits, including the aroma of the parent variety. RD15, on the other hand, is non-glutinous and aromatic like the parent, but ripens 10 days earlier than the parent, which is a major advantage for harvesting before the onset of the rainy season in the respective areas. Even 30 years after their release these two varieties are still grown extensively in Thailand, covering 80% of the rice fields in north-eastern Thailand. According to the Bureau of Economic and Agricultural Statistics, during 1995-96, RD 6 was grown on 2,429,361 ha, covering 26.4% of the area under rice in Thailand, producing 4,343,549 tons paddy [5, 18], and in 2006 was still cultivated on an area of more than one million ha (S. Taprab, personal communication, July 2007). Thailand is the largest exporter of aromatic rice to the world market. Thus, the impact of the two rice mutant varieties is far beyond the farm gate with a major contribution to the export earnings. Between 1989 and 1998, the contribution of RD6 paddy was 4.76 billion US dollars, of milled rice 15.3 billion US dollars, and that of RD15 485.6 million US dollars for paddy, and 1.6 billion US dollars for milled rice. Hence, from 1989-98, the two varieties RD6 and RD15 yielded a total of 42.0 million tons paddy or 26.9 million tons milled rice worth16.9 billion US dollars [5].

Other Asian countries

Induced mutations have also been widely used in many other Asian countries for breeding new varieties and in turn contributed to food security. Detailed information for Pakistan [19] and Viet Nam [20] can be found elsewhere in this book.

In the Republic of Korea, sesame (*Sesamum indicum*) yield has been increased more than twice (from 283 kg/ha to 720 kg/ha) due to development and release of 15 improved determinate type, high oil content mutant varieties having phytophthora blight resistance and good cooking quality. These mutants occupied 55% of the national acreage during the last two decades in Korea [21].

In Bangladesh, mutation breeding has resulted in the release of more than 40 mutant varieties belonging to more than 12 crop species. The Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh, is the major center of mutation breeding, and has released 16 mutant varieties of pulses, 11 of oilseeds, seven of rice, and five of tomato. Rice mutant var. Binasail, Iratom-24, Binadhan-6, all planted in a cumulative area of 795,000 ha, and mungbean mutant variety Binamoog-5, cultivated in 15,000 ha as a summer crop, have contributed substantially towards food security in Bangladesh [Ali Azam, personal communication, April 2008].

In Myanmar, the rice mutant variety 'Shwewartun' was developed and released in 1975 after irradiation of 'IR5' seeds in 1970. The improvement in grain quality, seed yield, and early maturity of the mutant compared to its parent variety, led to its large-scale planting. Between 1989-1993, it covered annually more than 0.8 million ha - 17% of the 4.8 million ha area under rice in Myanmar [5].

During the past decade, Viet Nam has become an icon for the success of mutation breeding. Though it used to import 2-3 million tons of food annually in the decade of 1970-1980, Viet Nam exported 4.3 million tons of rice, becoming the world's second-largest exporter of rice. The wide use of high yielding crop varieties including dozens of mutant varieties contributed substantially to this transformation into food self-sufficiency. For example, the mutant rice variety VND-95-20, grown on more than 300,000 ha/year, has become the top variety in southern Viet Nam, both as an export variety and in terms of growing area. More information about mutant varieties and their great importance for the food security in Viet Nam today, can be found in another paper in this book [20].

EUROPE

Induced mutations have become an inherent component of many current plant varieties in Europe, particularly for barley and durum wheat. Mutation techniques are also widely used in the breeding of flowers and horticulture cultivars, although it is not the topic of this paper. A few examples are given here, while the situation in Sweden is available elsewhere in this book [22].

Czech Republic and Slovakia (former Czechoslovakia)

The Gamma-ray induced cultivar Diamant was officially released in Czechoslovakia in 1965. Diamant was 15cm shorter than the parent cultivar 'Valticky,' and had an increased grain yield of around 12%. In 1972, 43% of 600,000 ha of spring barley in Czechoslovakia were planted under either Diamant or mutant cultivars derived from Diamant. Roughly estimated, the total increase in grain yield was about 1,486,000 tons. During the same year, the spring barley cultivars that had mutated Diamant's *denso* gene in their pedigree were grown all over Europe on an area of 2.86 million ha [23].

The high-yielding, short-height barley mutants Diamant and Golden Promise were a major impact on the brewing industry in Europe; they added billions of US dollars to the value of the brewing and malting industry. More than 150 cultivars of malting barley in Europe, North America, and Asia were derived from crosses involving Diamant [5].

Finland

Balder J, a high yielding barley mutant released in Finland, had higher yield, greater drought resistance, better sprouting resistance, and greater 1,000 kernel weight. Nearly 1 million kg of 'Balder J' seed were sold by Jokioinen Seed Center [24]. Oat stiff straw mutant cultivar Ryhti occupied up to 41% of the total area of oat in Finland during 1970-80. Another stiff straw oat mutant cultivar, Puhti, released in 1970, occupied 30% of the oat planting area in Finland. Many new varieties now grown are derived from crosses with these mutant varieties [25].

Germany

Trumpf, the best-known barley mutant cultivar obtained after crossing with cultivar Diamant occupied more than 70% of the barley planting area in Germany. The mutant had a yield increased by 15% and better disease resistance. Used extensively in crossbreeding, Trumpf became incorporated into many barley breeding programs in a large number of countries [25].

Italy

Mutant cultivar Creso of durum wheat was grown in about one-third of the total area of durum wheat in Italy. During a period of 10 years, in Italy alone, an extra economic profit of 1.8 billion US dollars was obtained by growing this cultivar. Castelporziano and Castelfusano high-yielding durum wheat mutants had shorter culms and spike length, better resistance to lodging, but higher numbers of grain per spikelet. Planted in sizable areas, they contributed notably to the national economy of Italy. Both mutants were also used in extensive crossbreeding [5, 24].

NORTH AMERICA

In North America, the USA is one of the world pioneering countries in the exploitation of induced mutation for plant improvement and has had many extraordinary successes. Significant progress has also been reported from Canada, and more recently Mexico.

USA

Wheat: Stadler, a high-yielding wheat mutant released in Missouri, had early maturity, resistance to races of leaf rust and loose smut, as well as better lodging resistance. It was once grown on two million acres annually in the USA [24].

Barley: Luther, a barley mutant, had 20% increased yield, shorter straw, higher tillering, and better lodging resistance. About 120,000 acres were planted annually in three states of the USA - a gain of an estimated 1.1 million US dollars in one year. It was used extensively in cross-breeding and several mutants were released. Pennrad, a high yielding winter barley mutant was released in Pennsylvania, had winter hardiness, early ripening and better lodging resistance. It was grown on about 100,000 ha in the USA [24].

Beans: Sanilac, a high-yielding Navy pea bean mutant cultivar, developed after irradiation with X-rays and released in Michigan, was grown on more than 87,000 ha. Similarly, about 160,000 ha were planted with common bean cultivars Gratiot and Sea-way, developed likewise by cross-breeding with a Michelite mutant [5, 24].

Rice: The semi dwarf gene allele *sd1*, which was induced through Gamma-ray mutagenesis, has enabled the American version of the "Green Revolution" in rice. Details of the *sd1* allele and its contribution to the rice production in the USA (as well as in Egypt and Australia) are shown in this book [26].

Two grapefruit varieties, Star Ruby and Rio Red, both developed through thermal neutron mutagenesis [27], have become a widely grown variety during the past two decades. The fruits of both cultivars are sold under the trademark 'Rio Star.' 'Rio Star' grapefruit is currently grown on 75% of the grapefruit planting area in Texas. The development of the two radiation induced mutant cultivars is considered as the most significant breakthrough in grapefruit growing in Texas since the discovery of Ruby Red in 1929 [5].

Canada

Rapeseed-Canola (Double zero rapeseed): Canola is Canada's third most important grain export, after wheat and barley. Contribution of Canola cultivars to the Canadian economy has been outstanding. In 2000, Canada planted 5,564,000 ha under canola and earned 350.5 million US dollars. Mutant cultivars with low erucic acid and very low (more than 30µm/g) glucosinolates have been developed and released in Canada [5].

The strongest modification of oil composition with induced mutations has been the development and release of linseed cultivars of the 'linola' type in Australia and Canada. Zero is the low-linolenic acid genotype derived by EMS (ethyl methanesulphonate) mutagenesis of the Australian linseed cultivar Glenelg and recombination of two mutated genes [28].

Mexico

In Mexico, promotion of radio-induced mutation breeding started in 1974. Two new wheat varieties, 'Centauro' and 'Bajio Plus,' were derived from 'Salamanca' seeds irradiated at 500 Gy; they showed increased yield and tolerance to lodging. Two soybean varieties, 'Hector' and 'Esperanza', were obtained by irradiation of seeds from variety 'Suaqui 86' at 150 Gy. These new varieties exhibit an increased yield and reduction in dehiscence and lodging, being tolerant to white fly. 'SalCer' is another new soybean variety obtained through irradiation of seeds from line $ISAEGBM_2$ at 200 Gy. Its improved traits are higher yields and increased height to first pod [29].

LATIN AMERICA

Argentina

Colorado Irradiado, a groundnut mutant with high yield and fat content, induced by X-rays, occupied more than 80% of the groundnut area (280,000 ha) in Argentina in the 1970s [Prina, A.R., Personal communication, August 2008]. Puita INTA-CL, a rice mutant with high yield and herbicide resistance, released in 2005, has occupied more than 18% of the rice growing area (32,400 ha) in Argentina since then[Prina, A.R., Personal communication, August 2008]. Also planted in Brazil, Costa Rica, Paraguay and Bolivia, this mutant variety has contributed significantly to these Latin American countries' economies and their food security.

Cuba

Rice: Attempts to obtain a rice mutant variety with good agronomical characteristics and salinity tolerance have been successful in Cuba. The first mutant released from *in vitro* mutagenesis using proton radiations in Cuba is 'GINES,' which shows the best performance under saline conditions, and has been successfully introduced in rural areas of Pinar del Rio and Havana provinces [30].

Tomato: The very first tomato mutant released in Cuba, 'Maybel,' has shown very high performance under drought conditions and has been introduced in rural areas of different provinces of Cuba [31].

Peru

Mutation breeding has been very successfully used in breeding barley, the fourth most important food crop in terms of area in Peru. Centenario, a barley mutant with high yield (37% over the parent cultivar), earliness (18 days), higher protein (10.3%), better test weight and resistance to yellow rust, was released in 2006, is replacing the traditional cultivars of the central highlands of Peru, and contributes significantly to the food security of the country [32].

Kiwicha (A*maranthus caudatus*) is a native and ancient crop of the Andean Region. Centenario (MSA-011), a mutant with high yield, earliness (45 days), tolerance to salinity, wide adaptability, better grain color and size, as well as higher market price, was released in 2006 and has covered 40% of the total Peruvian land dedicated to kiwicha crops [32].

AUSTRALIA

Rice: Nine rice varieties - 'Amaroo; (1987), 'Bogan' (1987). 'Echua' (1989), 'Harra' (1991). 'Illabong' (1993), 'Jarrah' (1993), 'Langi' (1994), 'Millin' (1995), and 'Namaga' (1997)- have been introduced in Australia. Rice mutant variety Amaroo has covered 60-70% of the rice cultivation area of Australia, and on average yielded 8.9 t/ha grain with a potential of 13.3 t/ha [33].

Lupine: Spontaneous mutation has been discovered and utilized in domestication of narrow-leafed lupine (*Lupinus angustifolius L.*). As the result of the domestication, lupine has become a dominant grain legume crop in Western Australia. Facing the new challenge of developing herbicide-tolerant cultivars, chemical mutagenesis has been used to create new tolerance to herbicide. The two lupine mutants (Tanjil-AZ-33 and Tanjil-AZ-55) are highly tolerant, six times more tolerant to metribuzin herbicide than the original parental cultivar Tanjil. This mutant Tanjil-AZ-33 is the most tolerant germplasm in narrow-leafed lupine. Both mutants also maintain the high yield and resistance to the disease anthracnose as cv Tanjil. These facts indicate that the mutation process has created tolerance to metribuzin in Tanjil, but has not altered Tanjil's yield capacity and anthracnose resistance. Induced mutation proves to be an effective tool in lupine improvement [34].

AFRICA

Egypt

As a result of the introduction of the two semi-dwarf mutant varieties, 'Giza 176' (1989) and 'Sakha 101' (1997) in Egypt, the average yield of rice in Egypt increased to 8.9 t/ha, compared with 3.8 t/ha in the rest of the world. Of these two, 'Giza 176' became the leading variety, with a potential yield of 10 t/ha [35].

Sudan

Mutation breeding in Sudan was effectively started about 20 years ago and covered crops like cotton, sugarcane, sesame, banana, tomato, groundnuts, and cereals. A banana mutant cultivar (Albeely) was released in the year 2003. Albeely excelled the yield of the existing cultivars by 40% and has better crop stand and fruit quality. Albeely is becoming popular and is widely preferred by farmers. A drought tolerant groundnut mutant (Barberton-B-30-3) and a number of promising mutants resistant to tomato yellow leaf curl virus (TYLCV) are being evaluated in multi-location trials, in preparation for their commercial release. Cotton germplasm has been enriched with a number of useful mutants carrying resistance for bacterial blight and fusarium wilt disease, in addition to mutants for weak fiber attachments, high ginning out turn, and lint percentage. These mutants are being used in the breeding program, and promising lines are under field evaluation for release [36].

Ghana

Over two decades of application of induced mutation techniques toward crop improvement in Ghana have led to the production of improved mutant varieties in two crops. In cassava (*Manihot esculenta* Crantz), irradiation of stem cuttings using gamma irradiation resulted in the production of "Tek bankye,' a mutant variety with high dry matter content (40%) and good poundability from the parental line, which was a segregant of a hybrid between the Nigerian landrace Isunikaniyan (ISU) and the breeder's line TMS4(2)1425, both from IITA, Nigeria. Similarly, irradiation of vegetative buds of 'Amelonado' (P30), 'Trinitario' (K.5), and 'Upper Amazon' (T85/799) cocoa varieties resulted in the production of a mutant variety resistant to the Cocoa Swollen Shoot Virus (CSSV). Multi-location on-farm trials of the mutant line indicate significant increases in yield for farmers, without symptoms of the disease [37].

Perspectives

World food security deteriorated very sharply in the 1960's when developing countries like India, Pakistan, and Indonesia were desperately short of food grains. Fortunately, agricultural scientists responded with a new production technology, which has popularly been described as "Green Revolution Technology." This helped to avoid large-scale starvation for around 40 years. However, the food security problem has again seen a major deterioration in the last few years; food prices are rising sharply and once again the poor people of the world are threatened with serious malnutrition. The underlining causes that drove to food security deterioration, i.e. rising fuel and fertilizer prices, climate change related erratic rain falls, sudden and severe drought conditions, excessive floods, divert of food grains into bio-fuel production, will remain for the years to come. Food security will even get worse since population is still growing while no significant expansion of arable lands is foreseen. FAO estimates that world food production should increase by more than 75% in the next 30 years to feed about eight billion people by 2025 [38]. Therefore, a new "Green Revolution" is desperately needed to solve the food security issue in the years to come.

The massive advent of plant molecular biology is anticipated to provide a sound solution to further increase food production by both increasing yield potential and stability. In this regard, induced mutagenesis is gaining importance in plant molecular biology as a tool to identify and isolate genes, and to study their structure and function. Several papers in this book report the progress being made in this area. Recently mutation techniques have also been integrated with other molecular technologies, such as molecular marker techniques or high throughput mutation screening techniques; mutation techniques are becoming more powerful and effective in breeding crop varieties. Mutation breeding is entering into a new era: molecular mutation breeding. Therefore, induced mutations will continue to play a significant role for improving world food security in the coming years and decades.

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