Induced Mutations for Food and Energy Security: Challenge of Inducing Unique Mutants for New Cultivars and Molecular Research

Hitoshi NAKAGAWA *1 and Hiroshi KATO

Abstract

Following the construction of the Gamma Field at the Institute of Radiation Breeding（IRB） in 1960, mutation breeding was accelerated in Japan. The facility is used to artificially induce mutations with a higher radiation dose（up to 2 Gy/day, that is *ca.* 300,000 times that of natural background）at a higher frequency than occurs in nature. Since the unit became operational, the number of mutant cultivars generated in Japan increased until 2000–2010 and has since decreased. There have been 295 direct-use mutant cultivars representing 70 species generated through irradiation utilizing gamma-rays, X-rays, ion beams and chemical mutagenesis and *in vitro* culture. Each cultivar has been registered and released in Japan, with approximately 79% of these induced by radiation. There have been 335 indirect-use mutant cultivars, including 298 rice, of which 150 cultivars（50.3%）were derived from the semi-dwarf mutant cv. "Reimei" or its offspring. The economic impact of these mutant cultivars, primarily of rice and soybean, is very large. Some useful mutations are discussed for rice, such as low digestible-protein content, low amylose content, giant embryo and non-shattering. Useful mutations in soybean such as radio-sensitivity, fatty acid composition, lipoxygenase lacking, glycinin rich and super-nodulation have been identified. A similar series of advantageous mutations have been found in Japanese pear and other crops through various screening methods. The achievements of biological researches such as characterization and determination of deletion size generated by gamma-rays, the effect of deletion size and the location are identified. Similarly, genetic studies generated through the use of gamma-ray induced mutations, such as phytochrome research, aluminum tolerance and epicuticular wax have also been conducted in Japan. A unique mutation induction technique for outcrossing Italian ryegrass is also explained. Mutation breeding is a very interesting and useful technology for isolating genes and for elucidating gene functions and metabolic pathways in various crops. Records show that mutation induction is a very useful conventional breeding tool for developing superior cultivars. The IRB is well equipped with appropriate facilities and equipment that will contribute to future mutation breeding developments and it will be a contributor in solving various genomic, proteomic and metabolic problems.

Keyword: genetic analysis, gamma-ray irradiation, Gamma Field, mutation breeding, mutant cultivar

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*1 Current affiliation: Central Research Laboratory, Hamamatsu Photonics K.K., 5000 Hirakuchi, Hamakita-ku, Hamamatsu, Shizuoka, 434−8601

食料・エネルギー安全保障に貢献する誘発突然変異 ：品種育成や分子遺伝学的研究のための 新たな突然変異体誘発への挑戦

中川　仁[*1]・加藤　浩

抄　　録

1960 年、放射線育種場にガンマーフィールドが建設されて以来、我が国では突然変異育種が加速された。ガンマーフィールドは人工的に突然変異の誘発率を高める施設であり、線源から最も近い地点では 1 日に 2 グレイ（Gy）（自然界の 30 万倍：1 日で 1,000 年分）照射できる。我が国の突然変異品種登録数は、2000-2010 年がピークとなり、現在は減少傾向にある。これまでの、ガンマ線、X 線、イオンビーム、化学誘発剤、培養変異を利用した突然変異直接利用品種数は 70 作物、295 にのぼり、その 79%が放射線による突然変異である。直接利用品種との交配による間接利用品種数は 335 であり、その大半はイネ（298 品種）であり､そのうちの 150 品種（50.3%）は「レイメイ」に由来する。突然変異品種の経済効果は、イネとダイズ品種の貢献が大きい。有用な突然変異としてイネの低易消化性タンパク質、低アミロース含量、巨大胚および難脱粒性、ダイズの放射線感受性、脂肪酸組成改変、リポキシゲナーゼ欠失、高グリシニンおよび根粒超着生などを記述した。また、生物学的研究の成功例として、ガンマ線が誘発する突然変異と欠失の大きさ、欠失の位置と大きさの差による突然変異形質の変化が解明された。実験材料としての成功例は、フィトクローム研究、アルミニウム耐性および無ワックス特性の解明である。また、放射線育種場で開発された他殖性のイタリアンライグラスの変異作出技術についても紹介した。突然変異育種は遺伝子単離や遺伝子機能や代謝経路の解明において魅力的かつ有用なテクノロジーである。突然変異品種数が示すように、突然変異誘発技術は優れた品種を育成するための簡易な従来育種ツールである。アジアでは韓国とマレーシアにガンマ線緩照射施設が建設され、突然変異育種が推進されている。放射線育種場はガンマーフィールドなどの有用な施設を有し、今後も突然変異育種の発展と生物学的問題解決に貢献していくことが期待される。

キーワード：遺伝解析、ガンマ線照射、ガンマーフィールド、
突然変異育種、突然変異品種

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[*1]　現　浜松ホトニクス株式会社　中央研究所

Content

Ⅰ　Introduction

After the construction of the Gamma Field, considered the world’s largest radiation field（100 m radius with an 88.8 TBq ^{60}Co source at the center; Fig. 1), at the Institute of Radiation Breeding（IRB）in Ohmiya-machi（now Hitachi-Ohmiya), Ibaraki, Japan in 1960, mutation breeding was accelerated through cooperative research with national and prefectural breeding laboratories, private companies and universities in Japan（Yamaguchi 2001).

Fig. 1. Gamma Field of IRB

In the New York Times (Broad 2007), Dr. P. J. L. Lagoda of the Joint FAO/IAEA was quoted to say, “Spontaneous mutations are the motor of evolution. We are mimicking nature in this. We’re concentrating time and space for the breeder so he can do the job in his lifetime. We concentrate how often mutants appear – going through 10,000 to one million – to select just the right one”.

The concept and objectives of the IRB’s Gamma Field has the same goals for the plant breeder. The facility has an irradiation tower installed with an 88.8 TBq ^{60}Co at the center of a circular field with a radius of 100 m (Nakagawa 2010), and used to artificially induce mutations at a higher frequency than that occurs in nature. The radiation dose at the nearest point of the field (10 m from the center: *ca.* 2 Gy/day) is estimated to be about 300,000 times that of normal and natural background radiation when it is operated for 8 hours per day (Fig. 2). At the farthest point (100 m from the center: ca. 0.01 Gy/day), the radiation dosage is about 2,000 times the normal background radiation. This means that plants growing at the nearest point to the gamma-ray source are being treated to a 1,000 years of accumulated normal background rates of radiation per day. Although we do not know all the genes or mechanisms of mutations, radiation breeding has produced many useful mutant cultivars and contributed greatly to the farmers and industries of Japan and all over the world. In 1991, the Ministry of Agriculture, Forestry and Fisheries (MAFF) of Japan launched the Rice Genome Research Program, with the aim of fully decoding the rice genome in three phases over a 21-year period. With the cooperation of 10 participating countries (Sasaki and Burr 1998), the genome sequencing of the 12 rice chromosomes was completed in 2005 (International Rice Genome Sequence Project 2005). Following this achievement, molecular genetic studies based on the results of the genome sequencing project became the most powerful tool for selecting mutants of certain characteristics in rice. This is anticipated to revolutionize mutation breeding success in rice, and be applicable to a number of other important crop species.

In this report, the mutant cultivars developed mainly by gamma-ray irradiation in Japan are discussed. In addition, their economic impacts in Japan, as well as molecular studies performed to contribute to food security and elucidate the mutation at the DNA level, are described.

Part of this report was presented in the 53rd Gamma Field Symposium held in Mito, Ibaraki, Japan in 2014.

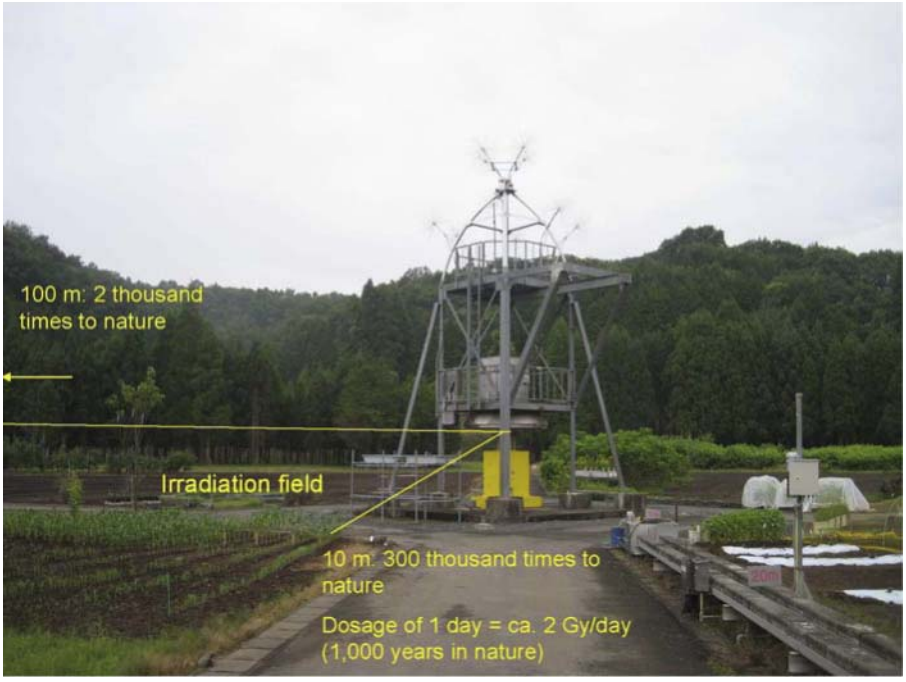


Fig. 2. Irradiation tower located in the center of the Gamma Field and its irradiation field.

Ⅱ Achievements from biological research on mutations induced by gamma-ray irradiation

1） Deletion size generated by gamma-ray irradiation

Naito *et al.*（2005）studied the deletion sizes of transmissible and non-transmissible mutations induced with gamma-ray and carbon ion beam irradiation by utilizing sophisticated pollen-irradiation methods in Arabidopsis. Many mutants induced with these ionizing irradiations possess extremely large deletions（more than 6 Mbp）and many also have small deletions（1 or 4 bp), which are normally transmissible. The larger 6-Mbp deletions were found to not be transmissible to the next generation.

In rice, the same trends were observed（Table 1). Morita *et al.*（2009）researched the frequency of transmission of different mutations possessing different deletion sizes obtained with gamma-ray irradiation. Among 24 gamma-ray induced mutants, three exhibited 1-bp substitution, 15 exhibited a small deletion, four exhibited large deletions and two exhibited inversions. Among 15 mutants with small deletions, six mutations including *cao*（*chlorophyllide-a oxygenase*), *cps*（*entcopalyl diphosphate synthase*), *ga3os*（*GA3-beta-hydroxylase*), *gid*（*GA-insensitive dwarf*), *gluA1*（*glutelin A1*）and *gluA2*（*glutelin A2*）exhibited 1-bp deletion; and nine mutations including *cao-g2* and *ga3ox-g2*, *kao-g1*, *kao-g2*, *pla1-g1* and *-g2*（*Plastochron1*), and *wx-g1, -g2, and -g3* exhibited deletion of 2–16 bp. In contrast, four mutations had large deletions including one *gid2-g1*, one *gluB4/5*（*glu1: Glutelin B4/5*), one *glb1*（*α-globulin*）and one *wx-g4* mutant with 42.2, 129.7, 62.8 and 9.4 kb, respectively. As a result, gamma-ray induced mutations transmittable to the next generation are primarily classified into four groups:（1）those with a base substitution;（2）those with small deletions（1–16 bp);

Table 1. I Gamma ray irradiation-induced deletions, base substitutions, and inversions and the size of mutation (Morita *et al.* 2009).

Mutation Type	Gene	Size (bp)
Small Deletion	*CAO* (*cao-g1*)	1
	CAO (*cao-g2*)	3
	CPS (*cps-g1*)	1
	GA3ox (*ga3ox-g1*)	1
	GA3ox (*ga3ox-g2*)	3
	GID1 (*gid1-g1*)	1
	GluA1 (*gluA1-g1*)	1
	GluA2 (*gluA2-g1*)	1
	KAO (*kao-g1*)	4
	KAO (*kao-g2*)	16
	PLA1 (*pla1-g1*)	5
	PLA2 (*pla2-g1*)	5
	Wx (*wx-g1*)	2
	Wx (*wx-g2*)	5
	Wx (*wx-g3*)	6
Large Deletion	*GID2* (*gid2-g1*)	42, 200
	Glb (*glb1*)	62, 800
	GluB4/B5 (*glu1*)	129, 700
	Wx (*wx-g4*)	9, 400
Base Substitution	*GluA2* (*gluA2-g2*)	1
	PLA1 (*pla1-g2*)	1
	Wx (*wx-g5*)	1
Inversion	*Wx*	1, 284, 800
	PLA2	3, 208, 500

CAO: chlorophyll b deficiency; *CPS*, *KAO* and *GA3ox*: gibberellin deficiency; *GID*: gibberellin insensitivity; *GluA* and *GluB*: glutelin deficiency; *Glb*: alpha-globulin deficiency; *PLA*: shortened plastochron; *Wx*: glutinous endosperm

(3) those with extremely large deletions; and (4) those with a large inversion of over 1 Mbp with small deletions. The mechanisms of generating extremely large deletions and inversions may be similar–the former mutation areas were missing and the latter mutation areas were reversely placed again. It is not known how difficult it may be to generate mutants with medium-sized deletions (1.0–5.0 kb) through gamma-ray irradiation, although some reports mentioned that neutrons with high linear energy transfer (LET) can induce deletions ranging between 300 bp–12 kb (Sun *et al.* 1992; Li *et al.* 2001; Nagano *et al.* 2008). However, it is interesting that inversions are not considered rare events following gamma-ray irradiation, as is the case for sorghum (Mizuno *et al.* 2013)–this is explained in the following section.

2) Different size and location of deletion generates different kinds of phenotypes

In the course of plant evolution, genes are often duplicated in tandem, resulting in functional redundancy. The analysis of function of these genes by developing double mutants may be difficult because they are located near each other and are tightly linked. Glutelin is a major digestible seed storage protein encoded by a multigene family. Mutants of tandem-duplicated glutelin genes were investigated for their genotypes and phenotypes. They represent a reversely repeated two-loci event (Fig. 3), with both regions coding for mRNA of glutelin production. Various mutants with low glutelin contents have been isolated using SDS-PAGE (polyacrylamide gel electrophoresis) (Iida *et al.* 1993, 1997). The mechanisms of low glutelin content in the mutants that have been studied suggest that the size and position of deletions generate different characteristics of mutations (Fig.

4). Some act as dominant or recessive genes, and these relationships between genotypes and phenotypes are provided as examples below.

Low glutelin content1 (*Lgc-1*) is a dominant mutation that reduces glutelin content in rice grain. Kusaba *et al.* (2003) reported that in *Lgc-1* homozygotes contain a 3.5-kb deletion between two highly similar glutelin genes that forms a tail-to-tail inverted repeat, that could produce a double-stranded RNA molecule, a possible potent inducer of RNA silencing (Fig. 3). As a result of this inverted repeat, glutelin synthesis is suppressed and the glutelin content is lowered. This was the first report that showed the mechanism of a mutation was RNA interference (RNAi) in plants. The *Lgc-1* provides an interesting example of RNA silencing among genes that exhibit various levels of similarity to a gene-induced RNA silencing.

The “glu1” is a gamma-ray-induced rice mutant, which lacks an acidic subunit of glutelin. Morita *et al.* (2007) elucidated that the *glu1* gene of the “glu1” mutant harbors a 129.7-kb deletion involving two highly similar, tandem-repeated glutelin genes, *GluB5* and *GluB4*. The deletion eliminates the entire *GluB5* and *GluB4* genes except for half of the first exon of *GluB5*. As a result, the phenotype of the *glu1* gene completely lacks the acidic subunit of glutelin and acts as a recessive gene for low glutelin content in rice grains (Fig. 4).

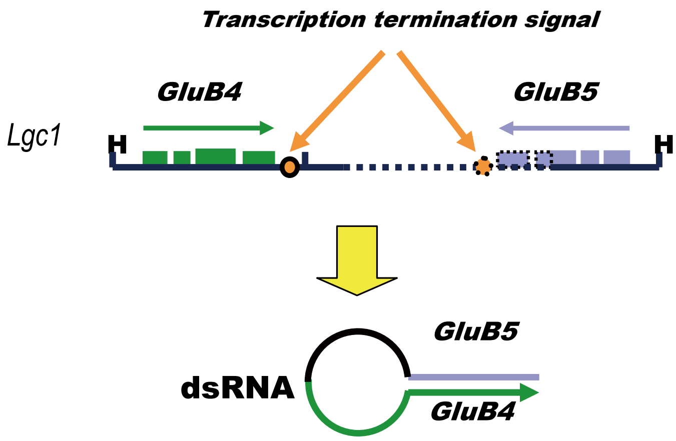
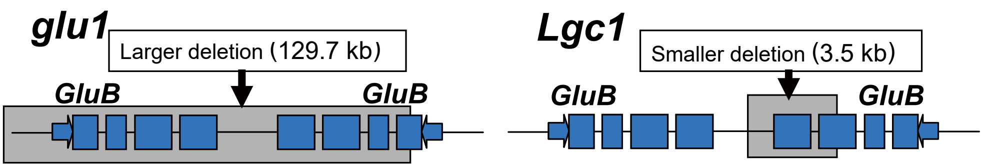


Fig. 3. Mechanism of low glutelin in LGC-1. A deletion containing the transcription termination signal between *GluB4* and *GluB5* causes generation of hairpin RNA with dsDNA region, which induces GluB mRNA degradation via RNA interference (based on Kusaba *et al.* 2003). (Courtesy of Prof. M. Kusaba, Hiroshima University)



	Phenotype	Dominant or Recessive	Mechanism
glu1[1]	Deletion of 1 acidic subunit of glutelin	Recessive	Knock-out of 2 genes
Lgc1[2]	Total glutelin contents lower	Dominant	Suppresses glutelin genes via RNAi

Fig. 4. Comparison of phenotype, mode of inheritance and mechanism of mutation character between *glu1* and *LGC1* mutation with different sizes and place of deletion in the same region of two loci, *GluB4* and *GluB5*; *glu1*[1]: Morita *et al.* (2007); *Lgc1*[2]: Kusaba *et al.* (2003). (Courtesy of Dr. R. Morita, RIKEN)

The above examples illustrate that the position and size of deletions at the same locus can dramatically alter the phenotype of mutant gene expression through the process of transcription and translation. The *glu1*, which has a large 129.7-kb deletion, acts as a recessive gene, while the *LGC1*, which has 3.5-kb deletion that probably includes a terminal signal of the transcript region, acts as a dominant gene.

Furthermore, the *GluB5* and the *GluB4* have the same amino acid sequence in their acidic subunit, suggesting that only the mutation involving both *GluB5* and *GluB4* generates the resultant phenotype. This is the reason for the lack of the glutelin acidic subunit deleted in the "glu1" mutant.

Sequenced plant genomes exhibit that more than 14% of their genes are highly similar, tandem-repeated genes (Arabidopsis Genome Initiative 2000; International Rice Genome Sequence Project 2005). This finding suggests that gamma-rays can be an effective mutagen to generate knockout mutants of both loci and to use for analysis of tandem repeat and functionally redundant genes.

Ⅲ Useful mutations from various screening methods

1) Low digestible-protein content

Although rice is not a high-protein grain crop, the protein content is *ca.* 7% when white rice is cooked. A mutant line with a low glutelin content was obtained from the ethyleneimine (EI) treatment of cv. "Nihon-masari". The cv. "LGC-1" was developed from backcrossing this mutant with the original cv. "Nihon-masari" to eliminate undesirable characteristics, such as semi-sterility and semi-dwarfing (Iida *et al.* 1993). The seed protein of cv. "LGC-1" is mainly composed of a decreased amount of digestible glutelin induced by a dominant mutation that also increases the amount of indigestible prolamine. The characterization of this mutation and the mechanism were mentioned in the previous section. This construction of protein is disadvantageous for human digestion of rice grains, although the total amount of protein is similar to the original cultivar. As a result, cv. "LGC-1" is useful as a low-protein rice, and some clinical trials indicate that the cooked rice of this variety is a

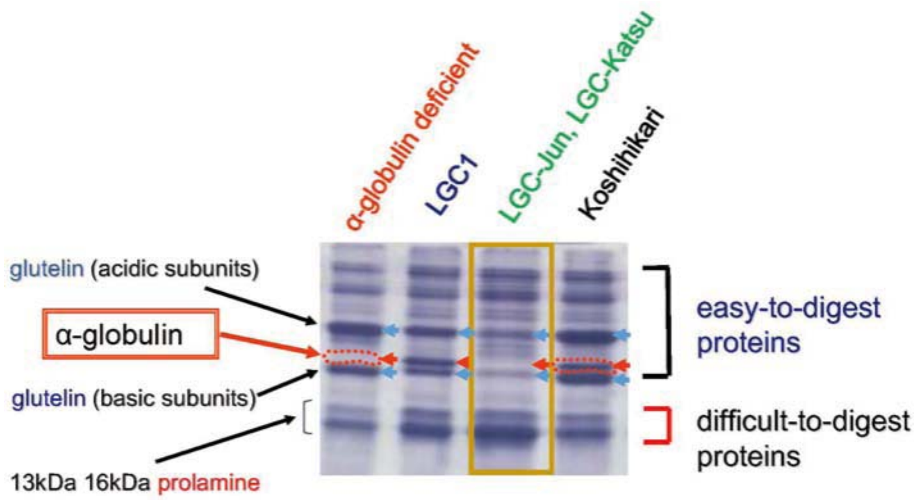


Fig. 5. Development of new cultivars, cv. "LGC-Jun" and cv. "LGC-Katsu" with lower easy-to-digest protein content by the hybridization of a low-glutelin mutant cv. "LGC1" and an α-globulin deficient mutant (named "89WPKG30-433") of cv. "Koshihikari" (SDS-PAGE data) (based on Nishimura *et al.* 2005). (Courtesy of Prof. M. Nishimura, Niigata University)

useful and effective daily food for patients with kidney disease (Mochizuki and Hara 2000). The defect of cv. "LGC-1" is its eating quality and the presence of other loci that control the biosynthesis of digestible protein, such as globulin. Therefore, Nishimura *et al.* (2005) induced a mutant line "89WPKG30-433" that exhibited a deficiency in globulin through gamma-ray irradiation from the leading Japanese cv. "Koshihikari", which is famous for a good eating quality. The "89WPKG30-433" was hybridized with cv. "LGC-1" and cvs. "LGC-Katsu" and "LGC-Jun" were selected from the hybrids (Fig. 5). The glutelin content of these two cultivars is as low as for cv. "LGC-1" and the globulin content is zero. The total digestible-protein content tested is about 30% of ordinary rice. As the eating quality is highly improved and digestible-protein content is lower than for cv. "LGC-1", these two cultivars will greatly help in the dietary management of proteins in cases of chronic renal failure.

2) Glutinous rice (low amylose content)

Stickiness of cooked rice is one of the most important characteristics of rice cultivars, which are diverse and unique among peoples of the world. In general, people in Japan as well as Korea, northern Thailand, Myanmar and southern China prefer sticky rice. Amylose contents are closely related to this character and range from 0 (waxy: glutinous) to higher than 20, especially in indica-type rice. In Japan, glutinous rice has a special utilization for "okowa" and "mochi" production for festivals and celebrations, as well as non-glutinous popular cultivars used for daily cooking, which exhibit ca. 17% amylose content. This waxy locus (*Wx*) was mapped on chromosome 6 of rice (Iwata and Omura 1971) and knockout of *Wx* makes non-glutinous ordinary rice completely glutinous (*wx*). The waxy genes were identified to encode granule-bound starch synthesis, which is performed by a key enzyme in amylose synthesis of plants (Nelson and Pan 1995). In Japan, glutinous cv. "Miyuki-mochi" (Toda 1982) was induced from non-glutinous cv. "Toyonishiki", glutinous cv. "Fujimi-mochi" from non-glutinous cv. "Aki-chikara", and gulutinous cv. "Odoroki-mochi" (Imbe *et al.* 2004) from non-glutinous cv. "Takanari" through gamma-ray irradiation in the IRB Gamma Field.

There is another type of endosperm starch mutation termed "dull", whose amylose content is not zero as found with the waxy (*wx*) mutation in rice. The dull mutation has *ca.* 10% amylose content, which is lower than the *ca.* 20% of non-waxy (*Wx*) rice, and exhibits partial stickiness when cooked. Genetic analysis of dull mutants induced by ^{32}P (beta-ray radiation) showed that the mutations were controlled by a single recessive gene which is non-allelic to the *wx* alleles (Okuno *et al.* 1983). One of the most popular dull cultivars is cv. "Milky Queen" induced by chemical mutagen (MNU: N-methyl-N-nitrosourea) treatment of the most popular cv. "Koshihikari" with amylose content of 9–12% (Ise *et al.* 2001). This dull phenotype is caused by *wx* locus mutation (*Wx-mq*) (Sato et al. 2002).

3) Giant embryo

The rice embryo contains a high level of proteins, fats, vitamins and some compounds good for human health. As the embryo grows, gamma-aminobutyric acid (GABA) accumulates following transformation from glutamic acid caused by soaking rice in water (Saikusa *et al.* 1994a, 1994b). Defatted rice embryos enriched with GABA are useful as a functional food for controlling blood pressure and sedative qualities related to sleeplessness and autonomic disorder (Okada *et al.* 2000). The GABA-accumulated brown rice is already on the market as a health food based on an ordinary rice variety. The giant embryo lines "EM40" and "GM15-34", each possessing giant embryo by treating cv. "Kinmaze" with MNU (Satoh 1981), useful for this purpose are anticipated. The embryo volume of these lines is 3–4 times that of ordinary rice cultivars. The giant embryo trait of the "EM40" is known to be controlled by one recessive gene (*ge*) located on chromosome 7 (Satoh and Iwata

1990).

The utilization of the giant embryo mutants was previously limited to the development of rice bran oil. However, the nutritional value of cooked brown rice is beginning to attract the attention of consumers interested in healthy food. The first giant embryo mutant cv. "Haiminori" was developed by the hybridization between the "EM40" and cv. "Akenohoshi", and selection from the hybrid population in 1990 (Nemoto *et al.* 2001). The embryo volume of cv. "Haiminori" is 3–4 times that of ordinary rice. After soaking in water for four hours, the amount of accumulated GABA in cv. "Haiminori" is about four times that of the traditional cv. "Nipponbare". The cv. "Haiminori" is utilized in the commercial production of rice cakes. Common defects of giant embryo cultivars are lower germination and seedling establishment rates, sometimes only 40–50 % of that of cv. "Nipponbare".

The GIANT EMBRYO (*GE*) gene has been identified as essential for controlling the size balance in rice, and the function of *GE*, which encodes CYP78A13, is predominantly expressed in the interfacing tissues of the both embryo and endosperm and controlling cell size in the embryo and cell death in the endosperm (Nagasawa *et al.* 2013). Development of giant embryo lines with good seedling establishment will be a continuing objective of the breeding.

4) Non-shattering

Much attention has been paid recently to indica-type high-yielding genetic resources for improving biomass productivity as forage rice. Seed shattering is one of the most important characteristics of indica-type rice that requires improvement. Mutation in the dominant *qSH1* gene in domesticated rice eliminates the abscission layer and results in non-shattering seeds (Konishi *et al.* 2006). Thus, knockout of this dominant gene generates a non-shattering rice. Kato *et al.* (2006) attempted to induce a mutation at this locus in cv. "Mohretsu". The cv. "Mohretsu" is a mutant forage rice cultivar induced through NMU treatment and through gamma-ray irradiation of seeds in IRB, National Institute of Agrobiological Sciences (NIAS), which was eventually developed as the direct-use, non-shattering mutant cv. "Minami-yutaka" for use as rice silage. Sakai *et al.* (2013) attempted to induce mutation at the same locus in the high-yielding traditional cv. "Taporuri" introduced from Taiwan through gamma-ray irradiation of seeds in IRB, and successfully released the direct-use non-shattering mutant cv. "Ruri-aoba" as a rice silage crop. The loci or genes controlling non-shattering in these newly induced mutant cultivars have not been identified. However, through genetic analyses of rice cultivars and wild relatives, as well as chromosomal segment substitution lines and an induced shattering mutant line derived from gamma-ray irradiation (Zhou *et al.* 2012), several quantitative trait loci associated with seed shattering have been identified. These includes *SH4* which promotes hydrolyzing of an abscission zone cells during the abscission process (Li *et al.* 2006), *OsCPL1* (*Oryza sativa CTD phosphatase-like 1*) that enhances the development of the abscission layer during panicle development (Ji *et al.* 2010) and *SHAT1* (*Shattering Abortion1*), the AP2 domain-containing transcription factor gene responsible for abscission zone development (Zhou *et al.* 2012).

5) Radio-sensitivity

Takagi (1969) identified two major genes that control radio-sensitivity in some soybean cultivars. When the 50% reduction rate (RD_{50}) of root length was associated with exposure to acute irradiation of seeds or chronic irradiation of plants for the entire growth period, radio-sensitivity of soybean was identified. The cv. "Shinmejiro" is more than twice as high for radio-sensitivity as the resistant cv. "Tachisuzunari". The differences in radio-sensitivity between the cultivars to chronic irradiation in the Gamma Field are controlled by a single recessive *rs1* gene. A second recessive gene, *rs2*, was discovered in cv. "Goishi-shirobana", whose activity is only expressed following acute seed radiation.

6） Fatty acid composition

Soybean is the most widely used source of edible oil for human consumption. Every oil crop produces unique oil with a specific fatty acid composition. For example, linolenic acid content is high and generally 8.0% in soybean, and is not found in oils from maize, traditional sunflower and traditional safflower. There is an extremely high diversity of fatty acid compositions across the oil crops. The biosynthesis of fatty acids in oil crops is summarized in Fig. 6. The biosynthesis for fatty acid composition, common to all plant species, involves a carbon elongation process（palmitic acid（16:0）→ stearic acid（18:0））and unsaturated reaction process（stearic acid（18:0）→ oleic acid（18:1）→ linoleic acid（18:2）→ linolenic acid（18:3））. Another biosynthesis is a carbon elongation reaction unique to traditional rapeseed of oleic acid（18:1）→ eicosenoic acid（20:1）→ erucic acid（22:1）. The particular fatty acid contents of these cultivars or species result from differences in activity or reactivity of their enzymes and the number of genes encoding each enzyme involved in the various steps related to carbon elongation and unsaturated reaction of their fatty acids.

The incorporation of target genes, known to modify the fatty acid components of oil crops were initially identified in natural populations of specific species, and then incorporated by various breeding techniques. White *et al.*（1961）previously identified inter-varietal variation of fatty acid composition in 251 soybean cultivars and reported that contents of linoleic and linolenic acids were controlled by polygenes and exhibited heritability typically associated with quantitative traits because the investigated hybrid population exhibited continuous variation across their fatty acid compositions. However, Takagi *et al.*（1986）reported that the expression and levels of oleic and linolenic acids were controlled by two and one gene, respectively. Recent research suggests that the effects of each gene on fatty acid content are small and indicates quantitative trait expression and larger

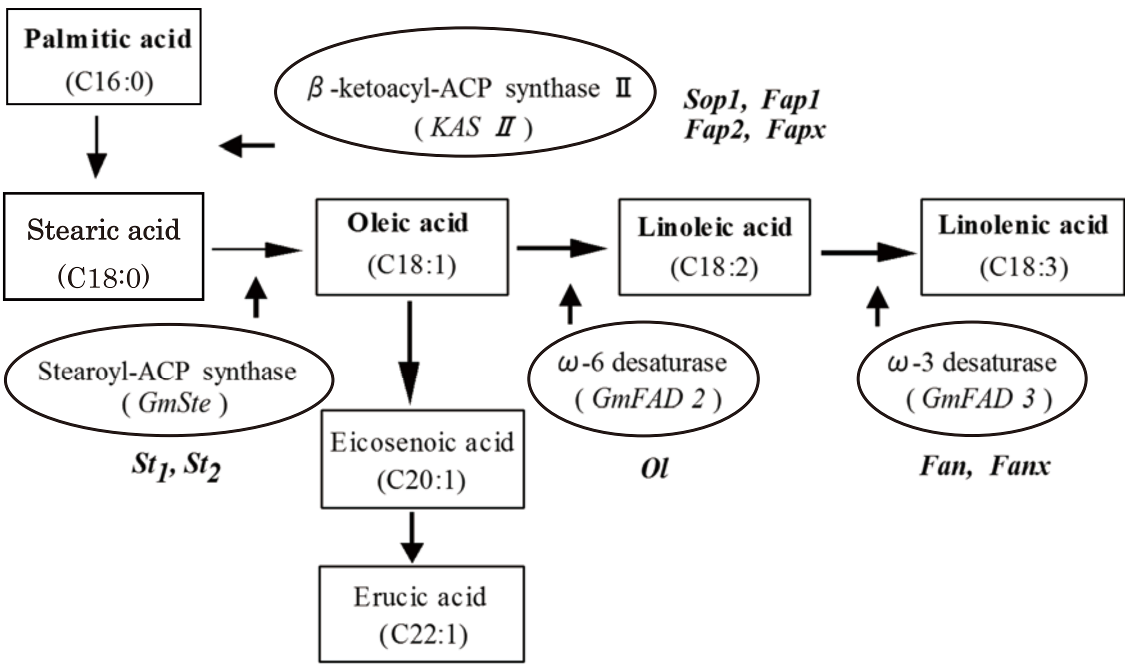


Fig. 6. Genes responsible for different fatty acid biosynthesis（based on Takagi and Anai 2006; Nakagawa *et al.*, 2011）.（Courtesy of Prof. Y. Takagi, Saga University）.

environmental effects.

Takagi and his colleagues identified 46 mutant lines from a 12,266 M_2 population generated by X-ray application to cv. "Bay". Fatty acid compositional changes of the mutant lines are listed in Table 2. The mutant lines include "J3" with low palmitic acid content (6.1%) (Takagi *et al.* 1995), "J10" with high palmitic acid content (17.2%) (Takagi *et al.* 1995), "M25" with high stearic acid content (21.2%) (Rahman *et al.* 1995), "M23" with high oleic acid content (48.6%) (Rahman *et al.* 1994), "M5" with low linolenic-acid content (4.9%) (Takagi *et al.* 1990) and "B739" with high linolenic acid content (18.4%) (Takagi *et al.* 1989). In addition, lines with wider fatty acid composition variability were obtained from the hybridization between these mutants.

The 46 individual mutant populations generated from cv. "Bay" exhibit a wider range of fatty acid composition than the 99 landraces developed from naturally occurring variation (Table 3) (Takagi and Rahman 1995). This induction of fatty acid variability confirms that artificial mutation is useful for enhancing fatty acid diversity of soybean.

Table 2. Fatty acid composition (% of total oil) of different soybean mutants and their genotypes (Nakagawa *et al.* 2011).

Mutant Line	Fatty Acid Composition (%)					Genotype
	Palmitic Acid (16:0)	Stearic Acid (18:0)	Oleic Acid (18:1)	Linoleic Acid (18:2)	Linolenic Acid (18:3)	
J3	6.1	3.4	26.5	55.4	8.6	*sop1*
C1726	8.5	3.9	22.1	56.0	9.6	*fap1*
LPKKC-3	4.4	3.2	27.1	55.5	9.8	*sop1, fap1*
KK7	14.2	5.0	23.3	49.5	7.9	*fapx*
J10	17.2	5.0	19.7	48.4	9.7	*fap2*
HPKKJ10	21.6	5.7	18.0	45.6	9.0	*fapx, fap2*
KK-2	10.3	7.2	23.1	51.6	7.9	st_1
M25	9.5	21.2	15.6	44.0	9.8	st_2
M25KK2	9.4	31.4	12.4	38.4	8.4	st_1, st_2
M11	10.3	4.3	35.8	41.4	8.2	ol^a
M23	8.9	4.4	48.6	29.5	8.5	*ol*
M24	10.0	5.3	27.3	51.5	5.9	$fanx^a$
M5	9.8	4.9	25.5	55.3	4.9	*fan*
LOLL	10.3	4.5	27.7	54.7	2.9	*fan*, $fanx^a$
B739	7.9	4.3	14.3	55.1	18.4	lin^h
cv. Bay	10.6	4.2	25.2	51.7	8.3	

Table 3. Mean and range of fatty acid composition (% of total oil) in 46 different soybean mutants and 99 cultivars developed by using natural resources (Takagi and Rahman 1995).

	Fatty Acid Composition (%)				
	Palmitic Acid (16:0)	Stearic Acid (18:0)	Oleic Acid (18:1)	Linoleic Acid (18:2)	Linolenic Acid (18:3)
Mutants					
Mean	10.6	5.2	26.5	49.8	7.9
Range	6.3-16.7	2.9-16.1	17.5-48.2	32.2-60.5	4.6-12.6
Cultivars					
Mean	12.1	2.9	25.1	51.9	8.0
Range	10.0-15.5	1.6-4.1	14.2-44.3	36.6-61.1	5.2-12.6

As mentioned above, Takagi and his colleagues isolated a significant number of mutant lines exhibiting varying fatty acid composition through use of X-rays. Hybridization of these mutant lines, selection, characterization and experimentation can attain the pyramiding of mutant genes exhibiting complementary gene action in order to modify expression of various fatty acids. Following the hybridization and examination of the subsequent generations, the inheritance of genes conditioning low and high palmitic, high stearic, high oleic, and low and high linolenic acids were elucidated.

Figure 6 illustrates the fatty acid biosynthesis pathway of soybean seed oil. Palmitoyl-ACP（16:10）is synthesized from malonyl-ACP（4:0）through the condensation（fatty acid elongation）cycle. Three types of β-ketoacyl-synthases（βKASs）are involved in this condensation cycle. Palmitoyl-ACP is synthesized by βKASI and βKASIII, and then stearoyl-ACP（18:0）is synthesized by βKASII. Following this process, stearoyl-ACP is converted into oleoyl-ACP by stearoyl-ACP desaturase. Acyl-ACP thioesterase catalyzes the acyl-ACPs, and palmitic, stearic and oleic acids are produced with these reactions. Then oleic acid is converted to linolenic acid through linoleic acid by two distinct microsomal fatty acid desaturases, omega-6 and omega-3. These fatty acid biosynthesis enzymes are encoded by *GmβKASII*, *GmSte*, *GmFAD2* and the *GmFAD3* gene family, respectively. As discussed above, genetic analysis of fatty acid content in soybean mutants suggests that several genes are involved in each step of fatty acid synthesis pathway.

Byrum *et al.*（1997）reported that one of the low linolenic-acid mutants, “A5”, carries a deletion in gene *GmFAD3*. Takagi’s group also identified a large deletion in gene *GmFAD3* of “J18”（Yamashita *et al.* 1998）, *GmFAD2* of “M23”（Kinoshita *et al.* 1998）and *GmSte* of “KK2”（Rahman *et al.* 1998）with Southern-blot analysis and also confirmed that these deletions co-segregated with their fatty acid content phenotypes. However, the vast majority of fatty acid mutants of soybean have not been characterized in detail. A superior understanding of the relationships between the corresponding gene and the phenotype of individual mutants will be valuable for soybean oil breeding programs.

Takagi’s group determined the corresponding genes of three low linolenic-acid mutants（“M24”, “M5” and “J18”）and divided them into two groups: “M24” had a mutation on gene *GmFAD3-1a*, and “M24” and “J18” had a respective mutation on *GmFAD3-1b*（Anai *et al.* 2005）. The molecular status of these mutated genes were as follows: a 1-bp deletion in the open reading frame（ORF）of gene *GmFAD3-1a*, a 19-bp deletion in the ORF of *GmFAD3-1b* and a large deletion in the region containing *GmFAD3-1b*, respectively. The mutant of *GmFAD3-2a* has not yet been obtained from Takagi’s mutant collection, but this mutant represents an important target for decreasing linolenic acid content in soybean. Because gene *GmFAD3-2a* is expressed in developing seeds and its product exhibits the correct enzymatic activity in yeast cells（Anai *et al.* 2005）, it is anticipated that further study of the *GmFAD3-2a* mutant line may result in development of a near-zero linolenic acid soybean cultivar.

Allele-specific genotypic selection, through use of molecular markers related to these gene families, will be superior to phenotypic selection using gas-liquid chromatography. Multiple sources of alleles for each candidate gene isoform can provide further benefits in the breeding of germplasm with superior fatty acid composition and minimize fixation of alleles linked to target genes（Takagi *et al.* 1998; Anai *et al.* 2005; Takagi and Anai 2006; Nakagawa *et al.* 2011a）.

7） Lipoxygenase-lacking soybean

Lipoxygenase is an enzyme that generates a beany-flavor within soybean and its processed products. When soybean meal is mixed with water, lipoxygenases oxidize the abundant unsaturated fatty acids in the soybean seed and produce aldehydes such as n-hexanal（Fig. 7）. Heat treatment is generally used to reduce this

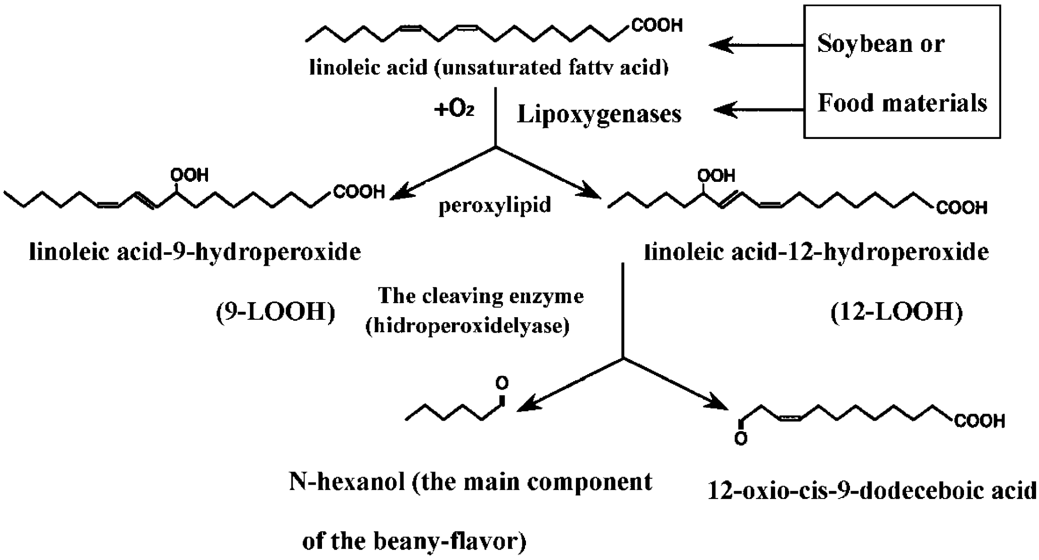


Fig. 7. The reaction pathway of the seed lipoxygenases (based on Arai *et al.* 1970). (Courtesy of Dr. M. Hajika, NARO)

flavor in soybean products; however, once produced, heat treatment will not completely eliminate this flavor and this results in soybean products with poor taste quality. Trials have been performed to determine a better method to remove these undesirable flavors from soybean products in the food processing industry.

Soybean seed has three lipoxygenases: L-1, L-2 and L-3 (Arai *et al.* 1970). In the 1980s, mutant cultivars lacking lipoxygenase were isolated from germplasm (Hildebrand and Hymowits 1981; Kitamura *et al.* 1983, 1985) and both L-1 and L-3 lacking and L-2 and L-3 lacking lines were bred by hybridizations between the two types. However, neither L-1 and L-3 lacking plants nor plants lacking L-1, L-2 and L-3 were obtained through breeding and hybridization. Therefore, mutation breeding was conducted to induce soybean mutants lacking L-1, L-2 and L-3 (Kitamura *et al.* 1985). Expecting not only the mutations but also chromosome crossing-over, 100−150 g of F_2 seeds derived from the cross between cv. "Kankei 2" (later named cv. "Kanto No. 102", which lacks L-1 and L-3), and cv. "Kankei 1" (later registered as cv. "Yume-yutaka", which lacks L-2 and L-3) were irradiated at the IRB in 1989.

The irradiated F_2 seeds (M_1) were planted to establish the M_1 population and obtain M_2 seeds. Harvested M_2 seeds were analyzed for protein composition using SDS-PAGE. The F_2 seeds derived from a cross between a line without *L-1* and *L-3* and a line without *L-2* and *L-3* were irradiated with gamma-rays. After surveying 1,813 M_3 seeds using SDS/PAGE, one mutant seed lacking *L-1, L-2*, and *L-3* was selected (Hajika *et al.* 1991; Nakagawa *et al.* 2011a). This lipoxygenase-lacking line was accelerated to obtain the M_6 generation in a field in summer and a greenhouse in winter. From the M_7 generation, field tests were conducted to evaluate yield and agronomic characteristics. In 1995, one selected line was released as cv. "Ichi-hime" (Hajika *et al.* 2002), and exhibits similar agronomic characteristics to cv. "Suzu-yutaka", the recurrent parent of "Kankei 1" and "Kankei 2". Several all-lipoxygenase-lacking soybean cultivars were developed by crossing between normal soybean cultivars and the all-lipoxygenase-lacking mutant lines. Several of these lines were sent to other countries and many all-lipoxygenases-lacking cultivars have since been developed.

8) Glycinin-rich soybean

The major components of soybean seed storage proteins are glycinin (11S globulin) and β-conglycinin

(7S globulin), which account for about 70% of all seed proteins. The amount of sulfur-containing amino acids (methionine and cysteine) in glycinin is 3–4 times that of β-conglycinin. Compared with β-conglycinin, glycinin exhibits better processing properties in texturized and filmed soy foods as well as in tofu gels. The β-conglycinin is composed of α-, α'- and β-subunits. The cv. "Keburi" characterized by the absence of the α'-subunit, and cv. "Mo-shi-dou Gong 503" with low levels of α- and β-subunits, were identified in Japanese soybean germplasm collections (Kitamura and Kaizuma 1981). Ogawa *et al.* (1989) developed some lines from these spontaneous soybean mutants and showed that it was possible to increase the amount of glycinin by decreasing the amount of β-conglycinin. The cv. "Kari-kei 434" was developed as one line characterized by the lack of the α'-subunit and a marked decrease of the level of α- and β-subunits of β-conglycinin. However, neither α-less nor β-less cultivars were identified in the germplasm collection. Therefore, knockout of the α-subunit gene was attempted by gamma-ray irradiation of seed of cv. "Kari-kei 434" at the IRB, and five mutated seeds, which exhibited loss of the α-subunit and α'-subunit, were identified using SDS-PAGE in the M_2 and M_3 populations. The deleted form of the α-subunit was controlled by a recessive gene and crossing studies showed that existence or nonexistence of the α-subunit was independent of the α'-subunit (Takahashi *et al.* 1996). In 2001, a new mutant cv. "Yumeminori" was developed from this mutation and released as a glycinin-rich and hypoallergenic soybean (Fig. 8; Takahashi *et al*, 2004; Nakagawa *et al.* 2011a). The cause for the hypoallergenic property in cv. "Yumeminori" is due to; (a) the α-subunit is a major allergen in soybean (Ogawa *et al.* 1991); and (b) GlymBd30K, which represents one major allergen, was effectively removed from soybean protein isolates using chemical and physical methods (Samoto *et al.* 1996). Almost all growth habits of cv. "Yumeminori" were similar to cv. "Tachinagaha" except for the slightly lower seed weight and ca. 4% higher protein content. However, the processing properties of tofu curd were poorer than those for normal soybeans presumably caused by the high reactivity of glycinin proteins in cv. "Yumeminori". To solve this problem, further studies are required. Recently, it was clearly shown that the deficiency of the α-subunit in a mutant line "α-null (1)" was caused by the termination codon resulting from inserting four bases into gene *CG-2* encoding the α-subunit (Ishikawa *et al.* 2006).

Today, these glycinin-rich soybeans are utilized for soymilk products with decreased allergic reaction.

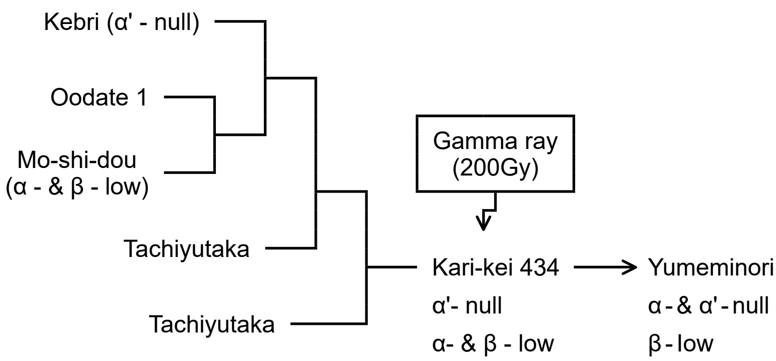


Fig. 8. Pedigree chart of glycinin rich mutant cv. "Yumeminori" (based on Takahashi *et al.* 2004). (Courtesy of Dr. M. Hajika, NARO)

9) Super-nodulation

Super-nodulation is a character that generates a large number of root nodules in leguminous plants. Super-nodulating mutants of soybean may provide a new genetic resource for improving soybean productivity by higher nitrogen-fixation as well as for elucidating mechanism of rhizobium-plant interactions. A super-nodulating mutant "En6500" was isolated from a 2,800 M_2 population generated by treating cv. "Enrei" with 0.5% of ethyl methanesulfonate (EMS) (Akao and Kouchi 1992). The “En6500” had an increased number of nodules, inherited as a Mendelian recessive trait (Kokubun and Akao 1994); however, its growth and yield performance were inferior to that of cv. “Enrei”. The cause of this reduced yield performance is presumably from the high consumption of carbohydrates by nodules and a decrease of total nitrogen assimilation through the reduction of nitrate absorption (Takahashi, *et al*, 1995). Due to the inferior performance of this new germplasm, a second attempt utilizing traditional backcross breeding to cv. “Enrei” was initiated and the super-nodulating cv. “Kanto 100” was successfully selected at the National Institute of Crop Science (NICS), National Agriculture and Food Research Organization (NARO). The cv. “Kanto 100” exhibits super-nodulation and the yield is similar to that of cv. “Enrei” (Takahashi *et al.* 2003). This super-nodulating mutation has potential impact on the development of high efficiency, nitrogen-fixing soybeans as well as for elucidation of rhizobium-plant interaction.

10) Japanese pear and apple resistant to Alternaria disease

A popular cultivar of Japanese pear (*Pyrus serotina* Rehd. var. *culta* Rehd.), cv. “Nijisseiki”, was a leading cultivar that occupied 28% of the total cultivated area of Japanese pear in 1990 in Japan. However, the cultivar is highly susceptible to the black spot disease, *Alternaria alternata* (Fr.) Keissier (= *Alternaria kikuchiana* Tanaka), one of the most serious diseases of pear (Nishimura *et al.* 1978). Growers need to spray fungicides several times during the growing season to counter the disease. To induce mutations resistant to the disease, small plants of the cv. “Nijisseiki” were planted every 4 meters within 37-63 m from the ^{60}Co source in 1962 and chronic gamma-ray irradiation was applied (30×10^{-2} to 4×10^{-2} Gy/day) in the Gamma Field (Sanada *et al.* 1993). In 1981, nearly 20 years after the planting, a twig bearing green leaves exhibiting no symptom of the disease while all the other twigs were infected by the fungus and most leaves had many black spots. The resistant twig was found on a plant planted 53 m from the radiation source. As it was ascertained that there was no difference in other agronomic characteristics between the mutant and the original cultivar except for resistance to black spot disease, it was registered and released in 1991 with the name cv. “Gold Nijisseiki” (Sanada *et al.* 1993). It was registered under the same name in Australia in 2004 (Certificate Number 2533).

Dr. Sanada, one of the breeders of this cultivar mentioned, “The situation of mutation breeding on Japanese pear has been severely criticized because there have been no successful results”. Although it took them nearly 20 years to identify a useful mutation and 30 years for its registration, the release of cv. “Gold Nijisseiki” became a monumental achievement for the IRB’s Gamma Field.

At the same time, an easy and effective method for screening of resistance to the fungus was developed by treating leaf disks (punched out by 7 mm in diameter) of each branch by the toxin produced by the fungus in the culture (Sanada 1988). After that, Nakashima *et al.* (1982, 1985) isolated and identified the chemical structure of the toxin (“AK-toxin”) produced by the fungus of black spot disease. As a consequence, the breeding group of the IRB entered into a cooperative research program with the chemistry group in Kyoto University and established the further use of this approach. When the punched leaf disks are placed on filter paper in a Petri dish soaked with AK-toxin obtained either from the extracts of the fungal body or artificial synthesis, and kept for 2 days at 25°C, leaves of susceptible cultivars such as cv. “Nijisseiki” turn black and leaves of resistant cultivars such as cv. “Chojyurou” stay green (Fig. 9). The intact leaves and old leaves of cv. “Gold Nijisseiki” are completely resistant, but interestingly the cut young leaves are partially susceptible, probably because only leaf surface tissues (the L1 layer) became resistant but inner tissues still keep susceptible genotype. As a result, leaves of cv. “Gold Nijisseiki” is really resistant to the disease in the field. Following its development, two new mutant cvs. “Osa-Gold (Masuda *et al.* 1997, 1998)” and “Kotobuki Shinsui (Kitagawa *et al.* 1999)” were

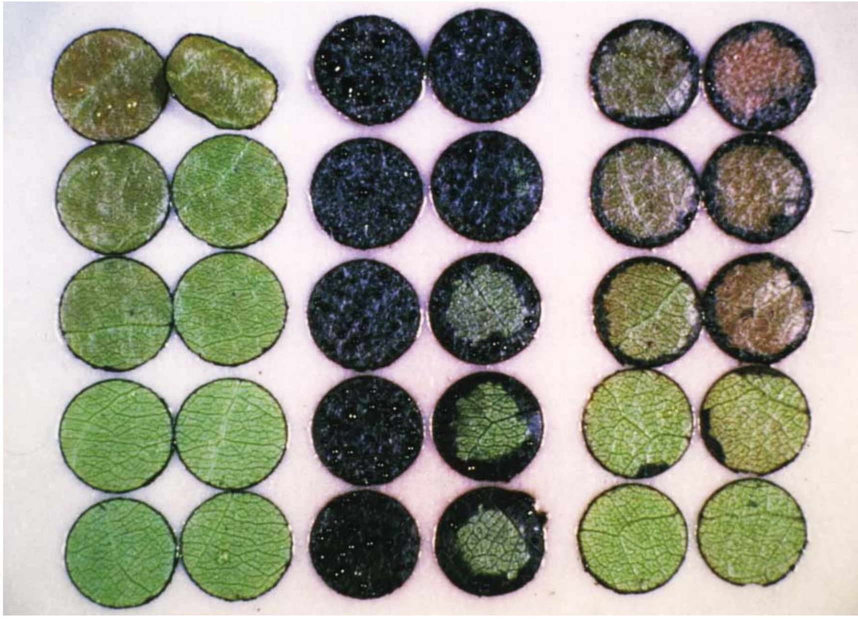


Fig. 9. Resistance bioassay for black spot disease using the AK-toxin obtained from the culture of the fungus （based on Nakagawa 2009）. Upper to lower leaf disks （1–5） indicate 1 （young） to 5 （older） leaf; cv.“Chojyurou”: highly resistant; cv. “Nijisseiki”: highly susceptible; cv. “Gold Nijisseiki”: resistant

developed in a short period using this unique screening method. The economic effect of this research has been great.

Furthermore, the same bioassay method can also be utilized for the selection of plant resistant to Alternaria blotch disease using the AM-toxin （Ueno *et al.* 1977） produced by the fungus *Alternaria mali* that attacks apple. A new mutant apple cv. “Houiku Indo” was selected from gamma-ray irradiated micro-propagated shoots of susceptible cv. “Indo” （total dose: 80 Gy） and found to be resistant to this disease （Yoshioka *et al.* 2001）.

This research suggests that breeding of fruit trees requires patience and that development of simple, efficient and precise screening methods is very important for mutation breeding.

11） Others

Many other interesting mutations have been identified using various screening methods in Japan. Additional information about unique mutations, screening methods, and released cultivars is given in the Appendices of this report. Gamma Field Symposia （a series of proceedings; http://www.nias.affrc.go.jp/eng/public/index2.html） and Radiation Breeding Technologies （*ibid.*） also provide a wide range of information.

Ⅳ　Genetic studies of the useful mutations induced by acute or chronic gamma-ray irradiation

Spontaneous and induced-mutation resources have played important roles not only for mutation breeding but also in genetic studies and the elucidation of gene functions. Some examples are mentioned here.

1） Phytochrome

Takano *et al.* （2005） isolated *phytochrome B* （*phyB*） and *phy C* mutants from rice and produced all combinations of double mutants. Seedlings of *phy B* and *phyB phyC* mutants exhibited a partial loss of sensitivity to continuous red light but still showed significant de-etiolation responses. The response to red light was completely lost in *phyA phyB* double mutants. These results indicate that *phyA* and *phyB* act in a highly redundant manner to control de-etiolation under red light. They also found that mutations in either the *phyB* or *phyC* locus cause moderate early flowering under a long-day photoperiod, but monogenic *phyA* mutations had little effect on flowering time. However, the *phyA* mutation in combination with the *phyB* or *phyC* mutation caused dramatically early flowering. The *phyB* mutants were generated by chronic gamma-ray irradiation with dose rates of 3-6 Gy/day (Takano *et al.* 2005).

2) Aluminum tolerance

Ma *et al.* (2005) isolated a mutant with high sensitivity to aluminum (Al) concentration from cv. “Koshihikari”, an Al-resistant japonica rice (Wu *et al.* 1997). The mutant was induced through chronic gamma-ray irradiation and exhibited the same phenotype as the wild-type; however, without Al tolerance. That is, M_1 plants were irradiated in the Gamma Field from 7 days before heading to 2 days after heading under 20 Gy/day for 8 days. The root elongation of the mutant was highly inhibited in the presence of 10 μM Al. The mutant also exhibited poorer root growth in acid soil. Genetic analysis showed that the high sensitivity to Al is controlled by a single recessive gene, mapped to the long arm of chromosome 6.

3) Wax-free mutation of sorghum

Sorghum (*Sorghum bicolor* (L.) Moench.) produces and deposits bloom or epicuticular wax on the surface of stems and leaves (Fig. 10 left). The deposition of this wax is a dominant trait (*Bm*) with variation under different environments (Jordan *et al.* 1983), and bloomless (*bm*) mutants have no bloom or wax on the surface of plant parts. This wax is thought to make an important contribution to tolerance to abiotic stresses such as drought through reduced cuticular transpiration (Blum 1975) and protection from ultraviolet (UV) light in the semiarid tropics (Jordan *et al.* 1983). Reducing cuticular wax and cuticle deposition is also known to increases susceptibility to the fungal disease northern corn leaf blight caused by *Exserohilum turcicum* (Jenks *et al.* 1994). However, *bm* sorghum tends to increase resistance to biotic stresses such as resistance to greenbug attacks (Peiretti *et al.* 1980; Nakagawa *et al.* 2011b), which is achieved through nonpreference (Weibel and Starks 1986), and sheath blight (Kasuga *et al.* 2001).

In Japan, sweet sorghum has recently become a candidate crop for bioethanol production by utilizing the sugars produced and stored in stems and lignocellulose of stems and leaves through fermentation (Nakagawa *et al.* 2013). The development of sorghum cultivars resistant to biotic-stresses will have advantages for low-input without pesticides and fungicide and sustainable biofuel production. In 2006, groups of 1,000 seeds of sweet sorghum cv. “Italian” were irradiated with different doses of gamma-rays (0, 100, 200, 400, 500, 800, and 1,000 Gy for 20 hours) in the Gamma Room at the IRB, NIAS. After germination tests of the M_1 seeds, the seedlings were transplanted in the field and self-pollinated M_2 seeds were obtained by bagging of M_1 inflorescences before heading. In 2008, six seeds from each M_2 line were planted in the field plots for the evaluation. Two *bm* mutant plants without visible epicuticular wax (bloom) on the stems (Fig. 10) were identified from the M_2 population irradiated with 400 Gy of gamma-rays. The two self-pollinated lines were planted in the field and identified as pure lines with no variations. At the same time, these two lines were hybridized with the original cv. “Italian” plants, and the F_1 seeds and self-pollinated F_2 seeds were obtained. In 2010, 96 F_2 seeds from each hybridization were planted in the field for genetic and molecular analyses. The F_2 population segregated for individuals with

Fig. 10. Wild type (left) and *bm* mutant (right) of sorghum cv. "Italian".

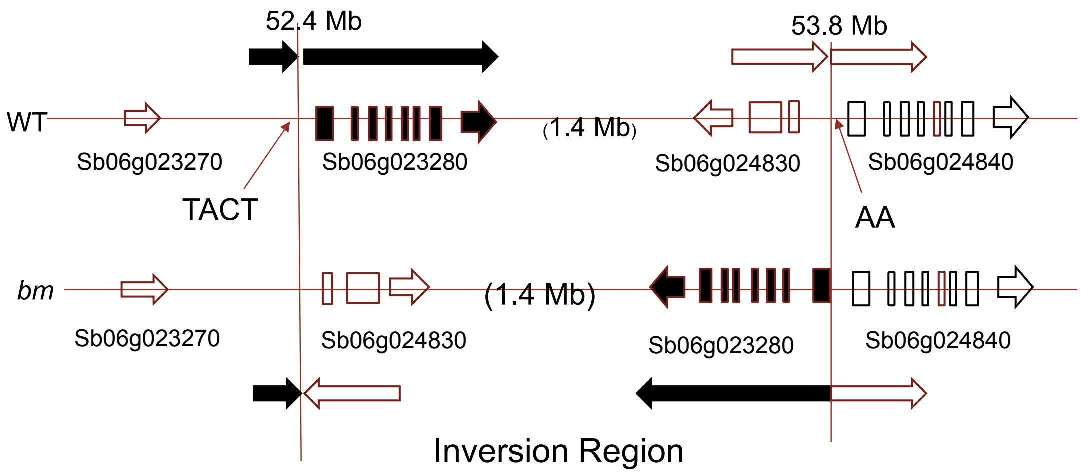


Fig. 11. Genomic inversion in the *bm* mutant. An inversion of *ca.* 1.4 Mbp occurred on the chromosome 6 (based on Mizuno *et al.* 2013). Arrows indicate cloned sequence from the wild-type (WT) and the *bm* mutant genome. At the junction, four bases (TACT) or two bases (AA) were deleted in the *bm* mutant genome. Because of this inversion, the upstream region of the Sb06g023280/WBC11 gene (black arrow) was exchanged with the downstream sequence. (Courtesy of Dr. H. Mizuno, NARO)

and without epicuticular wax at a frequency of 74:22 (χ^2 = 0.1277; P = 0.7209 for a 3:1 segregation ratio, Chi square test) suggesting that the *bm* phenotype was controlled by a single recessive nuclear gene (Nakagawa *et al.* 2011c; Mizuno *et al.* 2013). The leaf-sheath of F_2 plants with the wild-type phenotype and those with the *bm* phenotype were subjected to RNA-seq analysis. In addition, the sorghum *bm* mutant and wild-type plants were examined using scanning electron microscopy, which showed that the wax was not located on the leaf surface of plants but deposited inside of the cells (Mizuno *et al.* 2013).

Total RNA of both wild-type and *bm* mutant were extracted from leaves, and converted to cDNA for massive parallel sequencing in an Illumina Genome Analyzer and differentially expressed genes were identified (Mizuno *et al.* 2013). Of the 31 downregulated genes, one gene was similar to the ABC transporter responsible for wax secretion in Arabidopsis (Bird *et al.* 2007; Panikashvili *et al.* 2007; Ukitsu *et al.* 2007). The induced *bm* mutant was identified to carry a 1.4-Mb genomic inversion proximal to the promoter region of Sb06g023280, which is the candidate gene of the *bm* mutant, with small deletions at both ends (Fig. 11). Using genome PCR, six *bm* mutant-phenotype progeny of the F_2 population were found to carry the same inversion. The analysis proved that the inversion involving the Sb06g023280 gene inhibited wax secretion in the bloomless sorghum, although the epicuticular wax was synthesized inside the cells.

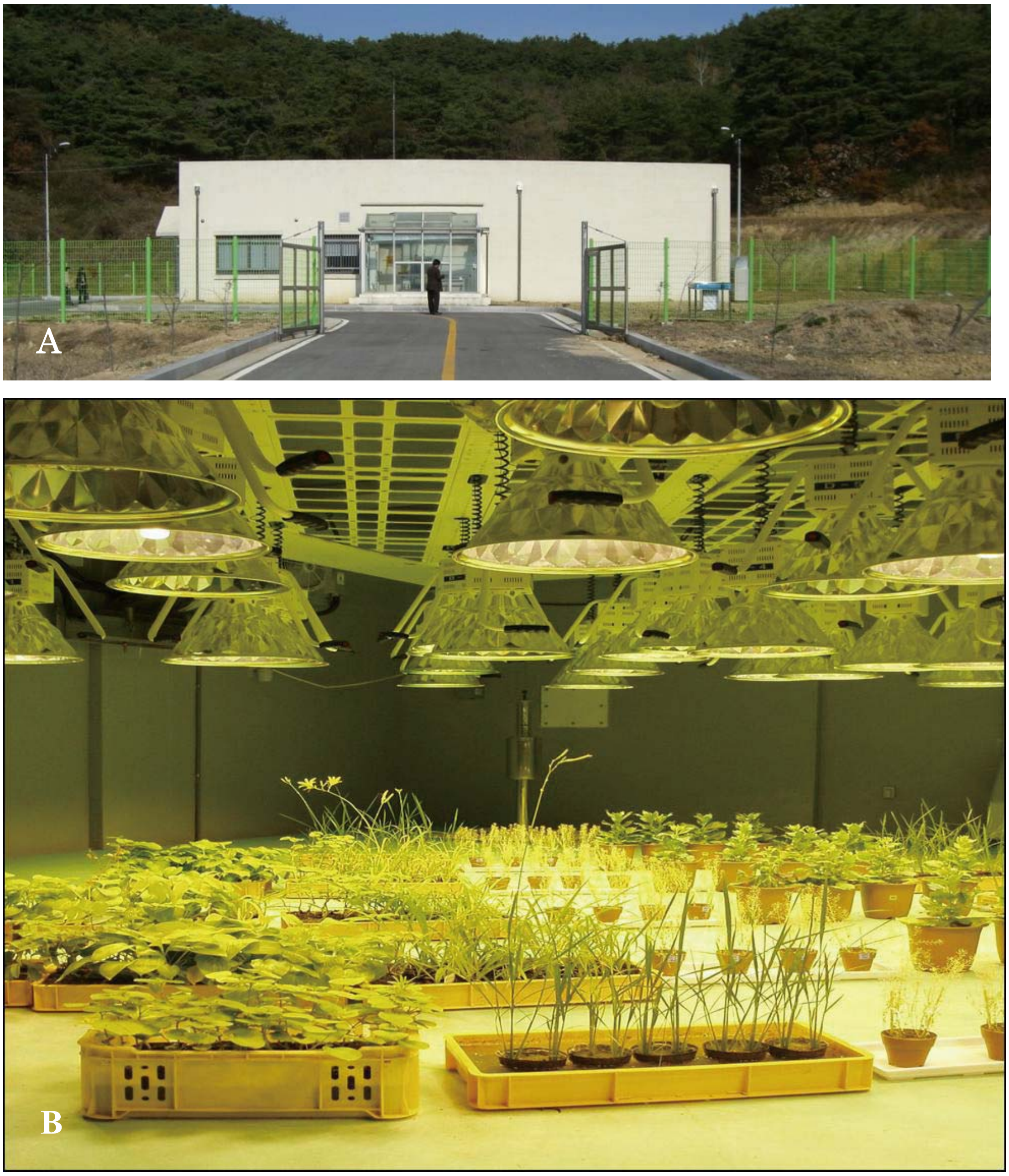


Fig. 12. Gamma Phytotron located at Korean Atomic Energy Research Institute (KAERI) in Jeoungup, Jeon buk Province, Republic of Korea. (Courtesy of Dr. Si-Yong Kang, KAERI), A: A building of the Gamma Phytotron; B: Inside the Gamma Phytotron

4）Chronic gamma-ray irradiation facilities in Asia

Two facilities for chronic gamma-ray irradiation were recently established in Asia. The Gamma Phytotron（Fig. 12）was established at the Advanced Radiation Technology Institute, Korea Atomic Energy Research Institute in Jeongeup, Jeollabuk-do, Rep. of Korea in 2005. The irradiation source is ^{60}Co with the radioactivity strength of about 400 curies（Kang et al. 2010）. The Gamma Greenhouse（Fig. 13）was established at the Malaysian Nuclear Agency, Ministry of Science, Technology and Innovation in Bangi, Selangor, Malaysia

Fig. 13. Gamma Greenhouse located at Malaysia Nuclear Agency, Ministry of Science, Technology and Innovation, Bangi, Kajang, Selangor, Malaysia.（Courtesy of Dr. Rusli bin Ibrahim, Malaysian Nuclear Agency）. A: A building of the Gamma Greenhouse; B: Inside the Gamma Greenhouse

in 2008. The Gamma Greenhouse is a circular greenhouse with a radius of 15 m, installed with ^{137}Cs with the radioactivity strength of about 800 curies at the center (Ibrahim 2010). As with the Gamma Field, both facilities are focused on the induction of mutation by chronic gamma-ray irradiation in growing plants of important crop species. As described above, chronic irradiation is a useful tool for the generation of mutant genome resources that have application for molecular analysis as well as conventional breeding.

Ⅴ Mutation breeding of outcrossing crops

Mutation breeding has been primarily performed in seed propagated, self-pollinated species. Although several methods have been widely used for screening of mutants in self-pollinated species by the single-seed descent approach (Stadler 1930; Nybom 1954) and by one-plant-one-grain method (Yoshida 1962), these methods have not been applied to cross-pollinated species. Ukai (1990) developed a new and efficient method - the "crossing-within-spike-progenies method"- for obtaining mutants of cross-pollinated species in a temperate forage grass, Italian ryegrass (*Lolium multiflorum* Lam.). This method composes (1) taking seeds separately from each spike from a population of plants following gamma-ray irradiation, (2) sowing the seeds in a hill plot as a spike-progeny, (3) isolating each hill from others at the time of flowering and allowing the open-pollination of plants within hills and (4) taking seeds from each of the hills and sowing the seeds in hill progenies for the screening of mutants. This procedure is repeated each year. Using 300 Gy of gamma-ray irradiation for the seed, the frequency of chlorophyll mutations was approximately 70.6% per hill progeny and 1.87% per plant; in comparison, open-pollinated populations exhibited only 10% per progeny and 0.12% per plant. This method has application in other wind- or insect-pollinated outcrossing crop species.

Ⅵ Mutation breeding and cultivars released in Japan

In a 2015 search regarding the number of induced-mutation cultivars in the IAEA database (http://mvgs.iaea.org/AboutMutantVarities.aspx), China had the most described induced-mutation cultivars with 810, Japan was second with 481 and India was third with 330 (including those with doubled chromosome numbers through colchicine treatment). The total number of mutant cultivars, including direct-use mutant cultivars and indirect-use cultivars exceed these totals because all mutant cultivars have not yet been listed by breeders. A selection of mutant cultivars developed in Japan, including their economic impact of these cultivars, and their characteristics are reviewed here.

1) The number of cultivars developed by mutation breeding

The numbers of direct-use and indirect-use (hybrid) mutant cultivars registered in Japan in each 5-year period from 1960 to 2015 are shown in Fig. 14. The number of registered direct-use cultivars rapidly increased until 2000 when 65 cultivars were registered in five years (13 cultivars per year). This number has since fallen, with 49 cultivars registered during 2001-2005, 54 cultivars during 2006-2010 (*ca.* 10 cultivars per year) and 27 cultivars during 2011-2015. The number of indirect-use cultivars primarily generated in rice steadily increased with 79 during 2001-2005 and 80 during 2006-2010 but decreased to 58 during 2011-2015. This reduction can

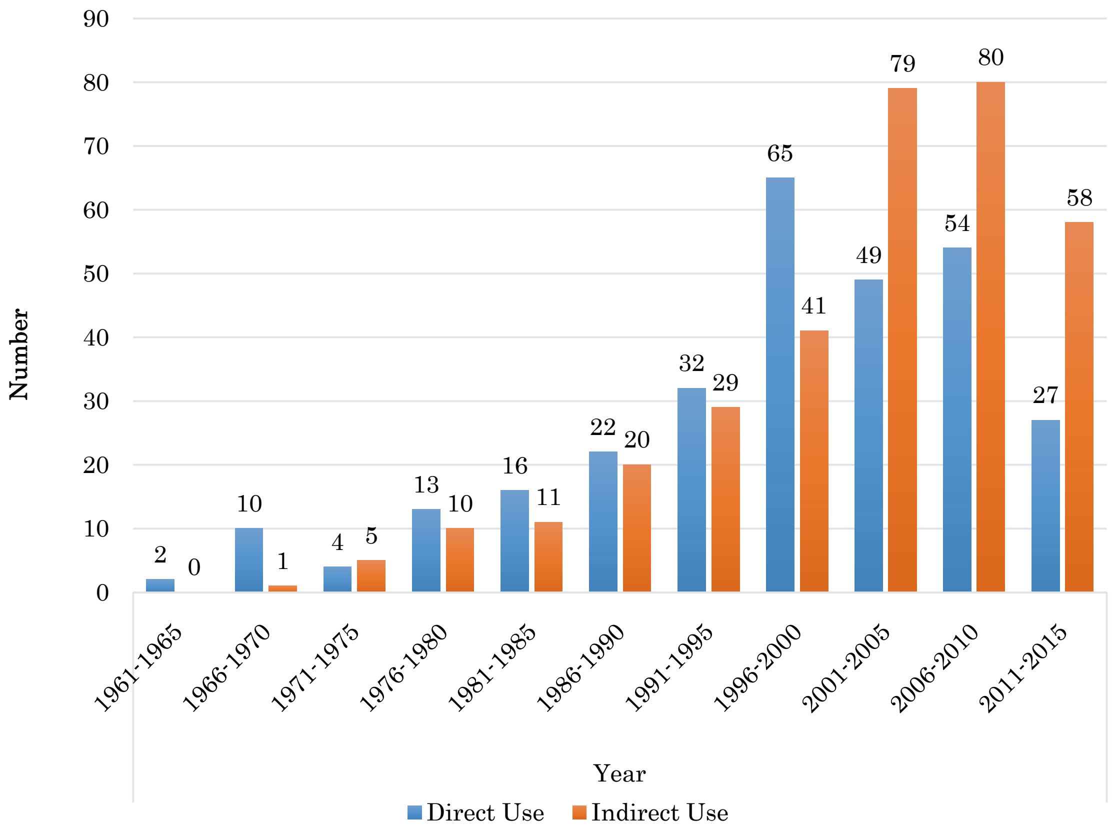


Fig. 14. Number of cultivars developed by mutation breeding in each five years from 1961–2015. The total number of direct use cultivars is 295 and that of indirect use cultivars is 334.

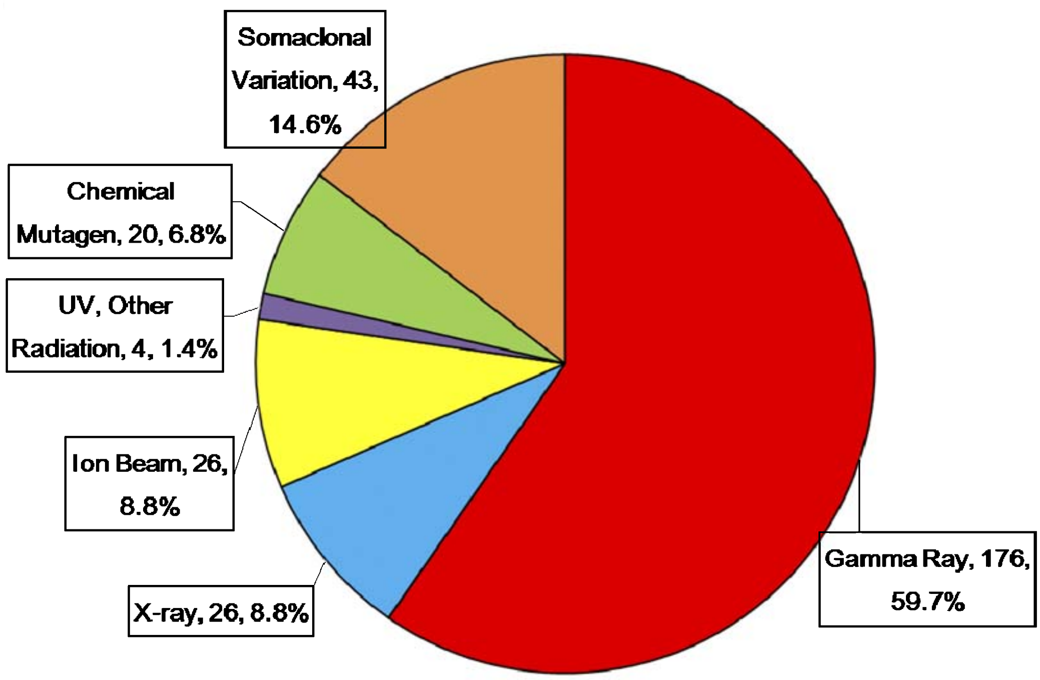


Fig. 15. Numbers and percentages of total 295 cultivars developed by mutation breeding using various methods in Japan (2016). Chemical mutagen does not include colchicine.

be turned around if agronomically useful, direct-use mutant cultivars, such as cv. "Reimei", possessing the *sd1* dwarf gene for rice are induced and utilized by rice breeders. It is presumed that such breeders will gravitate toward this and other cultivars carrying advantageous unique genes.

There have been 295 direct-use mutant cultivars comprising 70 species generated through irradiation utilizing gamma-rays, X-rays and ion beams, chemical mutagenesis and in *vitro* culture (somaclonal variation), registered and released in Japan (Fig. 15). Approximately 79% of these were induced by radiation, including gamma-rays (59.3%), ion beams (9.2%), X-rays (8.8%) and other radiation sources such as UV radiation or those providing no information of radiation source (1.4%). Those induced by somaclonal variation and chemical mutagens (not including those with doubled chromosome numbers through colchicine treatment), are 14.6 and 6.8%, respectively. Recently, the development of mutant cultivars of flower and food crops, generated by ion beam irradiation has been a growing area of mutation induction in Japan.

Table 4 shows the number of registered direct-use mutant cultivars of some crops developed by radiation, gamma-rays, and those irradiated at the IRB, NIAS. These include 43 mutant cultivars of rice (*Oryza sativa* L.), 17 of soybean (*Glycine max* (L.) Merrill), four of wheat (*Triticum aestivum* L.), four of barley (*Hordeum vulgare* L.), five of barnyard millet (*Echinochloa esculenta* (A. Braun) H. Scholz: glutinous mutants for

Table 4. Number of registered direct-use mutant cultivars developed by radiation, gamma rays, and those irradiated in the Institute of Radiation Breeding (IRB), NIAS (2016).

	Cultivar[1]	Radiation	Gamma rays	IRB[2]
70 Crops	295	228	176	127
Rice	43	21	20	19
Wheat	4	2	2	0
Barley	4	4	3	0
Soybean	17	16	15	9
Adzuki bean	1	1	1	1
Broad bean	1	1	1	0
Barnyard millet	5	5	4	4
Job's tear	2	2	2	2
Buckwheat	3	3	3	3
Tartary buckwheat	3	2	1	1
Taro	3	1	0	0
Potato	2	0	0	0
Sweet potato	1	1	0	0
Sugarcane	1	1	1	1
Burdock	5	5	5	4
Apple	2	2	2	2
Japanese pear	3	3	3	3
Peach	2	2	2	2
Loquat	1	1	1	1
Enoki mushroom	2	2	2	2
Chrysanthemum	60	55	40	38
Rose	10	7	7	6
Carnation	15	11	3	2
Sea pink (*Limonium*)	6	6	6	0
Cytisus	8	8	8	8
Statice	6	6	6	0
Begonia	6	6	6	0
Lily	4	4	4	0
Clematis	2	2	2	2
Petunia	5	5	0	0
Margaret	4	4	0	0
Others	64	39	26	17

1 : Total number of mutant cultivars developed by radiation (gamma-ray, X-ray, ultraviolet, ion beams and unwritten radiation), chemicals (excluding colchicine treatment), somaclonal variation: 2 : Number of mutant cultivars irradiated in the Institute of Radiation Breeding (IRB).

health food use), 60 of chrysanthemum (*Chrysanthemum*) and 10 of rose (*Rosa*). Among them, 126 cultivars (ca. 72.1% of gamma-ray induced cultivars) have been generated through gamma-ray irradiation in the Gamma Field, the Gamma Room and the Gamma Greenhouse of the IRB. This high percentage of gamma-ray-irradiated mutants indicates that mutation breeding via gamma-ray irradiation is an effective and highly successful approach for generation of commercial cultivars. Detailed data of developed cultivars are listed in Appendix 1, that includes cultivars induced through colchicine treatment.

The first mutant rice cultivar developed using gamma-ray irradiation was cv. “Reimei”, which means “dawn” in Japanese. Its development illustrated the potential of gamma-rays for breeding improvements in Japan. The cv. “Reimei”, registered in 1966 (Futsuhara 1968), was a successful case of an irradiation-induced semi-dwarf mutant. This cultivar exhibits a mutation of the *SD1* locus (Ashikari *et al.* 2002), which is same as the mutation of a miracle rice, cv. “IR8”, through cv. “Dee-geo-woo-gen” and later contributed to the “Green Revolution” of rice, and shows a culm 15 cm shorter than the original cv. “Fujiminori”. The semi-dwarf character is associated with the high-yielding ability and recorded the highest yield in Japan in 1967 (Futsuhara 1968)

In Japan, the total number of indirect-use mutant cultivars is 335, which includes 298 rice, 15 soybean, eight barley, six wheat, three tomato, one eggplant, one Japanese lawngrass (*Zoysia japonica* Steud), two mat rush (*Juncus effusus* L. var. *decipens* Buchen.) and one Job’s tear (*Coix lacryma-jobi* L. var. *ma-yuen* Stapf) in 2016 (Table 5). Detailed data of developed cultivars are listed in Appendix 2. Interestingly, among the 298 indirect-use mutant rice cultivars in 2016, 150 cultivars (50.3%) exhibited lodging resistance characteristics in the semi-dwarf cultivars derived from cv. “Reimei” or its offspring. This demonstrates that agronomically useful mutations can be efficiently and intensely utilized as parental lines to develop new cultivars with the same characteristic, and over the years the mutant gene multiplies itself in the farmers’ fields.

Table 5. Number of indirect-use mutant cultivars in Japan (2016).

Rice	Wheat	Barley	Soybean	Tomato	Others	Total
298	6	8	15	3	5	335

2) The economic impact of mutant cultivars in Japan

The increase of mutant rice cultivars derived from mutants generated by gamma-rays and sown in farmers’ fields in Japan since 1960 is shown in Fig. 16. The cv. “Reimei” was first cultivated on 61,598 ha in 1968 (http://ineweb.narcc.affrc.go.jp/). The number of mutant cultivars has been increasing and 99 mutant cultivars (two direct-use and 97 indirect-use cultivars) were in cultivation in 2005 (Nakagawa 2008).

The total cultivated area of mutant cultivars mostly derived from gamma-ray irradiation during 1961-2005 is shown in Fig. 17. This number increased after cv. “Reimei” was released for cultivation in 1968. The peak use of induced-mutation cultivars was 250,000 ha in 1986 and slightly exceeded 200,000 ha during 1994-2005. In 2005, the total cultivated area of mutant cultivars was 210,692 ha, which was 12.4% of the 1,702,000 ha cultivated for paddy rice in Japan (Nakagawa 2008).

The total crude income of farmers selling the brown rice of mutant cultivars has also increased with the expanding cultivation area. The amount of total income was estimated to be approximately 250 billion Yen (2.34 billion USD) in 2005 (Fig. 18) (Nakagawa 2008).

The following 17 cultivars were derived from mutant cultivars induced through gamma-ray irradiation (Appendix 2) and were cultivated on more than 5,000 ha during 2001-2005: cv. “Kinuhikari” (263,223 ha), cv. “Haenuki” (219,734 ha), cv. “Tsugaru-roman” (106,423 ha), cv. “Yume-akari” (66,491 ha), cv. “Yume-

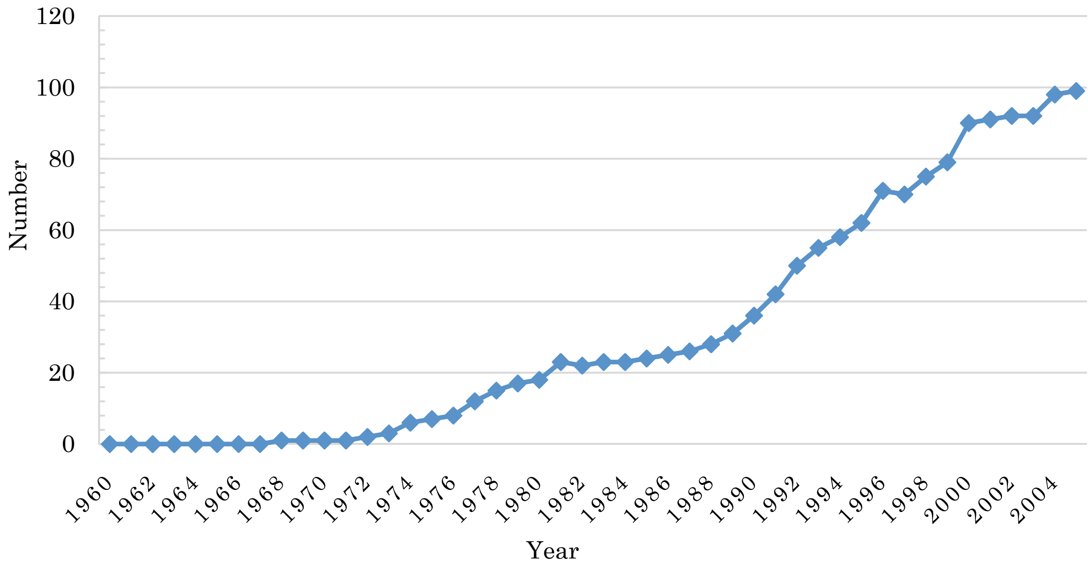


Fig. 16. Total number of mutant rice cultivars derived from mutants mostly generated by gamma-rays, cultivated in farmers' fields during 1960–2005 in Japan (Nakagawa 2008, 2009).

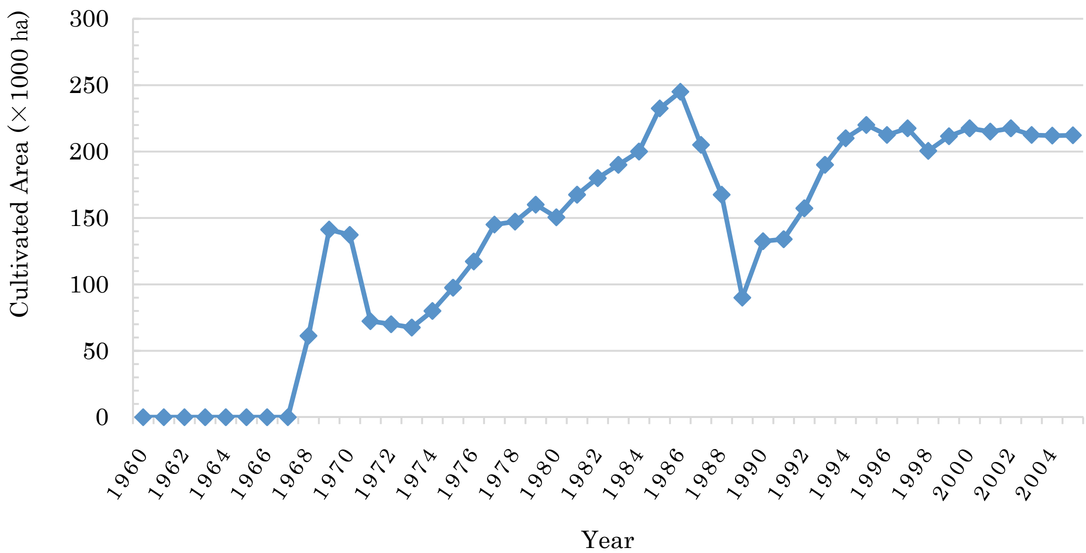


Fig. 17. Total cultivated areas of mutant rice cultivars derived from mutants mostly generated by gamma-rays, cultivated in farmers' fields during 1960–2005 in Japan (Nakagawa 2008, 2009).

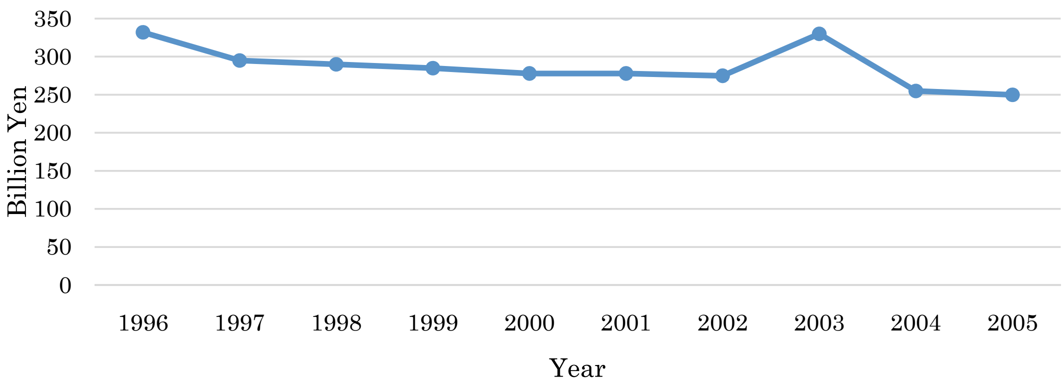


Fig. 18. Total estimated crude income of farmers obtained from cultivation of mutant rice cultivars mostly induced by gamma-rays in Japan during 1996–2005 (Nakagawa 2008, 2009).

tsukushi”（58, 893 ha), cv. “Aichi-no-kaori”（53,697 ha), cv. “Asahi-no-yume”（51,049 ha), cv. “Mutsuhomare”（46,959 ha), cv. “Dontokoi”（17,008 ha), cv. “Yume-shizuku”（14,076 ha), cv. “Mine-asahi”（10,698 ha), cv. “Yume-hitachi”（10,440 ha), cv. “Yume-minori”（9,957 ha), cv. Aki-geshiki”（7,510 ha), cv. “Aki-roman（7,450 ha)”, “Miyama-nishiki（7,242 ha)”, and “Tsukushi-roman（5,533 ha)”. The following five mutant cultivars have been cultivated on more than 100,000 ha of farmers’ fields: cv. “Akihikari”（1,410,810 ha), cv. “Reimei”（886,188 ha), cv. “Kinuhikari”（263,223 ha), cv. “Haenuki”（219,734 ha）and cv. “Tsugaru-roman”（106,423 ha). Among them, only cv. “Reimei” is a direct-use mutation cultivar and the others are indirect-use cultivars（Nakagawa 2008; Appendix 1, 2).

The latest data of the top three paddy rice cultivars in 47 prefectures of Japan in 2013 shows that 14 indirect-use mutation cultivars are listed in 180,233 ha of paddy field（11.03% of total paddy field)（Table 6). Among them, cv. “Kinuhikari”, which is descended from a gamma-ray induced semi-dwarf and lodging-tolerant mutant line, cv. “Hokuriku 100 Gou”（Samoto and Kanai 1975), from the most popular tall cv. “Koshihikari” and semi-dwarf “IR8”（Koga *et al* 1989), is the most popular mutation variety with a good taste and shorter stems and covered 48,187 ha in 11 prefectures in 2013. The cv. “Haenuki” descended from cv. “Reimei”, covered 63% of Yamagata Prefecture’s paddy fields（43,848 ha). Interestingly, cvs. “Yume-hitachi”, “Kinumusume”, “Ikuhikari”, “Yume-tsukushi”, “Genki-tsukushi”, “Yume-shizuku”, “Saga-biyori” and “Nikomaru” are descended from cv. “Kinuhikari”. Therefore, the total cultivated area of cv. “Kinuhikari” and its descendants was 95,103 ha or 5.8% of all the paddy field in Japan. The real cultivated areas of mutant cultivars exceed these values because the data include only the top three cultivars of prefectures and do not include all cultivars. This means the economic impacts of mutant cultivars of rice are huge and the roles of cvs. “Reimei”, “Kinuhikari” and “Mineasahi” are very important in Japan.

There have been 16 direct-use mutant cultivars of soybean registered in Japan（Table 4）since cvs. “Raiden” and “Raikou” were developed by gamma-ray irradiation in 1960. The improved characteristics were early- and late-maturity, yellow hilum, seed-coat color, short-stems, numbers of pods/stem, lipoxygenase-free and low allergens（Nakagawa *et al.* 2011a). Among them, cv. “Mura-yutaka” with yellow hilum color mutation is

Table 6. Mutant rice cultivars listed in the top 3 in 47 prefectures in 2013.

Variety	Cultivated Area（ha)	No. of Pref.	Origin of Mutant Cultivar
Kinuhikari	48,187	11	Hokuriku No. 100
Haenuki	43,848	1	Reimei
Koshi-ibuki	20,400	1	Reimei
Asahi-no-yume	17,598	3	Mineasahi
Yume-tsukushi	16,120	1	Kinuhikari
Yume-shizuku	8,463	1	Kinuhikari
Kinumusume	6,192	1	Kinuhikari
Sagabiyori	6,006	1	Mineasahi; Kinuhikari
Genki-tsukushi	3,627	1	Kinuhikari
Nikomaru	3,266	1	Kinuhikari
Aki-roman	2,358	1	Mineasahi
Yume-hitachi	2,331	1	Kinuhikari
Mie-no-yume	927	1	Mineasahi
Ikuhikari	911	1	Kinuhikari
Total	180,233	23	
Total paddy field in Japan	1,632,000		
%	11.03		

preferred in Japan and was induced by X-rays at Saga University (Nakamura *et al.* 1991; Appendix 1). There are 15 indirect-use mutant soybean cultivars (Table 5), of which four, including cv. "Ryuhou" are descended from a mutant cv. "Raiden" with induced early-maturity characteristics (Appendix 2). Table 7 shows the cultivated areas and estimated farmers' income for soybean mutant cultivars in 1997, 2001, 2005, 2006, 2011 and 2014 in Japan. Among the direct-use mutant cultivars, the cultivated area of cvs. "Mura-yutaka" was 1,173 ha (1,403 ha in 2011), "Kosuzu" 134 ha (194 ha in 2011) and "Akita-midori" 40 ha (0 ha in 2011) in 2014. Among the indirect-use mutant cultivars, the cultivated area of cv. "Ryuhou", a descendant of the gamma-ray induced mutant cv. "Raiden", was the third of all soybean cultivars planted in Japan with 10,548 ha in 2011 and fourth with 9,600 ha in 2014; cv. "Nanbu-shirome", which was selected from hybridization between cvs. "Raiden" and "Kitami-nagaha", had 1,472 ha (2,132 ha in 2011); and cv. "Suzu-sayaka" descended from a lipoxygenese-free mutant, and cv. "Suzu-kaori", which was selected from hybridization between cv. "Kosuzu", a gamma-ray induced direct-use mutant cultivar from cv. "Natto Kotsubu", and "Karikou 778F5", a descendant of cv. "Kosuzu" (Appendix 1, 2), had 61 ha (65 ha in 2011) and 70 ha (56 ha in 2011), in 2014, respectively. The cv. "Kyo-shirotanba", selected from hybridization between gamma-ray induced direct-use mutant cv. "Murasaki-zukin" and local cv. "Tamadaikoku" (Appendix 1, 2), was cultivated in 4 ha of Kyoto Prefecture. Thus, the economic impact of mutant cultivars of soybean is huge in Japan. The total cultivated area of mutant cultivars in farmers' fields was 14,399 ha (10.5% of total cultivated area of 136,700 ha of soybean in Japan) in 2011 and 12,614 ha (9.5% of total area of 131,900 ha in 2014), and total farmers' crude income was estimated as 11.6 billion Yen (*ca.* 116 million USD) in 2011.

Table 7. Cultivated areas (ha) of soybean mutant cultivars and income of farmers from the production in 1997, 2001, 2005, 2006, 2011 and 2014 in Japan.

Cultivar Name	1997	2001	2005	2006	2011	2014
Raiden[1]	80	8				
Wase-suzunari[1]	120					
Mura-yutaka[1]	3507	5910	2466	2265	1403	1173
Kosuzu[1]	498	863	576	512	194	134
Ichi-hime[1]		35	130			
Akita-midori[1]		8	87	95		40
Nanbu-shirome[2]	1246	1550	1534	1365	2132	1472
Tomo-yutaka[2]	2					
Suzu-no-ne[2]	10	50				
Eru-star[2]			447	43		
Suzu-sayaka[2]			10	234	65	61
Suzu-kaori[2]				25	56	70
Ryuhou[2]	1150	7050	8033	7955	10548	9600
Tsuya-homare[2]					1	
Kinu-sayaka[2]						61
Kyo-shirotanba[2]						4
Total	6,613	15,474	13,283	12,494	14,399	12,614
Total cultivated areas of soybean in Japan	83,200	143,900	134,000	142,100	136,700	131,900
%	7.95	10.75	9.91	8.79	10.53	9.56
Income of farmers (Million USD)	ca. 20	ca. 59	ca. 52	-	22.6 (115.7 with subsidy)	

[1] Direct-use mutant cultivar
[2] Indirect-use mutant cultivar

Ⅶ　Conclusions

A. M. van Harten（1998）describes in the Preface of "Mutation Breeding – Theory and Practical Application":

"An explanation for the decreasing interest in mutation breeding, at least in most "developed" countries, may be that during the past two decades attention has become more and more directed towards studying the possibilities offered to plant breeding by various new molecular technologies…As a result of these developments mutation breeding seems to have lost part of its previous attraction for young researchers. It is even not inconceivable that mutation breeding, as a discrete branch of plant breeding, may sink into oblivion and that, as a consequence, much valuable knowledge on this topic built up throughout the years, will be lost."

The record has also shown that mutation induction is a very useful conventional breeding tool for developing superior cultivars. Today, site-directed mutagenesis in *vivo* or *in vitro* cell can be envisioned and many researchers are conducting programs in this direction.

New fields of science and technologies were developed on the basis of achievements through the application of traditional or classic methods. It is highly desirable that the IRB continues its work while incorporating new discoveries and technologies. The IRB is well equipped with appropriate facilities and accumulated know-hows that will contribute to the future mutation breeding developments and it will remain a viable cooperator in solving the problems and opportunities of world food security and production.

The list of direct-use mutant cultivars（Appendix 1）includes information of crop species, cultivar names, year of registration in Japan and the registration number, breeding methods, the institutes of treatment and development, improved characteristics, ID numbers listed in IAEA database and references. The list of indirect-use（hybrid）mutant cultivars（Appendix 2）includes the crop species, cultivar name, parental lines（descendants of mutant cultivars are written in red font with the lineage), year of registration in Japan and the registration number, the institute of development, improved characteristics of original mutant cultivars, ID numbers listed in IAEA database, and references. These lists include only mutant cultivars identified from the references and a database of the Plant Variety Protection office at MAFF, Japan（http://www.hinsyu.maff.go.jp/en/en_top.html). Therefore, if the cultivar breeder did not mention that it was a mutation cultivar induced through a certain method, we cannot identify it. We did not include cultivars from spontaneous mutations, which are mentioned just as a mutant plant or twig found in the original cultivar, in the lists. We anticipate that these lists will demonstrate the importance of mutation breeding in Japan.

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Appendix 1. Direct-use mutant cultivars

No.	Cultivar Name	Original Cv. or Line	Treat. Year	Treatment	Treated Institution	Dev. year	Reg. Year	Reg. No.[a]	Institution of Development	Improved Characteristics	IAEA ID[b]	Reference
Rice		*Oryza sativa* L.										
1	Reimei	Fuji-minori	1959	Gamma ray 20kR	National Institute of Agricultural Sciences (Hiratsuka)	1966		-	Aomori PAES	Shorter stem; lodging resistance; high-yielding	1138	Futsuhara (1968)[5)]
2	Miyama-nishiki	Takane-nishiki	1972	Gamma ray 30kR	IRB	1978		-	Nagano PAES	High ratio of white core; very suitable for sake brewery	1129	
3	Miyuki-mochi	Toyo-nishiki	1973	Gamma ray 20kR	IRB	1979		-	Nagano PAES	Became glutinous	1131	
4	Shinano-sakigake	Toyo-nishiki	1973	Gamma ray 20kR	IRB	1982	1983	335	Nagano PAES	Big grain; very high-yielding; rice for forage	1141	
5	Shirakaba-nishiki	Reimei	1973	Gamma ray 20kR	IRB	1982	1983	336	Nagano PAES	Big grain; white core; brewery use	1142	
6	Iwate 21	Sasa-nishiki	1979	Gamma ray 20kR	IRB	1986		-	Iwate PAES	Shorter stem; earlier maturity; good taste	1156	Ishikawa *et al*. (1988)[18)]
7	Iwate 26	Koshihikari	1979	Gamma ray	IRB	1989		-	Iwate PAES	Extremely early maturing; shorter stem; good taste	2445	
8	Hatsu-akane	Sasa-nishiki	1984	Protoplast culture	Mitsui Chemical Ltd.	1988	1990	2508	Mitsui Chemical, Inc.	Shorter stem	2446	
9	Hatsu-yume	Koshi-hikari	1985	Protoplast culture	Plantech Research Institute	1988	1990	2509	Plantech Research Institute	Shorter stem	2447	Ito (1991)[19)]
10	Suzu-takara	Akenohoshi	1984	EMS treatment	Sumitomo Chemical Company	1988	1990	2510	Sumitomo Chemical Co.	Shorter stem; earlier maturity	1165	
11	Sumi-takara	Kogane-bare	1986	Anther culture	Sumitomo Chemical Company	1987	1991	2627	Sumitomo Chemical Co.	No hairs on the leaf blade; smaller seed	2448	
12	Yume-kahori	Tsukino-hikari	1986	Protoplast culture	Plantech Research Institute	1990	1993	3573	Plantech Research Institute	Short stem; lower 1000-kernel weight	2449	Ito (1991)[19)]
13	Fujimi-mochi	Aki-chikara	1988	Gamma ray	IRB	1991	1994	4052	ZEN-NOH	Became glutinous; white seed color	2450	
14	Rinx-Kobayashi	Rinx89	1989	NMU	Plant Laboratory, Kirin Brewery Co., Ltd.	1991	1994	4170	Plant Laboratory, Kirin Brewery Co., Ltd.	Seed-shattering resistance (no seed shattering)	2451	
15	Hareyaka	Sasa-nishiki	1989	Protoplast culture	Plantech Research Institute	1993	1995	4413	Plantech Research Institute	High lodging tolerance	2452	
16	Yume-gokochi	Koshihikari	1986	Protoplast culture	Plantech Research Institute	1992	1995	4709	Plantech Research Institute	Lower amylose	2454	
17	Syonan 3 Gou	Aki-chikara	1988	Radiation		1994	1996	5125	ZEN-NOH	Long and thin grain; high ratio of white core	2453	
18	Meguriai	Norin No. 22	1980	EMS	Hiroshima PARC	1994	1996	5187	Hiroshima PARC	Short stem; for brewery	2355	Maeshige *et al*. (1995)[27)]
19	Akane-fuji	Norin No. 8	1974	EMS	IRB	1994	1997	5307	IRB and Institute of Processing Rice Breeding	Low amylose	2456	

No.	Cultivar Name	Original Cv. or Line	Treat. Year	Treatment	Treated Institution	Dev. year	Reg. Year	Reg. No.[a]	Institution of Development	Improved Characteristics	IAEA ID[b]	Reference
20	Oita 3 Gou	Norin No. 22	1988	Anther culture	Oita PARC	1993	1997	5308	Oita PARC	10% shorter stem; slightly small grain	2457	
21	Milky Queen	Koshihikari	1985	NMU	NARC	1995	1998	6385	NARC	Lower amylose content	2458	Ise *et al*. (2001)[16)]
22	Odoroki-mochi	Kanto No. 146	1988	Gamma ray 30kR	IRB	1996	1998	6386	NARC	Became glutinous	2459	Imbe *et al*. (2004)[14)]
23	Yume-ekubo	Sasa-nishiki	1988	Protoplast culture	Plantech Research Institute	1996	2000	8546	Plantech Research Institute	Short stem; late maturing	2460	
24	Sakata-mezuru	Mezuru	1988	Gamma ray	IRB	1996	2001	8628	Sakata City	Short stem	2461	
25	Iwata 15 Gou	Kinuhikari	1989	Seed callus	Japan Tobacco Inc.	1996	2001	8632	Japan Tobacco Inc.	Low amylose	2462	
26	Hana-kahori	Yamada-nishiki	1988	Radiation		1986	2002	9784	NARO	Short stem	2463	
27	LGC-1	Nihonmasari	1988	EI	IRB	2001	2002	10469	IRB	Low glutelin contents in grain	2464	Iida *et al*. (1993)[11)]
28	Moh-retsu	Rinx89	1989	EMS	Plant Laboratory, Kirin Brewery Co., Ltd.	1988	2003	10961	Plant Laboratory, Kirin Brewery Co., Ltd.	Long stem; tough stem; shattering resistance	2465	
29	Flower Hope	Koshihikari	1985	Gamma ray	IRB	1995	2003	11356	IRB	Low content of globulin in the grain	2466	
30	Kazoku Danran	Nihon-masari	1988	EI	IRB	2000	2004	12176	IRB and Institute of Allergen Free Technology	Low allergen	2467	
31	Minami-yutaka	Moh-retsu	2001	Gamma ray 200Gy	IRB	2004	2007	15001	Miyazaki PAES	Seed-shattering resistance	2886	Kato *et al*. (2006)[22)]
32	Homare-fuji	Yamada-nishiki		Gamma ray	IRB		2010	18111	Shizuoka PAES	Semi-dwarf		Shizuoka Prefecture (2010)[49)]
33	Shizuku-hime	Matsuyama-mitsui		Callus from mature grain	Ehime PAES		2010	19046	Ehime PAES	White center of grain appearing 11-20%		Kanetou *et al*. (2010)[21)]
34	Kumika 1 gou	Taichu 65 gou		Anther culture			2010	19048	Kumiai Kagaku and Tohoku Univ.	Herbicide tolerance		
35	Yuki-hime-habutae-mochi	Shiga-habutae-mochi		Anther culture of regenerated plant from callus	Shiga PARC		2010	19052	Shiga PARC	Long stem		http://www.pref.shiga.lg.jp/g/nogyo/saibai/files/yukihime.pdf (in Japanese)
36	Yuki-no-megumi	Yukihikari		Gamma ray	IRB		2010	19410	NARO (Institute of Crop Science)	Large embryo		https://www.naro.affrc.go.jp/patent/breed/0100/0107/001690.html (in Japanese)
37	Hatsu-yamabuki	Kinuhikari		Gamma ray	IRB		2012	22049	NARO and JIRCAS	Yellow endosperm color; semi transparent		Kaji *et al*. (2010)[20)]
38	Ruri-aoba	Taporuri		Gamma ray	IRB		2012	21771	NARO	Non or low seed-shattering		Sakai *et al*.(2013)[43)]
39	Hoshinoko	Hoshi-no-yume		Gamma ray	IRB		2012	21384	NARO	White colored brown-rice		https://www.naro.affrc.go.jp/project/results/laboratory/harc/2008/cryo08-03.html
40	Kikusui-HD1 gou	Kikusui		Gamma ray	IRB		2012	22079	Keiichi OKAZAKI (Kikusui Shuzou)	Later maturing		
41	EM10	Kinmaze		NMU	Kyushu University		2014	22986	Kyushu University	Smaller grain; white colored brown-rice		Nishi *et al*. (2001)[37)]
42	Amiro-mochi	Kinmaze		NMU	Kyushu University		2014	22987	Kyushu University	Smaller grain; white colored brown-rice		

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43	Koshihikari Kan 1 gou	Koshihikari		Carbon ion beam	Japan Atomic Energy Agency		2015	24338	NIAES and NARO (Institute of Crop Science)	Accumulation of cadmium (Cd) in the grain is less than that of Koshihikari.		
Wheat		*Triticum aestivum* L.										
1	Zenkouzi-komugi	Iga-Chikugo-Oregon	1958	Gamma ray 30kR	National Institute of Agricultural Sciences (Hiratsuka)	1969	-	-	Nagano PAES	Shorter stem (15−20cm lower than the origin); lodging tolerance	1144	
2	Shirowase-komugi	Shirogane-komugi	1966	Gamma ray 25kR	Kyushu University	1977	-	-	Kyushu NAES	Erect plant-type; large inflorescence; slightly heavier head type	1143	Nonaka *et al*. (1979)[38]
3	Wheat Noh PL 7	Kanto No. 107	1988	EMS	IRB	1994	1999	7169	NARC	Lower amylose content; lower 1,000 kernel weight	2469	Yamaguchi *et al*. (1998)[56]
4	Wheat Noh PL 8	Tani-kei A6099	1991	Sodium azide (NaN_3)	IRB	2000	2003	11365	NARC	Low amylose content	2470	Kiribuchi-Otobe *et al*. (2001)[24]
Barley		*Hordeum vulgare* L.										
1	Haya-shinriki	Aka-shinriki	1957	Gamma ray 40kR	National Institute of Genetics	1961	-	-	National Institute of Genetics	Extremely early maturing; good quality	1118	
2	Gamma 4	Kirin cyoku 1 gou	1958	Gamma ray 15kR	Kanagawa Prefectural Industrial Experiment Station	1962	-	-	Barley Research Center, Kirin Brewery Co., Ltd.	Short stem（15cm shorter); slightly early maturing（1-2 day earlier）	1116	
3	Amagi Nijo 1 gou	Fuji Nijo	1965	X-ray 20kR	Tokyo University (Faculty of Agriculture)	1971	-	-	Barley Research Center, Kirin Brewery Co., Ltd.	Early maturing（7 days earlier）; short stem（14cm shorter）	1114	
4	Fuji Nijo II	Fuji Nijo	1967	BUdR(1mM)＋gamma ray 1kR	Tokyo University (Faculty of Agriculture)	1974			Barley Research Center, Kirin Brewery Co., Ltd.	Tough stem	1115	
Barnyard millet		*Echinochloa esculenta* (A. Braun) H. Scholz										
1	Chojurou-mochi	Nogebie		Gamma ray	IRB		2012	21495	Iwate University	Became glutinous		Hoshino *et al*. (2010)[10]
2	Nebarikko 1 gou	Mojappe		Gamma ray	IRB		2012	21577	Iwate Prefecture	Medium stem length; fewer awns; earlier maturity		Nakajo *et al*. (2013)[35]
3	Nebarikko 2 gou	Mojappe		Heavy ion beam	Riken		2012	21578	Iwate Prefecture	Shorter stem length; very few awns		Nakajo *et al*. (2013)[35]
4	Nebarikko 3 gou	Mojappe		Gamma ray	IRB		2012	21579	Iwate Prefecture	Shorter stem length		Nakajo *et al*. (2013)[35]
5	Yume-sakiyo	Nogebie		Gamma ray	IRB		2013	22559	Iwate University	Short stem; earlier maturity		
Job's tear		*Coix ma-yuen* Roman.										
1	Hato-musume	Okayama Zairai	1980	Gamma ray 20kR	IRB	1992	1993	3634	Tohoku NAES	Early maturing; short stem	159	Okuyama *et al*. (1995)[40]

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2	Hato-hikari	Okayama Zairai	1980	Gamma ray 200Gy	IRB	1995	1996	5069	Tohoku NAES	Early maturing; short stem	2471	Ishida *et al*. (1995)[17)]
Buckwheat		*Fagopyrum esculentum* Moench										
1	Dewa-kaori	Mogami Wase	1988	Colchicine	Yamagata PAES	1995	1996	5069	Yamagata PAES	Larger grain	2472	
2	Hokkai 3 Gou	Botan-soba	1979	Colchicine	NARC for Hokkaido Region	2001	2005	12967	NARO	Tetraploid; large seed	2473	
3	Gamma-no-irodori	Botan-soba		Gamma ray	IRB		2005	22872	IRB, NIAS	Higher rutin content in the seed, smaller seed		
4	Cobalt-no-chikara	Botan-soba		Gamma ray	IRB		2013	22873	IRB, NIAS	Smaller seed		
5	Ruchiking	Botan-soba		Gamma ray (repeated irradiation for the generations)	IRB		2013	22874	IRB, NIAS	Very high rutin content in the seed; smaller seed		
Tartary buckwheat		*Fagopyrum tataricum* (L.) Gaertn.										
1	Daizen	No name		Colchicine	Tokita Seed Company		2010	19044				
2	Hokkai T9 gou	Dattan		Colchicine	NARO		2010	19466	NARO			Suzuki *et al*. (2008)[51)]
3	Hokkai T10 gou	Hokkai T8 gou		Ethyl methane sulfonate (EMS)	NARO		2010	19526	NARO	Pale red flower color; less maturing seed		Suzuki *et al*. (2008)[51)]
4	Shinano Kurotsubu	Bhate Parpar		Colchicine	Shinshu University		2010	19527	Shinshu University			
5	Daruma Dattan	Hokkai T8		Gamma ray	IRB		2013	22633	NIAS (IRB)	Semi-dwarf		
6	Ion-no-kousai	Routundatum		Helium ion beam	JAEA, Takasaki		2013	22634	NIAS (IRB) and JAEA	Shorter stem; light leaf		
Amaranthus		*Amaranthus* L.										
1	New Aztec	Mexico-kei	1989	Gamma ray 50kR	IRB	2001	2006	14399	NARO (National Institute of Crop Science)	Early maturing; short stem	2474	Katsuta *et al*. (2001)[23)]
Rapeseed		*Brassica napus* L.										
1	Haya-natane	Michinoku-natane	1955	Colchicine 0.03× 24h	Fukuoka PAES	1961			Fukuoka PAES	Maturing 3 days earlier than the original variety (earliest of all varieties)	1720	
2	Hanakkori	Wase-kei Saishin×Jyo-	1990	Colchicine treatment	Yamaguchi PAES	1995	1999	7324	Yamaguchi PAES	Morphology	2475	
Soybean		*Glycine max* (L.) Merr.										
1	Raiden	Nemashirazu	1960	Gamma ray 10kR	National Institute of Agricultural Sciences (Hiratsuka)	1966			Tohoku NAES	Earlier maturity (25 days); shorter stem lodging resistance	1594	Laboratory of Soybean Breeding (1970)[26)]

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2	Raiko	Nemashirazu	1960	Gamma ray 10kR	National Institute of Agricultural Sciences (Hiratsuka)	1969			Tohoku NAES	Earlier maturity (15 days); shorter stem lodging resistance	1595	Laboratory of Soybean Breeding (1970)[26)]
3	Wase-suzunari	Oku-shirome	1975	Gamma ray 10kR	IRB	1983	1984	610	Tohoku NAES	Earlier maturity (extremely early)	1597	Hashimoto *et al.* (1985)[8)]
4	Mura-yutaka	Fuku-yutaka	1984	X-ray 24kR	Saga Univ. Facul. Agric.	1988	1990	2156	Saga PAES	From brown hilum to white hilum	2476	Nakamura *et al*. (1991)[36)]
5	Kosuzu	Natto-Kotsubu	1979	Gamma ray 10kR	IRB	1987	1990	2397	Tohoku NAES	Earlier maturity (medium); lodging resistance	1596	Hashimoto *et al*. (1988)[7)]
6	Ryokusui	Fukura	1984	Gamma ray 20kR	IRB	1988	1980	2516	Iwate PAES	Later maturity; brown seed color	1598	
7	Saotome	Aji-ichiban	1986	Gamma ray 15kR	Tokyo Metropolitan Isotope General Research Institute	1991	1994	4055	Mitsui Chemical Ltd.	Yellow seed color; higher pod density	2477	
8	Kokoro-zukushi	Aji-ichiban	1986	Gamma ray 15kR	Tokyo Metropolitan Isotope General Research Institute	1991	1994	4115	Mitsui Chemical Ltd.	Earlier maturity; higher pod density	2478	
9	Murasaki-zukin	Kyoto No. 1 (Shin-Tanba)	1975	Gamma ray 10Gy	Kyoto Univ. Facul. Agric.	1992	1995	4715	Kyoto PARI	Later maturity; for green soybean-use	2479	
10	Ichi-hime	（Kanto No. 2/Kanto No. 1）F2	1989	Gamma ray 15kR	IRB	1996	1997	5369	Kyushu NAES	All lipoxygenase knock-out	2480	Hajika *et al*. (2002)[6)]
11	Taki-hime	Komaki Dadacha	1988	Gamma ray 8kR	IRB	1996	2000	8365	Yanagawa Saisyu Kenkyukai	Shorter stem; high pod density; earlier maturity	2481	
12	Aomori-toyomaru	Kemame （Aomori Local var.）	1989	Gamma ray	IRB	1995	2001	8642	Aomori Prefectural Agriculture and Forestry Research Center	Earlier maturity; shorter stem; ecological mutation （summer-type）	2482	
13	Aomori-fukumaru	Kemame （Aomori Local var.）	1989	Gamma ray	IRB	1995	2001	8643	Aomori Prefectural Agriculture and Forestry Research Center	Earlier maturity; shorter stem; ecological mutation （summer-type）	2483	
14	Akita-midori	Aome-daizu	1990	Gamma ray 10kR	IRB	1998	2002	9650	Akita PAES	Earlier maturity	2484	Sasaki *et al*. (2000)[46)]
15	Yume-minori	Kari-kei No.434	1991	Gamma ray	IRB	2001	2004	12280	Tohoku NAES	Low-allergic	2485	Takahashi *et al*. (2004)[52)]
16	Sayane	Saya-musume	1995	Gamma ray	IRB	2002	2006	13749	Snow Brand Ltd.	Earlier maturity; shorter main stem length	2487	
17	Akita-honoka	Hiden		Somaclonal variation from somatic embryo	Akita PAES		2015	24350	Akita PAES	Earlier maturity; larger bean size		Sato *et al.* (2015)[47)]

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Adzuki bean		*Vigna angularis* (Willd.) Ohwi & H. Ohashi										
1	Beni-nambu	Monbetsu No.26	1968	Gamma ray 10kR	IRB	1978			Iwate PAES	Earlier maturity (10 days)	406	Satoh *et al* . (1982)[48)]
Broad bean		*Vicia faba* L.										
1	Rin-rei	Niigata Zairai one-bean type	1982-8	Gamma ray irradiation (recurrent irradiation)	Tokyo Metropolitan Isotope General Research Institute	1988	1991	2695	Hokuetsu Nouji Co.	Dwarf	2490	
Sweet potato		*Ipomoea batatas* (L.) Lam.										
1	Sweet Garden	CN1367-2	1990	Gmma-ray irradiation to tissue culture	Kagoshima Biotechnology Institute	1993	1998	6390	Miwa Green Co.	Leaf-shape	2491	
Potato		*Solanum tuberosum* L.										
1	White Baron	Danshaku	1989	Protoplast culture	Hokuren	1985	1997	5965	Hokuren	Less browning after cutting	2492	
2	Jagakids Purple	Neo Delicious	1986	Protoplast culture	Plant Laboratory, Kirin Brewery Co., Ltd.	1990	1994	4054	Plant Laboratory, Kirin Brewery Co., Ltd.		2493	
Sugarcane		*Saccharum officinarum* L.										
1	Nan-ei	Ni1	1976	Gamma ray to the plant	IRB	1985	1986	1024	Kagoshima University; Faculty of Agriculture	Larger plant size; High-yielding	375	
Chinese matgrass		*Cyperus malaccensis* Lam. ssp. *monophyllus* (Vahl) T. Koyama										
1	Toyo-midori	Ohoi 2 Gou	1969	Gamma ray to plant 115kR	IRB	1979			Ooita Prefectural Igyou Shidousyo	Thicker stem; lodging tolerance; resistance to fungal disease	373	
Rush		*Juncus effusus* L. var. *decipiens* Buchenau										
1	Seto-nami	Asa-nagi	1963	Gamma ray to plant 68kR	IRB	1982	1983	397	Hiroshima PAES, Rush Breeding Station	More longer stems; High yielding; good quality; beautiful straws	345	Sadahira *et al* . (1982)[41)]
2	Fuku-nami	Asa-nagi	1965	Gamma ray to plant 96kR	IRB	1984	1986	941	Hiroshima PAES, Rush Breeding Station	Early-harvest and high yielding; less browning of leaf tops; stronger straw	346	Sadahira *et al* . (1984)[42)]
3	Chikugo-midori	Iso-nami	1989	Meristem culture	Fukuoka ARC	1997	2001	9033	Fukuoka ARC	More long stem number; higher weight of total long stems	2494	Nakahara *et al* . (1998)[34)]
Lettuce		*Lactuca sativa* L.										
1	Evergreen	Waya-head	1959	^{32}P100μCi and gamma ray 42kR	Hyogo PAES	1966			Hyogo PAES	Later volting under high summer temperature	2219	

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2	Giant Green	Waya-head	1959	^{32}P	Hyogo PAES	1966			Hyogo PAES	More heat tolerance	2220	
3	Satilo	Empire	1990	EMS	Sumitomo Chemical company	1992	1995	4778	Sumitomo Chemical Co.	Shrunken leaf; wave in leaf edge	2495	
Japanese parsley		*Oenanthe javanica* (Blume) DC.										
1	Miyagi VWD 1 Gou	Shimane-midori	1994	Protoplast culture	Miyagi Prefectural Agriculture and Horticulture Research Center	1996	2002	10071	Miyagi Prefectural Agriculture and Horticulture Research Center	Resistant to leaf disease	3163	
Butterbur		*Petasites japonicus* (Siebold & Zucc.) Maxim.										
1	Okayama Nohshi B1 Gou	Aichi-wase	1985	Callus (meristem)	Okayama PAES	1992	1996	5017	Okayama PAES	Less anthocyanin in leaf stem	3164	Hikawa *et al*. (1998)[9)]
Tomato		*Solanum lycopersicum* L.										
1	Kyoryoku-reikou	Syugyoku	1967	Gamma ray irradiation to pollen 2340R	IRB	1974			Musashi Breeding Station Co.	Resistant to TMV and wilt disease	2221	
Strawberry		*Fragaria* L.										
1	Shin-Nyohou	Nyohou	1963	Callus formation	Tochigi PAES, Tochigi Branch	1989	1989	2048	Tochigi PAES, Tochigi Branch	Earlier harvest type; high yielding	3213	
2	Akita Berry	Morioka 16 Gou	1967	Meristem culture	Akita Prefectural College of Agriculture	1990	1992	3224	Akita Prefectural College of Agriculture	Resistant to black leaf spot disease (*Alternaria alternata*)	3214	
3	Anther	Nyohou	1986	Anther culture	Ibaraki PAES	1991	1994	4176	Ibaraki PAES	Early maturing	3215	Ezura *et al*. (1998)[2)]
4	Himatsuri	Toyonoka	1988	Meristem culture	Kyushu Tokai University	1992	1995	4593	Kyushu Tokai University	Bright red fruit skin; light red flesh color	3216	Fukuoka *et al*. (1996)[3)]
5	Smile Heart	Ai-berry	1993	Tissue culture	Shikoku Research Institute Inc.	1994	1998	6563	Shikoku Research Institute Inc.	Resistant to phytophthora rot (*Phytophthora nicotinae*)	3217	
Burdock		*Arctium lappa* L.										
1	Cobalt Wase	Yanagawa-risou	1969	Gamma ray 10kR	IRB	1978	1981	73	Yanaken Co.	Earlier root growth; earlier maturing (growing days: 120 days)	2218	
2	Cobalt Goku-wase	Yanagawa-nakate	1969	Gamma ray 10kR	IRB	1978	1981	74	Yanaken Co.	Shorter root; extremely early maturing (growing days 100 days)	2216	
3	Cobalt Okute	Yanagawa-nakate	1969	Gamma ray 10kR	IRB	1978	1981	75	Yanaken Co.	Less pithy tissue; higher storability; late maturing	2217	
4	Tsune-yutaka	Yanagawa-risou	1969	Gamma ray 10kR	IRB	1984	1986	1233	Yanaken Co.	Thicker root; thick at upper root	2225	

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5	Tegaru	Cobalt Goku-wase	1982	Gamma ray 10kR	Tokyo Metropolitan Isotope General Research Institute	1991	1995	4422	Yanaken Co.	Shorter root; thick at upper root	2496	
Taro		*Colocasia esculenta* Schott										
1	Fukugashira	Yatsugashira	1984	MNU	Saga University, Faculty of Agriculture	1989	1992	3172	Saga PAES	Round mother corm; higher cooking and processing suitability	2497	
2	Chiba-maru	Dotare	1995	Soft X-ray	Chiba PAES	2004	2007	15137	Chiba PAES	Tuber shape	2901	Suzuki *et al*. (2006)[50)]
3	Ehime-Noushi V2 gou	Onna-wase	1994	Callus from meristem part	Ehime PAES	2000	2008	16024	Ehime PAES	Number and size of grand-son tuber is larger		Nakagawa *et al.* (2015)[33)]
Wasabi (Japanese horseradish)		*Wasabia japonica* (Miq.) Matsum.										
1	Green Magic	Matsuma	1991	Meristem culture	Miyoshi Co.	1993	1997	5312	Miyoshi Co.	Longer stem; less anthocyanin at leaf stem; light color at root stem; stronger bitterness		
2	Amagi-nishiki	Matsuma	1988	Tissue culture	Miyoshi Co.	1991	1998	6030	Miyoshi Co.	Less pithy tissue	3219	
Scarlet runner bean		*Phaseolus coccineus* L.										
1	Shiro-hanakko	Oo-shirohana	1991	Gamma ray		2002	2002	14409	Hokkaido Prefectural Central Agriculture Experiment Station	Higher pod width		Minami, M. and H. Sato (2009)[29)]
Limonium		*Limonium* Mill.										
1	Tall Pink Emirre	Tall Emirre	1962	Gamma ray	Tokyo Metropolitan Isotope General Research Institute	1993	1998	6100	Miyoshi Co.	Petal color: pale pink	3181	
2	Neo Misty Blue	Misty Blue	1990	Gamma ray	Tokyo Metropolitan Isotope General Research Institute	1994	1998	6101	Miyoshi Co.	Less number of floral stalks	3182	
3	Daifura Lavender	Daifura Pink	1992	Gamma ray irradiation to tissue culture	Tokyo Metropolitan Isotope General Research Institute	1995	1999	7104	Daiichi Seed Co., Ltd.	Sepal color: bright reddish purple	3183	
4	Daifura Pink Super	Daifura Pink	1992	Gamma ray irradiation to tissue culture	Tokyo Metropolitan Isotope General Research Institute	1995	2000	7938	Daiichi Seed Co., Ltd.	Sepal color: bright purple; less number of floral stalks	3184	
5	Dai-lady Rose	Super Lady	1991	Gamma ray irradiation to tissue culture	Tokyo Metropolitan Isotope General Research Institute	1996	2000	8490	Daiichi Seed Co., Ltd.	Petal color: vivid yellowish green	3185	
6	Dai-lady White	Super Lady	1991	Gamma ray irradiation to tissue culture	Tokyo Metropolitan Isotope General Research Institute	1996	2001	8971	Daiichi Seed Co., Ltd.	Sepal color: pinkish white	3186	

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Showy baby's breath		*Gypsophyla elegans* M. Bieb.										
1	Kishu Kasumi 1 Gou	Perfecta	1989	Meristem culture	Wakayama Research Center of Agriculture, Forestry and Fisheries	1994	2000	7762	Wakayama Research Center of Agriculture, Forestry and Fisheries	More wax on the leaf surface; top of the petal, V-shape	3220	Miyamoto *et al*. (2003)[30)]
2	Buranka	Diamond	1993	Gamma ray	Tokyo Metropolitan Isotope General Research Institute	1997	2002	9667	Miyoshi Co.	Sepal shape	3165	
3	Ayami	Bristle Fairy	1993	Colchicine	Sumitomo Chemical company	1993	1999	7094	Sumitomo Chemical Company	Shorter internode length; more petal number	3166	
Gymnaster		*Aster savatieri* Makino										
1	Seto-no-otome	Hama-otome	1991	Gamma ray irradiation to meristem culture	IRB	1994	1998	6896	Minoru Industrial Co., Ltd.	More ligulose flowers; deep flower color	3167	
2	Minoru-otome	Hama-otome	1990	Gamma ray	IRB	1995	2000	7831	Minoru Industrial Co., Ltd.	Flower shape; flower color: bright reddish purple	3168	
Prairie gentian		*Eustoma grandiflorum* (Raf.) Shinners										
1	Purple Robin	Pastel Murasaki	1992	Gamma ray	IRB	1995	1999	7266	IRB and Naganoken Nourin	Small-flowered; spray type	2004	
2	Red Robin	Morugen Rhoto	1992	Gamma ray	IRB	1995	1999	7267	IRB and Naganoken Nourin	Small-flowered; spray type	2006	
3	Tokyo E1 gou	Crystal Yellow		Gamma ray	Tokyo Metropolitan Agriculture and Forestry Research Center	2011	2015	24321	Tokyo Metropolitan Agriculture and Forestry Research Center			Miyashita *et al*. (2014)[31)]
4	Izu-Ohshima E3 gou	Tenryu Otome		Gamma ray	Tokyo Metropolitan Agriculture and Forestry Research Center	2005	2009	18330	Tokyo Metropolitan Agriculture and Forestry Research Center			Miyashita *et al*. (2014)[31)]
Carnation		*Dianthus caryophyllus* L.										
1	Scarlet Bell	Angel	1977	Gamma ray 31kR	Tokyo Metropolitan Isotope General Research Institute	1980	1983	379	Miyoshi Co.	Flower color: from deep pink to red	53	
2	Mrs. Elegant	SP	1996	Tissue culture	Plant Laboratory, Kirin Brewery Co., Ltd.	1997	2001	9247	Plant Laboratory, Kirin Brewery Co., Ltd.	Small flowered; smaller number of flowers per flower stalk	2498	
3	Boh-red	Nora	1995	Meristem culture	Akita Prefectural Agriculture, Forestry and Fisheries	1998	2002	10550	Akita Prefectural Agriculture, Forestry and Fisheries	Flower color: vivid red	2499	

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4	Kirikami Red (Mrs. Red)	Mrs. Elegant	1997	Tissue culture	Plant Laboratory, Kirin Brewery Co., Ltd.	1999	2002	10926	Plant Laboratory, Kirin Brewery Co., Ltd.	Surface of flower: deep orange red	2500	
5	Garden Spice carnation Salmon (Kirinade Salmon)	Garden Spice carnation Cool Pink	1998	X-ray to tissue culture	Plant Laboratory, Kirin Brewery Co., Ltd.	1999	2004	12103	Plant Laboratory, Kirin Brewery Co., Ltd.	Flower surface: vivid pink	3169	
6	Garden Spice carnation Pink (Kirinade Cool Pink)	Garden Spice carnation Cool Pink	1998	X-ray to tissue culture	Plant Laboratory, Kirin Brewery Co., Ltd.	1999	2004	12103	Plant Laboratory, Kirin Brewery Co., Ltd.	Flower color: pale pink	2502	
7	Your Red	Nora	1995	Meristem culture	Akita Prefectural Agriculture, Forestry and Fisheries	2000	2005	13051	Akita Prefectural Agriculture, Forestry and Fisheries	Flower color: vivid red; suspended flower; large flower	2503	Arai (2001)[1)]
8	Garden Spice carnation Marble (Kirinade Marble)	Garden Spice carnation pearl White	1995	X-ray to tissue culture	Plant Laboratory, Kirin Brewery Co., Ltd.	2000	2005	13052	Plant Laboratory, Kirin Brewery Co., Ltd.	Flower color: pinkish white with vivid purple red stripe	2504	
9	Misty Pink Vital Ion	Vital	2000	C ion beam on regenerating callus	JAEA, Takasaki	2002	2005	13585	Plant Laboratory, Kirin Brewery Co., Ltd.	Flower color; petal shape	2505	
10	Dark Pink Vital Ion	Vital	2000	C ion beam on regenerating callus	JAEA, Takasaki	2002	2005	13586	Plant Laboratory, Kirin Brewery Co., Ltd.	Flower color; petal shape	2506	
11	Red Vital Ion	Vital	2000	C ion beam on regenerating callus	JAEA, Takasaki	2002	2005	13587	Plant Laboratory, Kirin Brewery Co., Ltd.	Flower color: bright red	2507	
12	Red Vital	Vital	2001	C ion beam on the leaf	JAEA, Takasaki	2004	2008	16064	Barbre & Branc S. A	Double flower with bright red color		
13	Beam Cherry	Vital		C ion beam on the leaf	JAEA, Takasaki		2009	17297	Barbre & Branc S. A	Flower color		Okamura *et al* . (2006)[39)]
14	Loro Red	Loro		Gamma ray	IRB	2007	2010	19121	Miyazaki Prefecture	Early flowering; flower color		http://www.pref.miyazaki.lg.jp/contents/org/nosei/mae-station/topics/21.html
15	Loro Pink	Loro		Gamma ray	IRB	2007	2010	19122	Miyazaki Prefecture			http://www.pref.miyazaki.lg.jp/contents/org/nosei/mae-station/topics/21.html
Clematis		*Clematis* L.										
1	Pastorale	Hakuba	1986	Gamma ray 2kR	IRB	1989	1992	3130	Mr. Fukutarou MIYATA	Flower color; flower shape	3170	
2	Nachtmusik	Hakuba	1986	Gamma ray 2kR	IRB	1989	1992	3131	Mr. Fukutarou MIYATA	Flower color; flower shape (double flowered)	3171	

No.	Cultivar Name	Original Cv. or Line	Treat. Year	Treatment	Treated Institution	Dev. year	Reg. Year	Reg. No.[a]	Institution of Development	Improved Characteristics	IAEA ID[b]	Reference
Chrysanthemum	*Chrysanthemum* x *morifolium* Ramat.											
1	Ki-uzushio	Uzushio	1962	Gamma ray 2.5kR	IRB	1983	1986	1044	Seikoen Ltd.	Flower color: from white to yellow	1987	
2	Baiogiku Rainbow White	Seikou-no-kurenai	1983	Gamma ray	IRB	1985			Seikoen Ltd.	Flower color: from red to white	1991	
3	Baiogiku Rainbow Yellow	Seikou-no-kurenai	1983	Gamma ray	IRB	1985			Seikoen Ltd.	Flower color: from red to yellow	1993	
4	Baiogiku Rainbow Peach	Seikou-no-kurenai	1983	Gamma ray	IRB	1985			Seikoen Ltd.	Flower color: from red to rose color	1988	
5	Baiogiku Rainbow Pink	Seikou-no-kurenai	1983	Gamma ray	IRB	1985			Seikoen Ltd.	Flower color: from red to pink	1990	
6	Baiogiku Rainbow Orange	Seikou-no-kurenai	1983	Gamma ray	IRB	1985			Seikoen Ltd.	Flower color: from red to reddish yellow	1989	
7	Pink Orizuru	Orizuru	1986	Gamma ray	IRB	1988	1990	2537	Seikoen Ltd.	Flower color: from white to pink	1997	
8	Hae-no-hatsu-yuki	Taihei	1987	Gamma ray to tissue culture	IRB	1990	1995	4305	IRB and Okinawa PAES	Flower color: yellowish white	2508	
9	Hae-no-kirameki	Taihei	1987	Gamma ray to tissue culture	IRB	1990	1995	4306	IRB and Okinawa PAES	Flower color: yellowish orange	2512	
10	Hae-no-kurenai	Taihei	1987	Gamma ray to tissue culture	IRB	1990	1995	4307	IRB and Okinawa PAES	Flower color: purple pink	2509	
11	Hae-no-miyarabi	Taihei	1987	Gamma ray to tissue culture	IRB	1990	1995	4308	IRB and Okinawa PAES	Flower color: pale yellowish pink	2513	
12	Hae-no-yuugure	Taihei	1987	Gamma ray to tissue culture	IRB	1990	1995	4309	IRB and Okinawa PAES	Flower color: pink	2514	
13	Hae-no-kagayaki	Taihei	1987	Gamma ray to tissue culture	IRB	1990	1995	4310	IRB and Okinawa PAES	Flower color: bright yellow	2515	
14	Iero Sei Roza (Reagan Yellow)	Sei Roza	1989	Gamma ray 2kR	IRB	1992	1997	5398	Seikoen Ltd.	Flower color: bright greenish yellow	2516	
15	Orenji Sei Roza (Reagan Orange)	Sei Roza	1989	Gamma ray 2kR	IRB	1992	1997	5399	Seikoen Ltd.	Flower color: orange	2517	
16	Dipu Sei Roza (Reagan Royal)	Sei Roza	1989	Gamma ray 2kR	IRB	1992	1997	5400	Seikoen Ltd.	Flower color: deep purplish pink	2718	
17	Paru Sei Roza (Reagan Pearl)	Sei Roza	1989	Gamma ray 2kR	IRB	1992	1997	5401	Seikoen Ltd.	Flower color: vivid purplish pink	2519	
18	Howaito Sei Roza (Reagan White)	Sei Roza	1989	Gamma ray 2kR	IRB	1992	1997	5402	Seikoen Ltd.	Flower color: yellowish white	2520	
19	Yellow Prism	Goldstock Bar	1991	Gamma ray to tissue culture	Plant Laboratory, Kirin Brewery Co., Ltd.	1997	1997	5874	Plant Laboratory, Kirin Brewery Co., Ltd.	Erect flower petal; petal color: bright yellow	2521	

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20	Pearl Prism	Goldstock	1992	Tissue culture	Plant Laboratory, Kirin Brewery Co., Ltd.	1993	1997	5875	Plant Laboratory, Kirin Brewery Co., Ltd.	Erect flower petal; more transparent petal	2522	
21	Amazon	Bred line	1992	Gamma ray to tissue culture	Plant Laboratory, Kirin Brewery Co., Ltd.	1998	1998	6167	Plant Laboratory, Kirin Brewery Co., Ltd.	Petal color: deep orange red	2523	
22	Joy Light	Bred line	1992	Gamma ray	IRB	1998	1998	6218	ZEN-NOH		2524	
23	Joy Coral	Bred line	1992	Gamma ray	IRB	1998	1998	6219	ZEN-NOH		2525	
24	Joy Royal	Bred line	1993	Gamma ray	IRB	1998	1998	6220	ZEN-NOH		2526	
25	Joy Apricot	Bred line	1993	Gamma ray	IRB	1998	1998	6221	ZEN-NOH		2527	
26	Royal Wedding Seruengi	Goldstock Rose	1992	Tissue culture	Plant Laboratory, Kirin Brewery Co., Ltd.	1998	1998	6638	Plant Laboratory, Kirin Brewery Co., Ltd.	Flower color: deep purple pink	2528	
27	Joy Light Yellow	Joy Light Salmon	1994	Gamma ray	IRB	1994	1999	7096	ZEN-NOH	Flower color: pale yellow	2529	
28	White Lineker OW-1	Goldstock Lineker	1995	X ray to tissue culture	Plant Laboratory, Kirin Brewery Co., Ltd.	2000	1998	8318	Plant Laboratory, Kirin Brewery Co., Ltd.	Flower color: white	2530	
29	Jey Prelude Apricot	Joy prelude Pink	1995	Gamma ray	IRB	1996	2000	8477	ZEN-NOH		2531	
30	Joy Prelude Coral	Joy prelude Pink	1995	Gamma ray	IRB	1996	2000	8479	ZEN-NOH		2532	
31	Etenraku	Kotobuki	1992	Tissue culture	Yamagata Prefectural Horticulture Experiment Station	1997	2001	8867	Yamagata Prefectural Horticulture Experiment Station	Shorter stem	2533	
32	Pretty Wedding	Royal Wedding	1996	X ray to tissue culture	Plant Laboratory, Kirin Brewery Co., Ltd.	2001	2001	8878	Plant Laboratory, Kirin Brewery Co., Ltd.	Flower color (bi-color; outside: pink; inside: white)	2534	
33	Remukoiero (Remco Yellow)	Remco	1995	Radiation	Kinki University	1998	2001	9570	Seikoen ltd.		2535	
34	Ray Sunrise	Erias	1991	Soft X ray	Shizuoka PAES	1997	2002	10538	Shizuoka PAES	Petal color (abaxial: orange; adaxial: yellow)	2536	Yamada *et al*. (1999)[54)]
35	Dreaming	Dream Nurse	1993	Soft X ray 200Gy	Shizuoka PAES	2000	2004	12420	Shizuoka PAES	Flower color: from white to yellow	2537	Yamada *et al.* (2002)[55)]
36	Princess Kagawa	Pink Seiko	1997	Tissue culture + X ray	Kagawa PAES	2001	2004	12415	Kagawa PAES	Stem color and petal color: reddish purple	2538	Furuichi *et al*. (2003)[4)]
37	Emi-akari	Sei-un	1997	Soft X ray irradiation to meristem culture	Aomori Prefectural Agriculture and Forestry Research Center	2003	2006	14099	Aomori Prefectural Agriculture and Forestry Research Center	Ligulate petal color: pale greenish yellow		

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38	Arajin (Araddin)	Jimba	2001	Ion beam irradiation to leaf	JAEA, Takasaki	2003	2006	14118	Kagoshima PAES	Reduction of axillary bud number (Farmers do not need to cut many axillary bud to produce one large flower)	2540	Imakiire *et al*. (2006)[13)]
39	Imajin (Imagine)	Jimba		Ion beam irradiation to leaf	JAEA, Takasaki	2003	2006	14119	Kagoshima PAES	Reduction of axillary bud number (Farmers do not need to cut many axillary bud to produce one large flower)	2541	Imakiire *et al*. (2005)[13)]
40	Hae-no-eikou	Taihei		Tissue culture of flower petals from plants irradiated in the Gamma Field were regenerated	IRB	2002	2006	14563	IRB	Petal color	3409	
41	Hae-no-myojyo	Taihei		Tissue culture of flower petals from plants irradiated in the Gamma Field were regenerated	IRB	2002	2006	14564	IRB	Petal color	3416	
42	Hae-no-yumeguruma	Taihei		Tissue culture of flower buds from plants irradiated in the Gamma Field were regenerated	IRB	2002	2006	14565	IRB	Petal shape and color	3417	
43	Hae-no-awabeni	Taihei		Callus generated from leaves was irradiated with gamma ray	IRB	2002	2006	14566	IRB	Petal color	3418	
44	Ion-no-koumyo	Taihei		Callus generated from petals was irradiated with a carbon ion beam	JAEA, Takasaki	2002	2006	14567	IRB and JAEA, Takasaki	Petal color	3395	
45	Ion-no-seikou	Taihei		Callus generated from petals was irradiated with a carbon ion beam	JAEA, Takasaki	2002	2006	14568	IRB and JAEA, Takasaki	Petal color	3396	
46	Ion-no-hatsune	Taihei		Callus generated from petals was irradiated with a carbon ion beam	JAEA, Takasaki	2002	2006	14569	IRB and JAEA, Takasaki	Petal color	3398	

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47	Ion-no-kouki	Taihei		Callus generated from petals was irradiated with a carbon ion beam	JAEA, Takasaki	2002	2006	14570	IRB and JAEA, Takasaki	Petal color	3399	
48	Ion-no-mahou	Taihei		Callus generated from petals was irradiated with a neon ion beam	JAEA, Takasaki	2002	2006	14571	IRB and JAEA, Takasaki	Petal color	3400	
49	Sei-faust-cream	Sei-faust		Gamma ray	IRB	2007	2010	19333	Seikoen Ltd.	Petal color: 155A		
50	Sei-piaje-white	Piaje		Gamma ray	IRB	2007	2010	19185	Seikoen Ltd.	Petal shape		
51	Sei-piaje-pink	Piaje		Gamma ray	IRB	2007	2010	19186	Seikoen Ltd.	Petal color: 187C		
52	Sei-piaje-yellow	Piaje		Gamma ray	IRB	2007	2010	19187	Seikoen Ltd.	Petal color: 9A		
53	Sei-rocket-yellow	A developed line		Gamma ray	IRB	2007	2010	19335	Seikoen Ltd.	Flower disc color: 144B		
54	Sei-patrick-yellow	Sei-patrick		Gamma ray	IRB	2007	2010	19336	Seikoen Ltd.	Flower color (182A); shape (flower disc is smaller)		
55	Sei-patrick-sermon	Sei-patrick		Gamma ray	IRB	2007	2010	19337	Seikoen Ltd.	Flower color: 49D		
56	Sei-roys-yellow	Sei-bingo		Gamma ray	IRB	2007	2010	19003	Seikoen Ltd.	Flower color: 4A		
57	Arajin 2 (Aladdin 2)	Arajin		Ion beam	JAEA, Takasaki	2007	2010	19096	Kagoshima PAES	Fewer flower buds		Ueno *et al*. (2013)[53)]
58	Lemon smile	Egao		Soft X-ray	Aomori Prefectural Agriculture and Forestry Research Center	2011	2013	22281	Aomori Prefectural Agriculture and Forestry Research Center and Seikoen Ltd.	Flower color (cream)		
59	Akebono-no-mai	Taihou-senryu		Soft X-ray irradiation to shoot-apex culture	Aomori Prefectural Agriculture and Forestry Research Center	2014	2016	24889	Aomori Prefectural Agriculture and Forestry Research Center and Seikoen Ltd.			
60	Akane-no-mai	Taihou-senryu		Soft X-ray irradiation to shoot-apex culture	Aomori Prefectural Agriculture and Forestry Research Center	2014	2016	24890	Aomori Prefectural Agriculture and Forestry Research Center and Seikoen Ltd.			
Lily		*Lilium* L.										
1	Rosetone	Rohto-horun	1987	Gamma ray	Tokyo Metropolitan Isotope General Research Institute	1992	1998	6608	Hanano-Yamato Co.	Leaf shape: ellipse	3172	

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2	Light Memory	Rohto-horun	1987	Gamma ray	Tokyo Metropolitan Isotope General Research Institute	1992	1998	6609	Hanano-Yamato Co.	Petal color: pale pink; deep purple stripe in the center rib of petal	3173	
3	Ivory Memory	Rohto-horun	1988	Gamma ray to tissue culture	Tokyo Metropolitan Isotope General Research Institute	1993	1998	6610	Hanano-Yamato Co.	Petal color: pale orange yellow	3174	
4	Coral Bouquet	Rohto-horun	1987	Gamma ray	Tokyo Metropolitan Isotope General Research Institute	1993	1999	7544	Hanano-Yamato Co.	No pollen production; smaller stem, umbel	3175	
Cymbidium		*Cymbidium* Sw.										
1	Cocktail Dress	Inasa	1987	Tissue culture (mericlone)	Purchase	1992	1997	5707	Mr. Makoto MATSUO	Color and shape of petal	3221	
Kalanchoe		*Kalanchoe* Adans.										
1	Harvest Moon	*K. miniata/K. polyphyloukaricus*	1985	Gamma ray	IRB	1992	1996	5148	Mr. Isao KOBAYASHI	Flower shape	2542	
Caladium		*Caladium* Vent.										
1	Soyogi	Candydam	1991	X ray	Kagoshima PAES	1993	2000	8250	Kagoshima PAES		3176	
Petunia		*Petunia* Juss.										
1	Kirimaji Cherry Red (Cherry Red Wave)	Kirimaji (Purple Wave)	1998	X-ray to protoplast culture	Plant Laboratory, Kirin Brewery Co., Ltd.	2000	2004	12082	Plant Laboratory, Kirin Brewery Co., Ltd.	Monotone flower color: vivid red	3177	
2	Sun-lobein	Revolution brilliant pink		Heavy ion beam irradiation to callus developed from axillary buds	Riken	2001	2006	13913	Suntory Flowers ltd and Keisei Rose Co.	Flower color: JHS color chart 9507		
3	Seto-fuku-white-bariegata	A developed line		Ion beam	The Wakasawan Energy Research Center	2007	2009	17653	Hakusan International Co. and The Wakasawan Energy Research Center	Flower color and plant type		
4	Hamapetu 3 gou	Calen Beach		X-ray	Shizuoka PAES	2007	2010	18926	The Yokohama nursery Co.	Flower color: 76C		
5	Sunsurfsirou	An original line		Radiation		2007	2014	23217	Suntory Flowers Ltd.			
Begonia		*Begonia* L.										
1	Ryoku-ha	Winter Queen	1966	Gamma ray 10kR	Tokyo Metropolitan Isotope General Research Institute	1976	-	-	Tokyo Metropolitan Industrial Technology Research Institute	Leaf color; variation in leaf spot; higher ozone/oxidant sensitivity	1985	

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2	Ginsei	Winter Queen	1966	Gamma ray 10kR	Tokyo Metropolitan Isotope General Research Institute	1976	-	-	Tokyo Metropolitan Industrial Technology Research Institute	Leaf color; variation in leaf spot	1981	
3	Orange Iron	Iron Cross	1971	Gamma ray 0.5kR	Tokyo Metropolitan Isotope General Research Institute	1976	-	-	Tokyo Metropolitan Industrial Technology Research Institute	Leaf color; leaf shape; brown purple iron-cruciate leaf spot	1984	
4	Mini-mini Iron	Iron Cross	1971	Gamma ray 1kR	Tokyo Metropolitan Isotope General Research Institute	1976	-	-	Tokyo Metropolitan Industrial Technology Research Institute	Dwarf; leaf spot; leaf shape	1983	
5	Big Cross	Iron Cross	1971	Gamma ray 3kR	Tokyo Metropolitan Isotope General Research Institute	1976	-	-	Tokyo Metropolitan Industrial Technology Research Institute	Leaf color; variation in leaf spot; larger iron-cruciate spot	1980	
6	Kaede Ion	Iron Cross	1972	Gamma ray 10kR	Tokyo Metropolitan Isotope General Research Institute	1976	-	-	Tokyo Metropolitan Industrial Technology Research Institute	Leaf shape; variation in leaf spot; reddish brown maple leaf shaped spot	1982	
Regal pelargonium		*Pelargonium* L'Her. ex Ait.										
1	Capri Ice	Strawberry Thunder	1976	Petal culture	Ehime University	1985	1988	1096	Daiichi Seed Co., Ltd.		3222	
2	Capri Lullaby	Strawberry Thunder	1976	Anther culture	Ehime University	1985	1986	1098	Daiichi Seed Co., Ltd.		3223	
Sonerila picta		*Sonerila* Roxb.										
1	Splash	Sonerila picta korth	1995	Chemical	Kansai TEC Co.	1997	2003	11451	Kansai TEC Co.	More spot on leaves	3178	
Glossy abelia		*Abelia* R. Br.										
1	Meihan Hane-tsukubane-utsugi	Hana-tsukubane-utsugi	1972	Gamma ray 3kR	Tokyo Metropolitan Isotope General Research Institute	1976	-	-	Tokyo Metropolitan Industrial Technology Research Institute	Leaf spot; slightly dwarf	1978	
Japanese azalea		*Rhododendron indicum* (L.) Sweet										
1	Cobalt	Takasago	1964	Gamma ray 5kR	National Institute of Agricultural Sciences (Hiratsuka)	1972	-	-	Tochigi PAES	More branching; dwarf (useful for bonsai)	1986	
Rose		*Rosa* L.										
1	Bridal Sonia	Sonia	1979	Gamma ray to plant 15kR	IRB	1982	1985	801	Kanagawa Prefectural Horticulture Experiment Station	Flower color: from salmon to pale pink	1994	
2	San Jol	Santa Monica	1985	Gamma ray	IRB	1987	1990	2264	Mr. Yuitsu MIZUTANI	Flower color: vivid purple pink	2543	

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3	Ohmiya-bito	Queen Elizabeth	1964	Gamma ray	IRB	1976	1990	2384	Keisei Rose Nurseries, Inc.	Flower color: from pink to pinkish white	1996	
4	Miss Ohmiya	Queen Elizabeth	1964	Gamma ray	IRB	1976	1990	2385	Keisei Rose Nurseries, Inc.	Flower color: from pink to vivid pink	1995	
5	Banbina	Green Eyes	1987	Chemical	KYOWA	1989	1995	4274	KYOWA	Flower color: pale pink	2544	
6	Ichi-anda	Asami Red	1983	Chemical	Mishima-shi	1996	2000	8349	Mr. Keiichi ICHIKAWA	Small leaf; thread type	2545	
7	Ichi-runa	Aarus Mail Goal	1994	Chemical	Mishima-shi	1996	2000	8350	Mr. Keiichi ICHIKAWA	Flower color and shape	2546	
8	Ichi-jiru	Ichity	1994	Gamma ray	Tokyo Metropolitan Isotope General Research Institute	1997	2001	8704	Mr. Keiichi ICHIKAWA	Flower color and shape	2547	
9	Hitachi Smile	Samantha	1990	Gamma ray	IRB	2002	2007	15714	IRB and Okinawa Prefecture	Flower color and shape		
10	Hitachi Poeny	Samantha	1990	Gamma ray	IRB	2002	2007	15715	IRB and Okinawa Prefecture	Flower color and shape		
Oncidium		*Oncidium* Group										
1	Gold One	Gower Ramsey	1986	Mericlone culture	Mr. Masayoshi SHIMOKAWA	1992	1995	4463	Mr. Masayoshi SHIMOKAWA	Flower color		
2	Sherley Baby White Flush Rika	Sherley Baby Sweet Fragrance	1988	Mericlone culture	Mr. Saneharu MATSUMOTO	1990	1997	5601	Mr. Saneharu MATSUMOTO	Flower color		
Salvia		*Salvia splendens* Ker Gawl.										
1	Magunasu Cherry	Cherry Sage	2001	Colchicine	Toyota Motor Cooperation	2003	2006	14059	Toyota Motor Cooperation	Larger petal		
2	TL585	Lady In red		Ion beam irradiation to seed	JAEA, Takasaki	2012	2015	24473	Takii & Co, Ltd.	Shorter stem		
Delphinium (larkspur)			*Delphinium* L.									
1	Star Dust	Bluecloud	1996	Colchicine	Toyama City Agriculture Center	1996	2001	8746	Toyama City Agriculture Center	Larger petal; leaf shape		
2	Sunny Sky	Plage Sky Blue	1988	Tissue culture	Kaneko Seeds	2000	2005	12735	Kaneko Seeds	Shorter plant; shorter inflorescence		
Torenia (wishbone flower)			*Torenia* L.									
1	San-reniramu	San-renimu	1998	Colchicine chromosome doubling	Suntory Flowers Ltd.	1999	2004	12092	Suntory Flowers Ltd.	Plant type: stoloniferous; flower color	3187	
2	San-renirahopasu	San-renihopasu	1998	Colchicine chromosome doubling	Suntory Flowers Ltd.	1999	2004	12093	Suntory Flowers Ltd.	Flower color of labium: uniformly colored	3188	

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3	San-reniraba	San-renireba	1999	Colchicine chromosome doubling	Suntory Flowers Ltd.	2000	2005	12993	Suntory Flowers Ltd.	Flower color of labium: uniformly colored	3189	
4	Sunreniripin	A developed line		Ion beam	Riken (Wako)	2007	2010	19301	Suntory Flowers Ltd.	Petal color: 72B		
5	Sunreniripihokai	Sunrenipiho		Colchicine	Suntory Flowers Ltd.	2003	2013	22609	Suntory Flowers Ltd.	Earlier flowering		
6	Sunrekodou	A developed line		Heavy ion beam	Riken (Wako)	2011	2013	22611	Suntory Flowers Ltd.	Petal color: 8B		
Margaret		Argyranthemum *frutescens* (L.) Sch. Bip.										
1	Star Light Ripple	Zairai-shiro	1998	Soft X-ray to immature ovary culture	Shizuoka PAES	2002	2005	12779	Shizuoka PAES	Shorter plant type; larger stock		
2	Angel Maisu	not written	2002	Soft X ray to cuttings	Shizuoka PAES	2003	2006	14146	Shizuoka PAES	Flower color		
3	Southern Venus White	An original line	2002	Soft X ray to plants	Shizuoka PAES	2005	2007	14971	Shizuoka PAES			
4	Canary Queen	Peach Queen	2003	Soft X ray to plants	Shizuoka PAES	2005	2007	14992	Shizuoka PAES	Ligulate flower color change		http://www.geocities.jp/yunakisaragi/x-ma-garetto-kanariakuiin.html (in Japanese)
Lavender		*Lavandula angustifolia* Mill.										
1	Cosmic Blue	Yuulong	1998	Tissue culture of leaf	Kyoto Prefectural University	2001	2006	14044	SAKATA SEED CORPORATION	Plant type: spreading; color of calyx: deep purple; more flowers in the inflorescence		
Cytisus (Scotch broom)			*Cytisus scoparius* (L.) Link									
1	Mei Shower	Crimson King	1990	Gamma ray to tissue culture	IRB	1993	1998	7027	IRB and Meiji Seika Kaisha, Ltd.	Extremely short plant; flower color: vivid yellow	3190	
2	Mei Wako	Crimson King	1990	Gamma ray to embryo culture	IRB	1993	1998	7028	IRB and Meiji Seika Kaisha, Ltd.	Extremely short plant; flower color: ground color: pale yellow; brown, deep purple pink	3191	
3	Mei Rose	Crimson King	1990	Gamma ray to embryo culture	IRB	1993	1998	7029	IRB and Meiji Seika Kaisha, Ltd.	Medium plant height; flower color: ground color: pale greenish yellow, brown purple pink	3192	
4	Mei Eve	Crimson King	1990	Gamma ray to embryo culture	IRB	1994	1998	7030	IRB and Meiji Seika Kaisha, Ltd.	Extremely short plant; flower color: ground color: pinkish white, brown reddish purple	3193	

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5	Mei Hiro	Crimson King	1990	Gamma ray to embryo culture	IRB	1993	2002	10948	IRB and Meiji Seika Kaisha, Ltd.	Outer standard ground color: rainbow; outer wing color: deep reddish brown	3194	
6	Mei Samson	Park Woody	1990	Gamma ray	IRB	1993	2002	10949	IRB and Meiji Seika Kaisha, Ltd.	Outer wing color: several colors; small wing	3195	
7	Mei Fanny	Crimson King	1990	Gamma ray to embryo culture	IRB	1997	2002	10950	IRB and Meiji Seika Kaisha, Ltd.	Outer standard and wing ground color: deep red	3196	
8	Mei Lord	Crimson King	1990	Gamma ray to embryo culture	IRB	1997	2002	10951	IRB and Meiji Seika Kaisha, Ltd.	Outer keel color: brown; wide keel	3197	
Abelmoschus		*Abelmoschus manihot* Medik										
1	Hiroshima Local No. 1	Hiroshima Zairai	1956	Gamma ray 0.5kR	Kyoto University	1967	−	−	Kagawa University	Higher resistance to phytophthora rot	341	
2	Hiroshima Local No. 3	Hiroshima Zairai	1956	Gamma ray 0.5kR	Kyoto University	1967	−	−	Kagawa University	Higher resistance to phytophthora rot	342	
3	Hiroshima Local No. 5	Hiroshima Zairai	1956	Gamma ray 0.5kR	Kyoto University	1967	−	−	Kagawa University	Higher resistance to phytophthora rot	343	
4	Hiroshima Local No. 8	Hiroshima Zairai	1956	Gamma ray 0.5kR	Kyoto University	1967	−	−	Kagawa University	Higher resistance to phytophthora rot	344	
Hibiscus (common rose mallow)			*Hibiscus moscheutos* L.									
1	Shirasagi-no-yume	Sakai-no-hana	1981	Gamma ray 30kR	Osaka Prefectural Radiation Research Center (now Osaka Prefectural University)	1987	1987	1311	Osaka Prefectural Radiation Research Center (now Osaka Prefectural University)	Flower color: pinkish white-vivid purple pink with purple red stripe	1979	
Gentiana		*Gentiana* L.										
1	Miyama Love	Sasa-rindou		Colchicine treatment	Sky Blue Seto Co.	2001	2005	13126	Sky Blue Seto Co.	Late maturing		
2	Shinano Love	Ezo-rindou		Colchicine treatment and hybridization between chromosome-doubled plants	Sky Blue Seto Co.	2001	2005	13128	Sky Blue Seto Co.	Chromosome doubling (tetraploid)		
Verbena		*Verbena* L.										
1	San-mariko-rabi	San-mariribi	1998	Ion beam	Riken (Wako)	2001	2005	12999	Suntory Flowers Ltd.	Flower color: vivid purple; eye-shaped spot on the petal		
2	San-mari-sakura	San-marisa		Radiation	No description	2003	2011	20462	Suntory Flowers Ltd.	Plant type		

No.	Cultivar Name	Original Cv. or Line	Treat. Year	Treatment	Treated Institution	Dev. year	Reg. Year	Reg. No.[a]	Institution of Development	Improved Characteristics	IAEA ID[b]	Reference
3	San-mari-peach	A developed line		Heavy nitrogen ion beam irradiation to flower buds	Riken (Wako)	2006	2008	16854	Suntory Flowers Ltd.	Flower color and shape		
Osteospermum		*Osteospermum* L.										
1	Viento Flamingo	Mother Symphony		Ion beam	JAEA, Takasaki	2007	2009	18549	JAEA and Hanasekiguchi Co.	Petal color: 29D		Iizuka *et al* . (2011)[12)]
2	Viento Labios	Viento Flamingo		Radiation	JAEA, Takasaki	2011	2016	24758	JAEA and Hanasekiguchi Co.			
Bidens		*Bidens* L.										
1	San-bideki	Bidens triplinervia	1997	Colchicine	Suntory Flowers Ltd.	2001	2004	12262	Suntory Flowers Ltd.	Ever-flowering		
Gardenia		*Gardenia jasminoides* J. Ellis										
1	Vald	A domestic line		Colchicine treatment to seeds	Toyota Motor Corporation		2005	13621	Toyota Motor Corporation	Leaf shape		
Asian melastoma		*Melastoma* L.										
1	Pink Pearl	Belgra	1996	Gamma ray irradiation to callus	GIFUSEED Co. Ltd.		2005	13519	GIFUSEED Co. Ltd.	Pattern of leaf surface		
Morning glory		*Ipomoea indica* (Burm.) Merr.										
1	IRBIi Light Blue	Capetown Blue		Chronic gamma ray irradiation in the Gamma Field	IRB, NIAS	2012	2015	24599	IRB, NIAS, Fukukaen Nursery & Bulb Co., Ltd.	Flower color: 98B		
Italian ryegrass		*Lolium multiflorum* Lam. ssp. *italicum* (A. Br.) Volkart										
1	Miyuki-aoba	Taka-kei No. 4		Maternal selection after colchicine treatment	Hokuriku NAES	1983	1984	649	Hokuriku NAES	Larger leaf	2548	
Japanese lawngrass		*Zoysia* Willd.										
1	Winter Carpet	Tsukuba-kei	1990	Gamma ray	IRB	1992	1995	4299	IRB and Sumitomo Metal Industries, ltd.	Earlier green color of leaf	3201	
2	Winter Field	Tsukuba-kei (*Z. Matrella; manilagrass*)	1990	Chronic gamma ray irradiation (Gamma field)	IRB	1994	1996	5254	IRB and Sumitomo Metal Industries, ltd.	Better stolon vigor; narrower and shorter leaf	3202	

No.	Cultivar Name	Original Cv. or Line	Treat. Year	Treatment	Treated Institution	Dev. year	Reg. Year	Reg. No.[a]	Institution of Development	Improved Characteristics	IAEA ID[b]	Reference
3	Kopurosu	Tottori-kourai	1995	X ray to meristem culture	Yamaguchi PAES	1998	2002	10638	Kaisui Chemical Industry Co.	Better spring vigor; earlier green color of leaf; no browning in winter	3203	
4	Tee Emu 9	*Z. matrella* ecotype	2000	Soft X-ray irradiation to the seeds	Toyota Motor Corporation	2003	2006	14320	Toyota Motor Corporation	More flower heads; earlier browning in autumn		
5	Shiba Noh Pl 1	Ecotype		Tissue culture of seeds and regeneration from callus	NARO, National Institute of Livestock and Grassland Science	2007	2009	18204	NARO	Thicker turf development		
Creeping bentgrass	*Agrostis stolonifera* L.											
1	Springs	Penncross	1970	Gamma ray	Kyushu University	1982	1983	469	Nihon Ryokuei Co.	Resistance to summer heat	293	
2	Chiba Green B-2	Penncross	1991	Soft X ray to seedling	Chiba PAES	1996	1997	5439	Chiba PAES	Resistant to brown patch disease	2549	
3	My Comfort	Penncross	1992	Tissue culture	Chiba PAES	1996	2001	9043	Maekawa MFG Co.	Taller plant	2550	
Guineagrass	*Panicum maximum* Jacq.											
1	guineagrass Noh PL 1 (Nekken No. 1)	GR297		Colchicine	Coastal Plain Experiment Station, Tifton, USDA, GA, USA	1990	1993	3708	Tropical Agriculture Research Center (Now JIRCAS)	Chromosome doubling; shorter plant		Nakagawa *et al*. (1992)[32)]
Red clover	*Trifolium pratense* L.											
1	Taisetsu	Sapporo		Colchicine	Hokkaido NAES		1991	2934	Hokkaido NAES	Chromosome doubling; larger leaf	3205	
Apple	*Malus pumila* Mills.											
1	Mori-hou-fu 3A	Fuji	1963	Gamma ray 3kR to scion	IRB	1963			IRB	Resistance to disease	2551	
2	Houiku Indo	Indo	1992	Gamma ray irradiation to meristem culture	IRB	2003	2007	15022	IRB	Resistant to Alternaria disease		
Japanese pear	*Pyrus pyrifolia* (Burm. f.) Nakai var. *culta* (Mak.) Nakai											
1	Gold Nijisseiki	Nijisseiki	1962～8	Chronic irradiation (53m from center of source in Gamma Field)	IRB	1990	1991	2932	IRB	Resistance to black spot disease	278	Sanada *et al*. (1993)[45)]
2	Kotobuki Sinsui	Sinsui	1989	Gamma ray 80Gy to scion	IRB	1996	1997	5436	IRB and Tottori Prefectural Horticulture Experiment Station	Resistance to black spot disease	279	Kitagawa, K. *et al*. (1999)[25)]

No.	Cultivar Name	Original Cv. or Line	Treat. Year	Treatment	Treated Institution	Dev. year	Reg. Year	Reg. No.[a]	Institution of Development	Improved Characteristics	IAEA ID[b]	Reference
3	Osa Gold	Osa-nijisseiki	1986～9	Chronic irradiation (40m from center of source in Gamma Field)	IRB	1995	1997	5620	IRB and Tottori Prefectural Horticulture Experiment Station	Resistance to black spot disease	2552	Masuda *et al*. (1998)[28)]
Peach		*Prunus persica* (L.) Batsch										
1	Fuku-ekubo	Akatsuki	1987	Gamma ray 3kR	IRB	1994	1996	5076	Fukushima Prefectural Fruit Tree Experiment Station	Early maturing	2553	Sakuma *et al*. (1999)[44)]
2	Shimizu Hakutou RS	Shimizu Hakutou	1996	Gamma ray irradiation to nursery stock	IRB	2001	2004	12302	Okayama PAES	Resistant to black spot disease	2554	Inoue *et al*. (2006)[15)]
Loquat		*Eriobotrya japonica* (Thunb.) Lindl.										
1	Shiro-Mogi	Mogi		Gamma ray	IRB	1981	1982	300	Nagasaki Prefectural Fruit Tree Experiment Station		240	
Cherry		*Prunus avium* (L.) L.										
1	Super 6	Koruto	1985	Colchicine treatment to meristem culture	Tenkoen Co.	1988	1997	5374	Tenkoen Co.	Thicker branch; flower petal: round; larger leaf		
2	Roman Nishiki	Masamitsu-nishiki	1987	Colchicine treatment to buds	Mr. Masamitsu SATO	1998	2005	9929	Mr. Masamitsu SATO	Larger leaf; stickiness between seed and skin: medium sticky		
Cherry flower		*Prunus* L.										
1	Nishina-Zaou	Gioiko		Carbon ion beam	Riken (Wako)	2007	2009	17785	Riken and Shigehisa ISHII	Leaf shape and flower structure	3355	
2	Nishina-otome	Keiou Zakura		Heavy ion beam	Riken (Wako)	2009	2011	21281	Riken	Perpetual flowering		
Mulberry		*Morus* L.										
1	Lala Berry	Kataneo	1994	Colchicine treatment to axillary buds	NIAS	2000	2003	11242	NIAS	Thicker and larger leaf		
2	Pop Berry	Daitou-guwa	1994	Colchicine treatment to axillary buds	NIAS	2001	2004	12194	NIAS	Periclinal chimera; heavier fruit		
Tea		*Camellia sinensis* (L.) Kuntze										
1	Tea Noh Pl 2	Yabukita	1970-1971	Chronic irradiation in gamma field	IRB	1988	1998	6449	IRB	From self-incompatible to self-compatible; deeper leaf color		

No.	Cultivar Name	Original Cv. or Line	Treat. Year	Treatment	Treated Institution	Dev. year	Reg. Year	Reg. No.[a]	Institution of Development	Improved Characteristics	IAEA ID[b]	Reference
Cape jasmine		*Gardenia jasminoides* J. Ellis										
1	Vald	Zairai-shu	1994	Colchicine treatment to seeds	Toyota Motor Cooperation	2002	2005	13621	Toyota Motor Cooperation	Leaf shape: reverse egg-shape		
Pineapple		*A. ananasoides* (Baker) Smith										
1	Natsu-hime	*A.ananasoides* (Baker) Smith		Chronic gamma ray irradiation (Gamma Greenhouse)	IRB	2004	2005	17459	Okinawa PAES and IRB	Leaf color	3209	
Velvet shank mushroom			*Flammulina velutipes* (Fr.) Sing.									
1	Shinano-no-hana	K1	1992	Gamma ray to tissue culture	IRB	1994	1998	6559	IRB and Nagano Prefectural Agricultural Engineering Experiment Station	Albino	3227	
2	Pakinko-ajihime	wild type	1997	Gamma ray	IRB	1998	2002	10048	Bio-oriented Technology Research Advancement Institution and Nagano Prefectural Agricultural Engineering Experiment Station	Color of surface of fungus: brown	3228	
Shiitake mushroom		*Lentinus edodes* (Berk.) Sing.										
1	Susono 360-gou	Nichinou 270-gou	1979	Ultraviolet light	Nihon Norin Shukin Co.	1991	1998	6383	Nihon Norin Shukin Co.	Shape of surface of fungus: un even	3229	
Oyster mushroom		*Pleurotus ostreatus* Quel										
1	Shinrinsouken PO 1 gou	Reserved line	1983	Nitrosoguanidine treatment	Forestry and Forest Product Research Institute	1990	1993	3451	Forestry and Forest Product Research Institute	Shorter maturity period, mushroom shape		
Chinese tallow		*Sapium sebiferum* (L.) Roxb.										
1	Green honet	unknown	1997	Gamma ray 50Gy	IRB	1998	2003	11568	Gyoutoku Ryokuka Noujyou	Round spot on the leaf	3210	
Mint		*Mentha* L.										
1	Rose mint		1977	Gamma ray to cell culture						Amount of substance of flavor (20 times stronger)		

Note:
[a]Reg. No. is the registration number of The Plant Variety Protection System in Japan
[b]IAEA ID is the variety ID number of the Joint FAO/IAEA Mutant Variety Database (https://mvd.iaea.org/#!Home)

Abbreviations:
ARC: Agricultural Research center
ARI: Agricultural Research Institute
IRB: Institute of Radiation Breeding
JAEA: Japan Atomic Energy Agency
JIRCAS: Japan International Research Center for Agricultural Sciences
NAES: National Agricultural Experiment Station
NARC: National Agriculture Research Center
NARO: National Agriculture and Food Research Organization
NIAES: National Institute of Agro-environmental Sciences
NIAS: National Institute of Agrobiological Sciences
PAES: Prefectural Agriculture Experiment Station
PARC: Prefectural Agriculture Research Center

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Appendix 2. Indirect-use mutant cultivars

No.	Cultivar Name	Maternal Line	Paternal Line	Origin of Parental Line	Institution of Development	Dev. Year	Reg. Year	Reg. No.[a]	Mutant Characteristics Transferred	IAEA ID[b]	Reference
Rice		*Oryza sativa* L.									
1	Hyokei-sake 18	Yamada-nishiki	I-M106*	*Gamma ray irradiation to cv. Norin No. 8	Hyogo PAES	1972			Short and tough culm; good quality; very large seed	1125	
2	Mutsuhonami	Etsu-nan No. 39	Fu-kei No. 70 (Reimei)*	*cf. cv. Reimei (Appendix 1)	Aomori PAES, Fujisaka Branch	1973			Short and tough culm; high-yielding	1133	
3	Kagahikari	R6-1*	Fu-kei No. 72	*Gamma ray to cv. Koshihikari	Ishikawa PAES	1973			Early maturity	1126	
4	Hanahikari	stripe36/Bi-kei No. 53/Bi-kei No. 53.	Fu-kei No. 70 (Reimei)*	*cf. cv. Reimei (Appendix 1)	Yamagata PAES	1975			Short and tough culm; early maturity	1122	Kamei *et al*. (1980)[58)]
5	Houhai	Ao-kei No. 62 (Kojyou-nishiki)	Reimei*	*cf. cv. Reimei (Appendix 1)	Aomori PAES	1975			Short and tough culm; cold tolerance	1124	
6	Akihikari	Ouu No. 269 (Toyonishiki)	Reimei*	*cf. cv. Reimei (Appendix 1)	Aomori PAES, Fujisaka Branch	1976			Short and tough culm; very high-yielding	1120	Kushibuchi *et al*. (1977)[85)]
7	Hayahikari	Fu-kei No. 70 (Reimei)*	Ouu No. 269 (Toyonishiki)	*cf. cv. Reimei (Appendix 1)	Tohoku NAES	1976			Semi-dwarf; lodging resistance	1123	Hirano *et al*. (1977)[26)]
8	Nadahikari	5810-19/Hyou-kei Sake No. 18*	Tou-Kin-kei No. 1011	*cf. cv. "Hyo-kei-sake No. 18	Hyogo PAES	1977			Short culm; big seed	1136	
9	Fujihikari	R151*	Fu-kei No. 71**/No. 67/Koshihikari B1F1	*Gamma ray to cv. Koshihikari; **Gamma ray to cv. Fujiminori	Chugoku NAES				Extremely early-maturing; short culm	1121	Fujii *et al.* (1981)[11)]
10	Sachiminori	Manryou/R4B*	Yamase-nishiki	*Gamma ray to "Pi No.4"	Hokuriku NAES	1978			Slightly tough stem; resistant to rice blast (Pi-ta^2)	1140	Samoto *et al*. (1979)[141)]
11	Katsura-wase	Fu-kei No. 67×Fu-kei No. 71*	Koshihikari	*Gamma ray to the seed of cv. Fujiminori	Kagoshima PAES	1978			Early maturing; short and tough culm	1127	
12	Miyanishiki	Kanto No. 79*	Todoroki-wase	*Gamma ray (20kR) to the seed of cv. Koshihikari	Miyazaki PAES	1978			Good quality; good taste	1130	Uchiyamada *et al*. (1979)[185)]
13	Niigata-wase	Fu-kei No. 91*	Chou 60	*A descendant (the 1st generation) of cv. Reimei	Niigata PAES	1979			Short and tough culm	1137	Ichikawa *et al*. (1981)[38)]
14	Mine-asahi	Kanto No. 79*	Kihou	*Gamma ray (20kR) to the seed of cv. Koshihikari	Aichi PAES	1980	1981	100	Good taste; short culm	1128	Morimoto *et al*. (1980)[108)]
15	Musashi-kogane	Tama-kei No. 56*	Aichi No. 21	*cv. Reimei/cv. Nipponbare	Saitama PAES	1981	1982	239	Short culm; lodging resistance	1132	Shiobara *et al*. (1982)[154)]
16	Mutsu-komachi	Mutsu-nishiki	Fu-kei No. 104 (Akihikari)*	*cf. cv. Akihikari (the 1st generation of cv. Reimei)	Aomori PAES	1981	1982	241	Short culm; lodging resistance	1135	Ono *et al*. (1982)[133)]
17	Mutsu-kaori	Mutsu-nishiki	Fu-kei No. 104 (Akihikari)*	*cf. cv. Akihikari (the 1st generation of cv. Reimei)	Aomori PAES	1981	1982	242	Short culm; lodging resistance	1134	Ono *et al*. (1982)[134)]
18	Rokko-nishiki	5810-19/Hyou-kei Sake No. 18*	Tou-Kin-kei No. 1011	*cf. cv. "Hyo-kei sake No. 18"	Hyogo PAES	1981	1983	326	Large seed	1139	
19	Miyakaori	Iwaga	Ouu No. 282*	*Named as cv. Hayahikari (the 1st generation of cv. Reimei)	Miyagi PAES Furukawa Branch	1983	1984	588	Semi-dwarf	2986	Oikawa *et al*. (1991)[130)]
20	Natsuhikari	Ka-kei No. 639*	Sei-nan No. 45	* Named as "Katsura-wase" (the 3rd generation of a gamma ray induced strain "Fu-kei 71")	Kagoshima PAES	1983	1984	598	Tough stems; lodging resistance	2987	Iwashita *et al*. (1984)[49)]
21	Megumi-mochi	Aichi-mochi No. 27	Fu-kei No. 102*	*cv. Reimei/cv. Fujiminori/cv. Somewake	Aichi ARC	1983	1985	623	Short and tough culm; high-yielding	1145	Koumura *et al*. (1983)[83)]

No.	Cultivar Name	Maternal Line	Paternal Line	Origin of Parental Line	Institution of Development	Dev. Year	Reg. Year	Reg. No.[a]	Mutant Characteristics Transferred	IAEA ID[b]	Reference
22	Hatsukogane	Fu-kei No. 102*	Matsumae	*cv. Reimei/cv. Fujiminori/cv. Somewake	Aomori PAES, Fujisaka Branch	1984	1985	889	Short and tough stem	1146	Shimura *et al.* (1986)[153)]
23	Okuhomare	Hyo-kei-sake No. 18*	Reimei**	*cf. cv. "Hyo-kei-sake No. 18";**cf. cv. Reimei (Appendix 1)	Hyogo PAES	1984			Semi-dwarf	2988	
24	Ibuki-wase	Mine-asahi*	Hourei	*cf. cv. "Mine-asahi" (the 1st generation of gamma ray induced mutant line "Kanto No. 79" from cv. Koshihikari)	Aichi ARC	1985	1986	1204	Cold tolerance	1148	Akama *et al*. (1985)[2)]
25	Mutsu-homare	Todoroki-wase/Akihikari*	Fuji 329	*cf. cv. Akihikari (the 1st generation of cv. Reimei)	Aomori PAES	1985	1986	1206	Short culm; good taste	1149	Yamazaki *et al*. (1987)[210)]
26	Hanafubuki	Ao-kei No. 79 (Oku-homare)*	Fu-kei No. 103**	*cf. cv. Okuhomare,**A descendant (the 1st generation) of cv. Reimei	Aomori PAES	1985	1988	1494	Semi-dwarf	2989	Tanabu *et al*. (1987)[172)]
27	Tamaminori	Tama-kei No. 56*	Aichi No. 21	*cv. Reimei/cv. Nipponbare	Saitama PAES	1986	1986	1196	Tough culm; semi-dwarf	2990	Niwayama *et al*. (1987)[125)]
28	Hyogo-Kitanishiki	Nadahikari*	Gohyaku-mangoku	*cf. cv. Nadahikari	Hyogo PAES	1986	1987	1374		2991	
29	Akichikara	Hokuriku No. 101*	Akihikari**	*A descendant of cv. Reimei; **A descendant (the 1st generation) of cv. Reimei	Hokuriku NAES	1986	1987	179	Short and tough culm; high-yielding	1147	Koga *et al*. (1987)[78)]
30	Manyo-mochi	77-5133*	To-kou No. 76	*A glutinous mutant of cv. Koshihikari	Toyama PAES	1987	1988	1738	Glutinous	2992	Yamamoto *et al*. (1989)[208)]
31	Seihou No. 1	Akihikari*	Nishihomare	*cf. cv. Akihikari (the 1st generation of cv. Reimei)	Mr. Seiichi HIROKI	1987	1988	1799		2993	
32	Aichi-no-kaori	Hatsushimo	Mine-asahi*	*A descendant of Gamma ray (20kR) induced mutant line "Kanto 79" from cv. Koshihikari	Aichi ARC	1987	1988	1802	Good taste; big seed	1151	Koomura *et al*. (1989)[82)]
33	Michinoku-wase	Bi-kei No. 113*	Bi-kei No. 110**	*, **A descendant of cv. Reimei	Yamagata PAES	1988			Semi-dwarf	2994	Sato *et al*. (1988)[149)]
34	Kinuhikari	Shu2800/Hokuriku No. 100*	Nago-yutaka	*Gamma ray to cv. Koshihikari	Hokuriku NAES	1988	1989	2037	Short culm; good taste; lodging resistance	1160	Koga *et al*. (1989)[77)]
35	Tsugaru-otome	Ouu 305	Mutsu-kaori*	*cf. cv. Mutsukaori: a descendant (the 2nd generation) of cv. Reimei through cv. Akihikari	Aomori PAES	1988	1990	2389	Good taste; cold tolerance; short culm	1153	Takadate *et al.* (1990)[161)]
36	Heisei-mochi	Musashi-kogane*	Musashi-mochi	*cf. cv. "Musashi-kogane": a descendant (the 2nd generation) of cv. Reimei	Saitama PAES	1988	1990	2394	Lodging resistance; resistant to stripe virus	1157	Niwayama *et al*. (1991)[127)]
37	Nijihikari	Tori-kei No. 4*	Satominori	*Gamma ray to cv. "Norin No. 8"	Tottori PAES	1988	1991	2867	Short culm; lodging resistance	1163	
38	Oochikara	BG1*	Shu3116**	*A descendant (the 1st generation) of mutant cv. Taihou; **A descendant (the 3rd generation) of "R4-B" through cv. Sachiminori	Hokuriku NAES	1989	1990	2271	Large seed; tough stem and lodging resistance	2295	Kobayashi *et al*. (1990)[71)]
39	Koihime	Koshihikari/Reimei*	Akihikari*	*cf. cv. Reimei (Appendix 1); **cf. cv. Akihikari (the 1st generation of cv. Reimei)	Aomori PAES, Fujisaka Branch	1989	1990	2329	High-yielding; cold tolerance	1161	Shimura *et al*. (1990)[152)]
40	Hirohikari	Fu-kei No. 130*	Akihikari**	*cv. Koshihikari/cv. Reimei//"Fu-kei No. 104"; **cf. cv. Akihikari	Hiroshima PAES	1989	1990	2392	Tough culm; high-yielding; good taste	1152	Maeda *et al.* (1990)[89)]
41	Hirohonami	Fu-kei No. 130*	Yoneshiro	*cv. Koshihikari/cv. Reimei//"Fu-kei No. 104"	Hiroshima PAES	1989	1990	2393	Tough culm	2996	Maeda *et al*. (1990)[89)]

No.	Cultivar Name	Maternal Line	Paternal Line	Origin of Parental Line	Institution of Development	Dev. Year	Reg. Year	Reg. No.[a]	Mutant Characteristics Transferred	IAEA ID[b]	Reference
42	Yumeminori	Etsunan No. 119	Musashi-kogane*	*cf. cv. "Musashi-kogane": a descendant (the 2nd generation) of cv. Reimei	Saitama PAES	1989	1992	3222	Lodging resistance	1166	Niwayama *et al.* (1994)[126)]
43	Koshi-no-hana	Shounai No. 32	To-kei 196*	*Gamma ray to cv. Koshihikari	Toyama PAES	1980	1991	2869	Low amylose; panicle weight type	2997	
44	Kitaou	Fu-kei No. 108	Fu-kei No. 113*	*A descendant (the 2nd generation) of cv. Reimei	Aomori PAES, Fujisaka Branch	1990	1991	2871	Short culm	2998	Kobayashi *et al*. (1993)[72)]
45	Kaguya-mochi	Chubo37*	Fu-kei No. 126 (Kochiminori)	*A descendant (the 2nd generation) of cv. Reimei	Aomori PAES, Fujisaka Branch	1990	1991	2872	Semi-dwarf; middle to short culm	2999	Horisue *et al.* (1992)[31)]
46	Hagi-no-kaori	Tohoku No. 125	Furu2986 (cv. Miyakaori)*/Tohoku No. 125	*A descendant (the 2nd generation) of cv. Reimei	Miyagi PAES Furukawa Branch	1991	1992	3044	Semi-dwarf	3000	Sasaki *et al*. (1994)[143)]
47	Aya	Douhoku No. 43 (Naga-kei 84271)*	Kita-ake	*NM391 (a gamma ray induced mutant from cv. "Nihon-masari")/cv. Ishikari	Hokkaido AES Kamikawa Station	1991	1992	3283	Good taste	1169	Tanno *et al*. (1997)[173)]
48	Yama-uta	Bi-kei No. 108*/ Akihikari**	Fu-kei No. 127***	*, **, ***A descendant of cv. Reimei	Aomori PAES, Fujisaka Branch	1991	1992	3284	Semi-dwarf	3001	Kobayashi *et al*. (1993)[70)]
49	Yukimi-mochi	Fuji-mochi712*	Fu-kei-mochi No. 119**	*, **A descendant of cv. Reimei	Aomori PAES, Fujisaka Branch	1991	1992	3285	Semi-dwarf	3003	Horisue *et al*. (1993)[30)]
50	Aneko-mochi	Fu-kei-mochi No. 133*	Fu-kei-mochi No. 119**	*, **A descendant (the 2nd generation) of cv. Reimei	Aomori PAES, Fujisaka Branch	1991	1992	3286	Semi-dwarf	3004	Horisue *et al.* (1993)[32)]
51	Yuki-gesyou	Oou No. 301	Bi-kei No. 94*	*"Bi-kei 67"/cv. Reimei//cv. Sasanishiki	Yamagata PAES	1991	1993	3344	Semi-dwarf	3005	
52	Doman-naka	Chubu No. 42*	Shounai No. 29**	*Named as cv. "Ibuki-wase" (the 1st generation of cv. Mine-asahi), **A descendant of cv. Reimei	Yamagata PAES	1991	1993	3345	Short stem	1168	
53	Hae-nuki	Shounai No. 29*	Akita No. 31	*A descendant (the 3rd generation) of cv. Reimei	Yamagata PAES	1991	1993	3346	Semi-dwarf	3006	Kyoya *et al*. (2002)[86)]
54	Hatsu-nanori	Natsuhikari	Niigata-wase*	*A descendant (the 2nd generation) of cv. Reimei; cf. cv. "Niigata-wase"	Kochi PARC	1991	1994	4051	Semi-dwarf	3007	Nakamura *et al.* (1993)[118)]
55	Hashiri-aji	Niigata-wase*	Shounai No. 32	*A descendant (the 2nd generation) of cv. Reimei; cf. cv. "Niigata-wase"	Niigata PAES	1991	1997	5784	Semi-dwarf	3008	Hoshi *et al*. (1998)[36)]
56	Ougi-wase	Inaba-wase	Yo128 (Kagahikari)*	*cf. cv. Kagahikari: a descendant (the 1st generation) of a gamma ray induced mutant of cv. Koshihikari	Ishikawa PAES	1991			Large grain; a good grain quality	3009	Matsumoto *et al*. (1993)[94)]
57	Gin-no-sei	Aikawa No. 1*	Aki-kei 53	*A mutant of cv. Akiyutaka	Akita PAES	1993	1993	3343		1167	Takahashi *et al*. (1999)[163)]
58	Kinu-no-hada	Chubu-mochi No. 37	Akihikari*	*cf. cv. Akihikari: a descendant (the 1st generation) of cv. Reimei	Akita PAES	1993	1993	3574	Tough stem; high-yielding	3010	Kato *et al*. (1995)[68)]
59	Tatsuko-mochi	Chubu-mochi No. 37	Akihikari*	*cf. cv. Akihikari: a descendant (the 1st generation) of cv. Reimei	Akita PAES	1993	1993	3575	Tough stem; high-yielding	3011	Kato *et al*. (1995)[68)]
60	Ippon-jime	Gohyaku-mangoku	Houhai*	*cf. cv. Houhai: a descendant (the 1st generation) of cv. Reimei	Niigata PAES	1993	1994	4172	Semi-dwarf	3012	Sasaki *et al*. (1994)[144)]
61	Natsu-no-tayori	Fu-kei No. 125*	Ouu No. 309	*cv. Sasaminori/cv. Reimei	Kagoshima PAES	1993	1995	4349	Semi-dwarf	3013	Yatou *et al*. (1994)[212)]
62	Yume-tsukushi	Kinuhikari*	Koshihikari	*cf. cv. Kinuhikari	Fukuoka PAES	1993	1995	4414	Good taste; lodging resistance	3014	Imabayashi *et al*. (1995)[42)]

No.	Cultivar Name	Maternal Line	Paternal Line	Origin of Parental Line	Institution of Development	Dev. Year	Reg. Year	Reg. No.[a]	Mutant Characteristics Transferred	IAEA ID[b]	Reference
63	Inahikari	Chubu No. 35	Mine-asahi*	*A descendant (the 1st generation) of Gamma ray (20kR) induced mutant line "Kanto 79" from cv. Koshihikari	Aichi ARC	1993	1995	4415	Short culm; good taste	3015	Inoue *et al.* (1993)[43)]
64	Matsuri-bare	Tsuki-no-hikari	Mine-asahi*	*A descendant of Gamma ray (20kR) induced mutant line "Kanto 79" from cv. Koshihikari	Aichi ARC	1993	1995	4416	Tough culm	3016	Syumura *et al*. (1994)[159)]
65	Maihime	Ao-kei No. 69	Fu-kei No. 130*	*cv. Koshihikari/cv. Reimei//"Fu-kei No. 104"	Aomori PAES, Fujisaka Branch	1993	1995	4471	Tough culm	3017	Horisue *et al*. (1994)[34)]
66	Fukuhibiki	Kochihibiki	Ouu 316 gou*	* A descendant (the 3rd generation) of cv. Reimei	Tohoku NAES	1993	1995	4710	Semi-dwarf	3018	Higashi *et al*. (1994)[21)]
67	Mitsu-tarou	Shinano-sakigake*	Akita-komachi	*cf. cv. "Shinano-sakigake" (a gamma ray induced mutant cultivar from cv. Toyonishiki)	Mitsui Chemicals, Inc.	1993	1996	5007		3019	
68	Owara-bijin	Shounai No. 32 (Hana-no-mai)	To-kei 196*	*A mutant strain induced through gamma ray irradiation to cv. Koshihikari	Toyama PAES	1994	1995	4409	Early-maturing; short culm	3020	Kaneda *et al.* (1996)[60)]
69	Dewahikari	Shounai No. 32 (Hana-no-mai)	Ouu No. 302*	*A descendant (the 2nd generation) of cv. Reimei	Akita PAES	1994	1996	5065	Semi-dwarf	3021	
70	Aki-roman	Mine-asahi*	Nakate-shinsenbon	*A descendant (the 1st generation) of Gamma ray (20kR) induced mutant line "Kanto 79" from cv. Koshihikari	Hiroshima PAES	1994	1996	5185	Good taste	3022	Tsuchiya *et al.* (1995)[183)]
71	Hoso-omote	Shin-hou No. 38 (Shinano-sakigake)*	Miyan No. 23	*cf. cv. "Shinano-sakigake" (a gamma ray induced mutant cultivar from cv. Toyonishiki)	Nagano PAES	1994	1996	5247		3023	
72	Nebari-gachi 94	Akinishiki	Tan-kei 1915*	*Named as "Noh PL No. 13" (a hybrid between two MNU induced mutants)	Plant Laboratory, Kirin Brewery Co., Ltd.	1994	1997	5844	Low amylose	3024	
73	Sai-no-yume	Kanto PL3	Tama-kei No. 74*	*cf. cv. "Yume-minori": a descendant (the 3rd generation) of cv. Reimei	Saitama PAES	1994	1998	6445	Semi-dwarf	3025	Tokura *et al*. (1999)[177)]
74	Dewa-sansan	Miyama-nishiki*	Ao-kei Sake No. 97 (Hanafubuki)**	*cf. cv. "Miyama-nishiki" (a gamma ray induced mutant cultivar from cv. "Takane-nishiki"; **cf. cv. Hanafubuki: a descendant (the 2nd generation) of cv. Reimei)	Yamagata PAES	1995	1997	5545	High % of white core rice; suitable for sake-brewery; semi-dwarf	3026	
75	Otome-gokoro	Akita-komachi	Akihikari*	*cf. cv. Akihikari: a descendant (the 1st generation) of cv. Reimei	Okayama PAES	1995	1997	5546	Semi-dwarf	3027	Nihara *et al.* (1996)[122)]
76	Yume-kogane	Yuki-hikari	Hatsu-kogane*	*cf. cv. Hatsukogane: a descendant (the 2nd generation) of cv. Reimei	Aomori PAES, Fujisaka Branch	1995	1997	5785	Semi-dwarf	3028	Uehara *et al*. (1997)[186)]
77	Hama-yutaka	Fu-kei No. 115×Ouu No. 321*	Fu-kei No. 140 (Kita-ou)**	*A descendant (the 3rd generation) of cv. Reimei; **cf. cv. Kitaou: a descendant (the 3rd generation) of cv.	Aomori PAES, Fujisaka Branch	1985	1997	5786	Semi-dwarf	3029	Uehara *et al.* (1997)[187)]
78	Dontokoi	Kinuhikari*	Hokuriku No. 120	*cf. cv. Kinuhikari	Hokuriku NAES	1995	1997	5845	Good taste; lodging resistance	3030	Uehara *et al*. (1995)[193)]
79	Soft 158	Hokuriku No. 127 (Kinuhikari)*	Ken-kei 2078**	*cf. cv. Kinuhikari; **A mutant from EMS treatment to cv. Sasanishiki	Hokuriku NAES	1995	1997	5846	Good taste; lodging resistance	3031	Uehara *et al*. (1995)[188)]

No.	Cultivar Name	Maternal Line	Paternal Line	Origin of Parental Line	Institution of Development	Dev. Year	Reg. Year	Reg. No.[a]	Mutant Characteristics Transferred	IAEA ID[b]	Reference
80	Rinx-wase	KRN3501 (Rinx-Kobayashi)*	KRN3502	*cf. cv. "Rinx-Kobayashi" (Appendix 1)	Plant Laboratory, Kirin Brewery Co., Ltd.	1995	1998	6265	Seed-shattering resistance	3032	
81	Hoho-emi	Aichi No. 52	Mine-asahi*	*A descendant (the 1st generation) of gamma ray (20kR) induced mutant line "Kanto 79" from cv. Koshihikari	Miyazaki PAES	1995	1998	6388	Good taste; tough culm	3033	Takita *et al*. (1997)[168)]
82	Shimasayaka	Tsuki-no-hikari	Kinuhikari*	*cf. cv. Kinuhikari	Plant Laboratory, Kirin Brewery Co., Ltd.	1995	1998	6444	Good taste; lodging resistance	3034	
83	Tsukushi-wase	Norin No. 22	Kinuhikari*	*cf. cv. Kinuhikari	Fukuoka PAES	1995	1999	7321	Good taste; lodging resistance	3035	Hamachi *et al*. (1998)[18)]
84	Tsugaru-roman	Fu-kei No. 141*	Akita-komachi	*A descendant (the 2nd generation) of cv. Reimei	Aomori PAES	1995	2000	8280	Semi-dwarf	3036	Takadate *et al.* (1997)[160)]
85	Ishikawa Sake No. 30	Gohyaku-mangoku	Hanafubuki*	*cf. cv. Hanafubuki: a descendant (the 2nd generation) of cv. Reimei	Ishikawa PAES	1996	1996	5188	Semi-dwarf	3037	
86	Asamurasaki	Tou-mochi 396	Ouu 331 gou (later named as "cv.	*A descendant (the 4th generation) of cv. Reimei	Tohoku NAES	1996	1998	6504	Semi-dwarf	3038	Higashi *et al*. (1997)[24)]
87	Sakitamahime	Kinuhikari*	Yumeminori**	*cf. cv. Kinuhikari; ** A descendant (the 3rd generation) of cv. Reimei through cv. "Musashi-kogane"	Saitama PAES	1996	2000	7644	Good taste; lodging resistance	3039	Tokura *et al.* (2000)[176)]
88	Aki-no-sei	Toyo-nishiki	Miyama-nishiki*	*cf. cv. "Miyama-nishiki" (a gamma ray induced mutant cultivar from cv. "Takane-nishiki")	Akita PAES	1996	2000	7755	High % of white core rice; suitable for sake-brewery	3040	Masaki *et al*. (1999)[93)]
89	Okini-iri	Chubu No. 47	Ouu No. 313*	*A descendant (the 3rd generation) of cv. Reimei	Tohoku NAES	1996	2000	7812	Semi-dwarf	3041	Higashi *et al.* (1997)[23)]
90	Ideyu-mochi	Fuji-mochi773*	Wasetora-mochi	*A descendant (the 2nd generation) of cv. Reimei	Aomori PAES, Fujisaka Branch	1996	2000	7813	Semi-dwarf	3042	Horisue *et al*. (1997)[33)]
91	Yume-musubi	Tohoku No. 137	Hokuriku No. 122 (Kinuhikari)*	*cf. cv. Kinuhikari	Miyagi PAES Furukawa Branch	1996	2000	7814	Good taste; tough culm	3043	Matsunaga *et al*. (2002)[97)]
92	Asahi-no-yume	Aichi No. 70 (Aichi-no-kaori)*	Aichi No. 56/Aichi No. 65**	*, **: A descendant (the 2nd generation) of a gamma ray induced mutant line "Kanto 79 gou" through "Mine-asahi"	Aichi ARC	1996	2000	7888	Good taste; tough culm	3044	Izawa *et al*. (2001)[50)]
93	Yume-izumi	Yumehikari	Kinuhikari*	*cf. cv. Kinuhikari	Kumamoto PARC	1996	2000	8124	Good taste; lodging resistance	3045	Izumi *et al*. (1998)[54)]
94	Yume-hitachi	Chiyo-nishiki	Hokuriku No. 122 (Kinuhikari)*	*cf. cv. Kinuhikari	Ibaraki PAES	1996	2000	8213	Good taste; lodging resistance	3046	Suga *et al.* (2000)[155)]
95	Rinx-nakate	Rinx Kobayashi*	KRN3505	*cf. cv. "Rinx-Kobayashi" (Appendix 1)	Plant Laboratory, Kirin Brewery Co., Ltd.	1996	2000	8359	Non seed shattering	3047	
96	Iwata No. 12	Asominori	Aichi-no-kaori*	*cf. cv. "Aichi-no-kaori"	Japan Tobacco, Inc.	1996	2001	8631	Semi-dwarf	3048	
97	Hoshi-akari	Hatsuboshi	Miyama-nishiki*	*cf. cv. "Miyama-nishiki" (a gamma ray induced mutant cultivar from cv. "Takane-nishiki") (Appendix 1)	Kako-mai Breeding Institute, Inc. and Tohoku Electric Power Co., Inc.	1996	2001	9116	High % of white core rice; suitable for sake-brewery	3049	

No.	Cultivar Name	Maternal Line	Paternal Line	Origin of Parental Line	Institution of Development	Dev. Year	Reg. Year	Reg. No.[a]	Mutant Characteristics Transferred	IAEA ID[b]	Reference
98	Hayatsukushi	Hatsuboshi	Seinan No. 89*	*Named as cv. "Natsu-no-tayori": a descendant (the 2nd generation) of cv. Reimei	Fukuoka ARC	1997	2000	8360	Semi dwarf	3050	Hamachi *et al.* (1998)[17)]
99	Aki-geshiki	Kyu-kei 919*	Hinohikari	*A descendant of cv. "Mine-asahi"	Miyazaki PAES	1997	2000	8544	Good taste; tough culm	3051	The Miyazaki Breeding Group of Rice (2005)[174)]
100	Oyama-nishiki	Hida-homare	Akita Sake No. 33*	*A descendant of cv. "Miyama-nishiki" (Appendix 1)	Toyama PAES	1997	2001	9029	High % of white core rice; suitable for sake-brewery	3052	Kaneda *et al.* (1999)[59)]
101	Hatajirushi	Tohoku No. 141	Tohoku No. 142* (Ibukiwase/Tohoku No. 125)	*cv. Ibukiwase: a descendant (the 2nd generation) of "Kanto 79 gou" through cv. "Mine-asahi"	Miyagi PAES Furukawa Branch	1997	2001	8832	High % of white core rice; suitable for sake-brewery	3053	Matsunaga *et al.* (2002)[98)]
102	Banbanzai	Chiyo-nishiki	Tama-kei No. 74 (cv. Yume-minori)*	*cf. cv. "Yume-minori": a descendant (the 3rd generation) of cv. Reimei through cv. "Musashi-kogane"	Saitama PAES	1997	2001	9304	Semi-dwarf	3054	Tokura *et al* . (2002)[175)]
103	Snow Pearl	74wx2N1*	Reimei**	*A mutant of "Norin No. 8"; **cf. cv. Reimei (Appendix 1)	Tohoku NAES	1998	1999	7062	Low amylose; semi-dwarf	3055	Higashi *et al* . (1998)[22)]
104	Koimomiji (Hiroshima No. 21)	Sachi-izumi	Fu-kei No. 141*	*A descendant (the 2nd generation) of cv. Reimei	Hiroshima PARC	1998	2001	9301	Semi-dwarf	3056	Maeda *et al.* (2000)[90)]
105	Daichi-no-kaze	A-kei 558 (Matsuribare)*	Aichi No. 78/4/Tsuki-no-hikari/3/Aichi No. 77//Iku D759/A-kei	*cf. cv. Matsuribare: a descendant (the 2nd generation) of a gamma ray induced mutant line "Kanto 79 gou" through cv. "Mine-asahi"	Aichi ARC	1998	2002	8640	Good taste; tough culm	3057	Izawa *et al* . (2001)[52)]
106	Koshihikari Toyama BL No. 1	Koshihikari	Koshihikari/BC-ta2*	*Kinuhikari2/"Tohoku IL No. 7"	Toyama ARC	1998	2002	9641	Good taste; lodging resistance	3058	Kojima *et al* . (2003)[79)]
107	Hanabusa	Douhoku No. 53*	Kita-ake	*A sister line of cv. Aya; a descendant (the 2nd generation) of a gamma ray induced mutant line "NM391"	Hokkaido NAES	1998	2002	9785	Low amylose	3059	Araki *et al.* (2002)[8)]
108	Sawa-pikari	Tan-kei 2018*	Asa-no-hikari	*A mutant line through MNU treatment to cv. Kochihibiki	Gunma PAES	1998	2002	9786	Low amylose	3060	Narizuka *et al* . (1998)[120)]
109	Awaminori	Hokkai No. 132	Hokuriku No. 122 (Kinuhikari)*	*cf. cv. Kinuhikari	Hokuriku NAES	1998	2002	9788	Good taste; lodging resistance	3061	Uehara *et al.* (1998)[192)]
110	Haiminori	EM40*	Ake-no-hoshi	*A mutant from MNU treatment to cv. Kinmaze	Chugoku NAES	1999	2000	8008	Giant embryo	3062	Nemoto *et al* . (2001)[121)]
111	Yume-ohmi	Etsunan No. 135*	Shi-kei No. 51	*A descendant (the 3rd generation) of cv. Reimei through cv. Akihikari.	Shiga PAES	1999	2001	8944	Semi-dwarf	3063	Noda *et al* . (1999)[128)]
112	Mie-no-emi	Yamagata No. 41*	Hitomebore	*"Shounai No. 32"/cv. "Mine-asahi" (a descendant (the 1st generation) of Gamma ray (20kR) induced mutant line "Kanto 79" from cv. Koshihikari)	Mie PARC	1999	2002	9911	Good taste; tough culm	3064	Yamakawa *et al* . (2000)[207)]
113	Yume-akari	Akita-komachi	Ao-kei No. 110*	*A descendant (the 4th generation) of cv. Reimei through cv. Mutsukaori	Aomori PAES	1999	2002	9912	Semi-dwarf	3065	Mikami *et al.* (2000)[100)]

No.	Cultivar Name	Maternal Line	Paternal Line	Origin of Parental Line	Institution of Development	Dev. Year	Reg. Year	Reg. No.[a]	Mutant Characteristics Transferred	IAEA ID[b]	Reference
114	Gin-ginga	Yamagata Sake No. 49*	Akita Sake No. 49**	*Named as cv. "Dewa-sansan" (a descendant (the 3rd generation) of cv. Reimei); **a descendant (the 3rd generation) of cv. Reimei through cv. Akihikari	Iwate PAES, Kennan Station	1999	2002	1047	Semi-dwarf	3066	Odanaka *et al*. (2000)[129)]
115	Yume-no-kaori	Hattan-nishiki No. 1	Yamagata Sake No. 49*	*Named as cv. "Dewa-sansan" (a descendant (the 3rd generation) of cv. Reimei)	Fukushima PAES	1999	2003	1096	Semi-dwarf	3067	Sato *et al*. (2003)[148)]
116	Aichi-no-kaori SBL	Aichi-no-kaori*	F3 (Aichi-no-kaori*/2//Aichi No. 78/Aichi-no-kaori*)	*cf. cv. "Aichi-no-kaori"	Aichi ARC	1999	2003	10968	Good taste; big seed	3068	Izawa *et al*. (2001)[51)]
117	Oku-no-murasaki	Tohoku Mochi 149 gou	Ouu 331 gou (later named as cv. Fukuhibiki")*	*A descendant (the 4th generation) of cv. Reimei	NARO NARC Tohoku Region	1999	2003	11088	Semi-dwarf	3069	Yokogami *et al*. (2000)[213)]
118	Oshimako 180	Douhoku No. 43 (NM391*/Ishikari)	Fu-kei No. 144**	*Gamma ray to cv. "Nihon-masari"; **A descendant (the 3rd generation) of cv. Reimei	Aomori PAES	1999	2003	11230	Semi-dwarf	3070	
119	Koshi-ibuki	Tohoku No. 143 (Hitomebore)	Yamagata No. 35*	*Named as cv. "Doman-naka" (a descendant (the 3rd generation) of a gamma ray induced mutant line "Kanto 79 gou" through cv. "Mine-asahi" from cv. Koshihikari)	Niigata PAES	1999	2003		Good taste; tough culm	3071	Hoshi *et al*. (2002)[37)]
120	Yawarakomachi	Nishihomare+B140	Tan-kei 2021*	*A mutant line through NMU treatment to cv. Kinmaze	Kyushu NAES	1995	1999	7084	Low amylose content	3072	Okamoto *et al*. (2001)[131)]
121	Kan-no-mai	Gohyaku-mangoku	Miyama-nishiki*	*cf. cv. "Miyama-nishiki" (Appendix 1)	Shimane PAES	1995	2000	7890	High % of white core rice; suitable for sake-brewery	3073	Yamamoto *et al*. (1999)[209)]
122	Hanakirari	PR3*	Koshihikari	*A mutant from protoplast culture of cv. Nipponbare	Plantec Research Institute	2000	2000	8545	Early-maturing	3074	
123	Chiho-no-kaori	Tohoku No. 144 (Hagi-no-kaori)*	Nankai No. 122	*cf. cv. "Hagi-no-kaori" (a descendant (the 4th generation) of cv. Reimei.)	Miyazaki PAES	2000	2002	1087	Semi-dwarf	3075	Takita *et al.* (2000)[169)]
124	Gin-otome	Akita Sake No. 44*	Tohoku No. 141	*Gamma ray to F6 ("Hyo-kei-sake No. 16"/cv. Yoneshiro)	Iwate PAES	2000	2003	1096	Short culm	3076	Sugawara *et a*l. (2012)[156)]
125	Yume-ippai	Yume-gokochi*	Yume-kahori**	*cf. cv. "Yume-gokochi"; **cf. cv. "Yume-kahori"	Mitsui Chemicals, Inc.	2000	2003	10965	Short culm	3077	
126	Yume-sayaka	Yamagata No. 40*	Oou No. 341	*A descendant (the 3rd generation) of cv. Reimei	Yamagata PAES	2000	2003	10966	Semi-dwarf	3078	Sato *et al*. (2000)[145)]
127	Itadaki	Shu4885 (Dontokoi)*	Shu4695	*cf. cv. Dontokoi: a descendant (the 2nd generation) of cv. Kinuhikari	NARO (NARC, Hokuriku Center)	2000	2003	11087	Good taste; lodging resistance	3079	Uehara *et al*. (2000)[195)]
128	Mine-hibiki	Sachi-izumi	Mine-asahi*	*cf. cv. "Mine-asahi": A descendant (the 1st generation) of gamma ray induced mutant line "Kanto No. 79" from cv. Koshihikari	Aichi ARC	2000	2003	11089	Good taste; tough culm	3080	Kudo *et al*. (2000)[84)]

No.	Cultivar Name	Maternal Line	Paternal Line	Origin of Parental Line	Institution of Development	Dev. Year	Reg. Year	Reg. No.[a]	Mutant Characteristics Transferred	IAEA ID[b]	Reference
129	Chiyo-no-mochi	Ouu-mochi No. 317*× Fu-kei No. 141**	Fu-kei No. 143***	*,**A descendant (the 3rd generation) of cv. Reimei; ***Named as cv. "Yama-uta" (a descendant (the 4th generation) of cv. Reimei)	Aomori PAES, Fujisaka Branch	2000	2003	11091	Semi-dwarf	3081	Uehara *et al.* (2001)[196)]
130	Milky Princess	Kanto No. 163	Kou272 (Milky Queen)*	*cf. cv. "Milky Queen" (Appendix 1)	NARO (National Institute of Crop Science)	2000	2003	11234	Low amylose content	3082	Sato *et al.* (2008)[146)]
131	Koshi-no-shizuku	Hyogo-kita-nishiki*	Miyama-nishiki**	*cf. cv. "Hyo-kei-sake No. 18"; **cf. cv. "Miyama-nishiki" (Appendix 1)	JA, Teraru-Echizen	2000	2003	11361		3083	
132	Yume-shizuku	Kinuhikari*	Tohoku No. 143 (Hitomebore)	*cf. cv. Kinuhikari	Saga PARC	2000	2003	11358	Good taste; lodging resistance	3084	Hirota *et al.* (2001)[28)]
133	Fusa-no-mai	Sirotae-nishiki	Chubu No. 72*	*A descendant of cv. Reimei (the 3rd generation) and cv. "Mine-asahi" (the 2nd generation)	Chiba PARC	2000		11583	Good taste; tough culm	3085	Wada *et al*. (2002)[197)]
134	Fukumirai	Chubu No. 82*	Chiyo-nishiki	*"Chubu No. 44"/cv. Mine-asahi; cf. cv. "Mine-asahi"	Fukushima PAES	2000	2004	11842	Good taste; tough culm	3086	Sato *et al.* (2006)[147)]
135	Ten-no-midori	PR3*	Koshihikari	*A mutant from protoplast culture of cv. Nipponbare	Mitsubishi Chemical Co.	1996	2001	8833	Early-maturing	3087	
136	Shun-you	LGC-1*	Hokuriku No. 153**	*cf. cv. LGC1 (Appendix 1); **cv. Oochikara (the 2nd generation) of cv. Taihou x cv. Kochihibiki	NARO (NARC, Hokuriku Center)	2001	2004	12181	Low glutelin content in the grain	3088	Uehara *et al*. (2002)[194)]
137	Silky Pearl	Tan-kei2019 (Noh PL No. 14)*	Fu-kei No. 143 (cv. Yamauta)**	*A mutant from NMU treatment to cv. Kochihibiki; **cf. cv. Yamauta (the 3rd generation of cv. Reimei)	NARO(NARC for Tohoku Region)	2001	2004	12274	Semi-dwarf	3089	Takita *et al.* (2002)[167)]
138	Asa-tsuyu	Hokuriku No. 127 (Kinuhikari)*	Douhoku No. 43 (NM391**/Ishikari)	*A descendant (the 2nd generation) of cv. Reimei; **Gamma ray irradiation to cv. Nihonmasari	NARO (NARC, Hokuriku Center)	2001	2004	12180	Semi-dwarf; low amylose content	3090	Uehara *et al*. (2002)[191)]
139	Takitate	Ouu No. 343*	Tohoku No. 153	*74wx2N1/Reimei	Miyagi PAES Furukawa Branch	2001	2004	12055	Semi-dwarf	3091	Nagano *et al.* (2005)[111)]
140	Yume-no-hana	Yume-gokochi*	Yume-kahori**	*cf. cv. "Yume-gokochi"; **cf. cv. "Yume-kahori"	Plantec Research Institute	2001	2004	12045	Low amylose contents; short stem	3092	
141	Kahoruko	Kanto No. 154 (Sally Queen)	Akihikari*	*cf. cv. Akihikari (a descendant (the 1st generation) of cv. Reimei)	Niigata ARI	2001	2004	11843	Semi-dwarf	3093	
142	Akigumo	Niigata-wase*	Tan-kei 2019**	*cf. cv. "Niigata-wase"; **Named as "Noh PL No. 14"	Niigata ARI	2001	2004	11844	Low amylose content	3094	
143	Natsugumo	Yuki-no-sei	Aya*	*cf. cv. Aya	Niigata ARI	2001	2004	11845		3095	
144	Shihou	Wataboushi	Asamurasaki*	*A descendant of cv. Reimei (the 5th generation)	Niigata ARI	2001	2004	11846	Semi-dwarf	3038	
145	Benika	Niigata-mochi No. 31/Shinonoi	Niigata-mochi No. 31/Tohoku No. 144 (Hagi-no-kaori)*	*cf. cv. "Hagi-no-kahori" (a descendant (the 4th generation) of cv. Reimei)	Niigata ARI	2001	2004	11847	Semi-dwarf	3097	
146	Benisarasa	Niigata-mochi No. 31/Shinonoi	Niigata-mochi No. 31/Tohoku No. 144 (Hagi-no-kaori)*	*cf. cv. "Hagi-no-kahori" (a descendant (the 4th generation) of cv. Reimei)	Niigata ARI	2001	2004	11848	Semi-dwarf	3098	

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147	Natsushizuka	Kanto No. 136/Koshihikari	Natsuhikari*	*cf. cv. Natsuhikari: a descendant (the 4th generation) of a gamma ray induced mutant line "Fu-kei 71 gou"	Shizuoka PAES	2001	2005	12562	Semi-dwarf	3099	Miyata *et al.* (2001)[106)]
148	Toji-no-hana (Hyo-kei-sake No. 65)	Hyogo-kitanishiki*	Hidahomare	*cf. cv. "Hyogo-kita-nishiki": a descendant (the 4th generation) of cv. Reimei	Hyogo PAFFRC	2001	2004	12178	Semi-dwarf	3100	
149	Toji-no-yume (Hyo-kei-sake No. 66)	Hyogo-kitanishiki*	Gin-no-sei**	*cf. cv. "Hyogo-kita-nishiki": a descendant (the 4th generation) of cv. Reimei; **cf. cv. "Gin-no-sei"	Hyogo PARC	2001	2004	12179	Semi-dwarf	3101	
150	Nebarigoshi	21-3-6*	Kinuhikari**	*A mutant of cv. "Todoroki-wase"; **cf. cv. Kinuhikari	Nagano PAES	1997	2002	9644	Good taste; lodging resistance	3102	
151	Koshihikari Niigata BL No. 4	Koshihikari/Niigata-wase*	Koshihikari	*A descendant (the 2nd generation) of cv. Reimei	Niigata ARI	1998	2002	1023	Semi-dwarf	3103	Ishizaki, K. (2007)[46)]
152	Misato-nishiki	Yamada-nishiki	Miyama-nishiki*	*cf. cv. "Miyama-nishiki" (Appendix	Akita PAES	1998	2002	1023		3104	Masaki *et al.* (2004)[92)]
153	Koimusubi	Chubu No. 73*	Tohoku No. 143 (Hitomebore)	*Chubu No. 44/Mine-asahi; cf. cv. "Mine-asahi"	Miyagi PAES Furukawa Branch	1998	2002	1036		3105	Nagano *et al*. (2005)[110)]
154	Hoshi-aoba	Tashu-kei174（Chugoku No. 113）	Hokuriku No. 130 (Oochikara)*	*cf. cv. Oochikara	NARO (NARC for Chugoku and Shikoku Region)	2000	2003	11360		3106	Maeda *et al*. (2003)[88)]
155	LGC Soft	NM391*	LGC-1**	*A mutant line induced through gamma ray irradiation to cv. Nihonmasari; **cf. cv. "LGC-1": a mutant cultivar induced through EI treatment to cv. Nihonmasari (Appendix 1)	NARO（NARC for Chugoku and Shikoku Region） and NIAS(IRB)	2002	2005	12564	Low amylose♀; low glutelin♂	3107	Iida *et al*. (2004)[41)]
156	Mebae-mochi	EM40*	Chubu-mochi No. 57	*A mutant from NMU treatment to cv. Kinmaze	NARO (NARC, Hokuriku Center)	2002	2005	13188	Giant embryo	3108	Uehara *et al.* (2003)[189)]
157	Kusa-yutaka	Chugoku No. 105	Hokuriku No. 130 (Oochikara)*	*cf. cv. Oochikara	NARO (NARC, Hokuriku Center)	2002	2005	13189		3109	Uehara *et al*. (2003)[190)]
158	Benigoromo	Fukuhibiki*//A5	Ouu 331 gou (later named as cv. Fukuhibiki)**	*, **A descendant of cv. Reimei (the 4th generation)	NARO (NARC, Tohoku Region)	2002	2005	13186	Semi-dwarf	3110	Yamaguchi *et al.* (2005)[204)]
159	Akisayaka	Saikai No. 195	Hokuriku No. 148 (Dontokoi)*	*cf. cv. Dontokoi: a descendant (the 4th generation) of a gamma ray induced mutant line "Hokuriku 100 gou" through cv. Kinuhikari	NARO（NARC for Kyushu and Okinawa Region）	2002	2005	13187	Good taste; lodging resistance	3111	Okamoto *et al*. (2008)[132)]
160	Mie-no-yume	Aichi No. 92 (Matsuribare)*	Etsunan No. 148	*cf. cv. Matsuribare	Mie PARC	2002	2004	12056		3112	Yamakawa *et al*. (2002)[206)]
161	Tsukushi-roman	Chikushi No. 6 (Yume-tsukushi)*	Chubu No. 88 (Mochi-kei 347/Mine-asahi**)	*cf. cv. "Yume-tsukushi"; **cf. cv. "Mine-asahi"	Fukuoka ARC	2002	2005	12959		3113	Hamachi *et al.* (2003)[19)]
162	Tabegokochi	Dontokoi*	Koshihikari	*cf. cv. Dontokoi	Monsanto Japan Limited	2002	2005	12827	Good taste; lodging resistance	3114	
163	Tone-no-megumi	Dontokoi*	Koshihikari	*cf. cv. Dontokoi	Monsanto Japan Limited	2002	2005	12828	Good taste; lodging resistance	3115	

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164	Hanaemaki	Douhoku No. 53*/Noh PL No. 11	Kuu-iku No. 139 (Yukimaru)	*A mutant of "Nihon-masari" (NM391)	NARO (NARC for Hokkaido Region)	2003	2006	14032	Low amylose content	3116	
165	Oborozuki	Kuu-iku No. 150 (Akiho)	Hokkai No. 287*	**in vitro* variation of cv. "Kirara 397"	NARO (NARC for Hokkaido Region)	2003	2006	14033		3117	Ando *et al*. (2006)[4]
166	Churahikari	Tohoku No. 143 (Hitomebore)	Ouu No. 338*	*A descendant (the 2nd generation) of cv. "Mine-asahi"	NARO (NARC for Tohoku Region)	2003	2006	14034		3118	Yamaguchi *et al*. (2005)[203]
167	Sakihikari	Hinohikari	Kinuhikari*	*cf. cv. Kinuhikari	Fukui PAES	2003	2006	13875	Good taste; lodging resistance	3119	Horiuchi *et al.* (2004)[35]
168	LGC-Katsu	LGC-1*	89WPKG30-433**	*cf. cv. "LGC-1" (Appendix 1); **A mutant with 26Da globulin deletion induced by gamma ray irradiation to WPK	NARO (National Institute of Crop Science) and NIAS (IRB)	2004	2006	13871	Easy-to-digest protein 50 % decrease	3120	Nishimura *et al.* (2005)[124]
169	LGC-Jun	LGC-1*	89WPKG30-433**	*cf. cv. "LGC-1" (Appendix 1); **A mutant with 26Da globulin deletion induced by gamma ray irradiation to WPK	NARO (National Institute of Crop Science) and NIAS (IRB)	2004	2006	13872	Easy-to-digest protein 50 % decrease	3121	Nishimura *et al*. (2005)[124]
170	Hana-omoi	Yamada-nishiki	Hanafubuki*	*A descendant (the 2nd generation) of cv. Reimei	Aomori PAES	2002	2006	13863	Semi-dwarf	3122	Mikami *et al*. (2003)[102]
171	Sai-no-kagayaki	Aichi No. 92 (Matsuribare)*	Tama-kei No. 88 (Sai-no-yume)**	*cf. cv. Matsuribare; **cf. cv. "Sai-no-yume"	Saitama PAFRI	2002	2005	12699		3123	Arakawa *et al.* (2003)[7]
172	Sai-no-kirabiyaka	Aichi No. 92 (Matsuribare)*	Tama-kei No. 88 (Sai-no-yume)**	*cf. cv. Matsuribare; **cf. cv. "Sai-no-yume"	Saitama PAES	2002	2005	12700		3124	Arakawa *et al*. (2003)[7]
173	Fuku-izumi	Saikai No. 199	Dontokoi*	*cf. cv. Dontokoi	NARO (NARC for Kyushu and Okinawa Region)	2004	2007	14889	Good taste; lodging resistance	3125	Kaji *et al*. (2006)[56]
174	Ikuhikari	Etsunan No. 148	Hokuriku No. 148 (Dontokoi)*	*cf. cv. Dontokoi	Fukui PAES	2004	2007	14999	Good taste; lodging resistance	3126	Tomita *et al.* (2005)[182]
175	Miya-yutaka	Nankai No. 133	Saikai No. 215 (Yawarakomachi)*	*cf. cv. Yawarakomachi	Miyazaki ARI	2004	2007	15000	Low amylose content	3127	Kato *et al*. (2006)[64]
176	Aki-neiro	Koganebare	Milky Queen (Kanto No. 168)*	*A mutant cultivar with low amylose content induced by a chemical mutagen (NMU) + anther culture; cf. cv. "Milky Queen" (Appendix 1)	Kumamoto PARC	2001	2005	12566	Low amylose content	3128	Mitsukawa *et al*. (2002)[103]
177	Seiki-wan	Koshihikari	Haenuki*	*A descendant (the 4th generation) of cv. Reimei	Mr. Masaki OIKAWA	1998	2003	11232	Semi-dwarf		
178	Komurasaki	Tohoku-mochi 149 gou	Tatsuko-mochi*	*A descendant (the 2nd generation) of cv. Reimei through cv. Akihikari	Akita PAES	2000	2004	11841	Semi-dwarf		Matsumoto *et al*. (2006)[96]
179	Hikari-shinseiki	Kanto 79 gou*	Jikkoku	*A mutant line induced through gamma ray irradiation to the seed of cv. Koshihikari	Tottori University	1999	2004	12273	Semi-dwarf		Tomita (2006)[178]
180	Kaze-naruko	Tsuyuhakaze	Ippon-jime*	*A descendant (the 2nd generation) of cv. Reimei through cv. Houhai	Kochi PARC	2001	2005	12563	Semi-dwarf		Mizobuchi *et al.* (2003)[107]
181	Chigo-no-hoho	Wataboushi	Hagi-no-kaori*	*A descendant (the 3rd generation) of cv. Reimei through cv. Houhai	Niigata PAES	2001	2005	12702	Semi-dwarf		Kobayashi (2008)[73]

No.	Cultivar Name	Maternal Line	Paternal Line	Origin of Parental Line	Institution of Development	Dev. Year	Reg. Year	Reg. No.[a]	Mutant Characteristics Transferred	IAEA ID[b]	Reference
182	Ekkakou	Todoroki-wase	Hagi-no-kaori*	*A descendant (the 3rd generation) of cv. Reimei through cv. Houhai	Niigata PAES	2001	2005	12703	Semi-dwarf		Kobayashi (2008)[73]
183	Koshiguruma	Hokkai 269 gou*	Niigata wase**	*A descendant of a mutant line "Tankei 2006", whose embryo is very large, that is induced through gamma ray irradiation to cv. Kinmaze; **A descendant (the 2nd generation) of cv. Reimei	Niigata PAES	2001	2005	12704	Large embryo		
184	Akita 63 gou	Oochikara*	Akita 39 gou	*A hybrid variety between 2 mutant lines, cf. cv. Oochikara	Akita PAES	2001	2005	12826			Kodama *et al*. (2014)[75]
185	Fukkura-momoko	Kinuhikari*	Koshihikari	*A mutant cultivar induced through gamma ray irradiation to cv. Koshihikari	Okayama PAES	2002	2005	13297	Good taste; lodging resistance		Hihara *et al.* (2004)[25]
186	Kinpika	An original line	Haenuki*	*A descendant (the 4th generation) of cv. Reimei	Ibigawa Kougyo Co. Ltd.	2002	2006	13636	Semi-dwarf		
187	Hana-hyogo	Hatsugozen	Kinuhikari*	*cf. cv. Kinuhikari	Hyogo PARC	2002	2006	13742	Good taste; lodging resistance		
188	Fuyu-geshiki	Yamagata 40 gou*	Ao-kei 113 gou**	*A descendant (the 3rd generation) of cv. Reimei through cv. Akihikari; **A descendant (the 3rd generation) of cv. Reimei	Aomori PAES	2002	2006	13867	Semi-dwarf		Mikami *et al.* (2004)[99]
189	Koma-no-mai	Yamagata 40 gou*	Fu-kei 164 gou**	*A descendant (the 3rd generation) of cv. Reimei through cv. Akihikari; **A descendant (the 3rd generation) of cv. Reimei through cv. Akihikari	Aomori PAEX	2003	2006	13874	Semi-dwarf		Sunohara *et al*. (2004)[158]
190	Yume-mirai	Yume-gokochi*	Yume-kahori**	*A mutant cultivar induced through a protoplast somaclonal variation from cv. Koshihikari; **A mutant cultivar induced through a protoplast somaclonal variation from cv. "Tsuki-no-hikari"	Plantec Research Institute Ltd.	2003	2006	14036	Low amylose content		
191	Tenshi-no-uta	Saikai 201 gou*	Kanto 165 gou**	*A descendant of cv. "Mine-asahi"; **A descendant of cv. Kinuhikari	Saga PARC	2001	2006	14296	Good taste; lodging resistance		
192	Yume-ikkon	Hokuriku 160 gou*	Yume-tsukushi**	*A descendant (the 3rd generation) of cv. Reimei through cv. "Niigata-wase"; **A descendant (the 2nd generation) of cv. Kinuhikari	Fukuoka PAES	2002	2006	14525	Semi-dwarf; good taste; lodging resistance		Hamachi *et al.* (2004)[20]
193	Nasuhikari	Koshihikari	Aichi 87 gou*	* A descendant of cv. "Mine-asahi"	Tochigi PAES	2004	2007	14775			Izawa *et al.* (2005)[53]
194	Hyogo-yume-otome	Kinuhikari*	Aoi-no-kaze	*cf. cv. Kinuhikari	Hyogo PARC	2003	2007	14776	Good taste; lodging resistance		
195	Chiba 28 gou	Chubu 64 gou*	Fusa-otome	*A descendant of cv. "Mine-asahi"	Chiba PARC	2003	2007	14882			Nishikawa *et al.* (2006)[123]
196	Koi-honoka	An original line	Yamauta*	*A descendant (the 3rd generation) of cv. Reimei through cv. Akihikari	Aomori PAES	2004	2007	14884	Semi-dwarf		Mikami *et al.* (2007)[101]
197	Yuki-no-hana	Oshimako180*	Kakehashi	*A hybrid between cv. Reimei and a mutant line of "Nihon-masari"	Aomori PAES	2003	2007	14886	Semi-dwarf		Sunohara *et al*. (2007)[157]

No.	Cultivar Name	Maternal Line	Paternal Line	Origin of Parental Line	Institution of Development	Dev. Year	Reg. Year	Reg. No.[a]	Mutant Characteristics Transferred	IAEA ID[b]	Reference
198	Yume-aoba	An indica-japonica hybrid line	Fukuhibiki*	*A descendant (the 4th generation) of cv. Reimei	NARO Hokuriku ARC	2004	2007	14887	Semi-dwarf		Miura *et al.* (2006)[105]
199	Nishi-aoba	Oochikara*	Hitohana	*cf. cv. Oochikara	NARO Kyushu Okinawa ARC	2004	2007	14888	Semi-dwarf	3325	Tamura *et al*. (2007)[171]
200	Dewa-no-sato	Gin-fubuki	Dewa-sansan*	*cf. "Dewa-sansan": a descendant of cv. Reimei (the 3rd generation) through cv. Hanafubuki and cv. "Miyama-nishiki" (the 2nd generation)	Yamagata PAES	2004	2007	15119	Semi-dwarf	3361	Yuki *et al*. (2006)[215]
201	Sato-no-yuki	Shou 1658*	Yamagata 63 gou**	*A descendant of a somaclonal variation from the anther culture of cv. "Akita-komachi"; **A descendant of cv. Kinuhikari	Yamagata PAES	2004	2007	15534	Good taste; lodging resistance		
202	Lake 65	Hinohikari	Kinuhikari*	*cf. cv. Kinuhikari	Shiga PAES	2004	2008	16011	Good taste; lodging resistance		Nakagawa *et al.* (2005)[115]
203	Yukinko-mai	Doman-naka*	Yukinosei	*A descendant (the 2nd generation) of cv. "Mine-asahi"; a descendant (the 3rd generation) of cv. Reimei	Niigata PAES	2004	2008	16012	Semi-dwarf		Ishizaki *et al.* (2008)[47]
204	Fuku-okoshi	Hoso-omote*	Fukuhibiki**	*A descendant of cv. "Shinano-sakigake", a mutant through gamma ray irradiation to cv. Toyonishiki; **A descendant (the 4th generation) of cv. Reimei	Nagano PAES	2004	2008	16288	Semi-dwarf		
205	Yume-kanae	LGC1*	Hitomebore	*cf. cv. LGC1 (Appendix 1)	Chiba PARC	2004	2008	16289	Low glutelin content in the grain		
206	Awayuki-komachi	Ouu 343 gou*	Dewahikari**	*A descendant (the 1st generation) of cv. Reimei; **A descendant (the 3rd generation) of cv. Reimei	Akita PAES	2002	2008	16290	Semi-dwarf		Kodama *et al*. (2010)[76]
207	Himuka-mochi	Mine-no-yuki-mochi*	Miyazaki-mochi	*A descendant of cv. Reimei through cv. Hayahikari	Miyazaki PAES	2005	2008	16466	Semi-dwarf		
208	Donpishyari	Gan-nan 7 gou	Fu-kei 179 gou*	*A descendant (the 4th generation) of cv. Reimei through cv. Hatsukogane	Iwate PAES	2005	2008	16604	Semi-dwarf		Tamura *et al.* (2007)[170]
209	Akimasari	Manpuku-mochi	Akisayaka*	*A descendant (the 2nd generation) of cv. Kinuhikari through cv. Dontokoi	NARO Kyushu Okinawa ARC	2006	2008	16606	Good taste; lodging resistance		Sakai *et al*. (2006)[138]
210	Ayu-no-hikari	EM5*	Fukuhibiki**	*A mutant induced through NMU treatment to cv. Kinmaze; **A descendant (the 4th generation) of cv. Reimei	NARO Hokuriku ARC	2005	2008	16607	Semi-dwarf		Miura *et al*. (2007)[104]
211	Kinumusume	Kinuhikari*	Matsuribare**	*cf. cv. Kinuhikari; **A descendant of cv. "Mine-asahi"	NARO Kyushu Okinawa ARC	2005	2008	16609	Good taste; lodging resistance		Kaji *et al.* (2009)[57]
212	Beko-aoba	Oochikara*	Saikai 203 gou	*cf. cv. Oochikara	NARO Tohoku ARC	2005	2008	16610		3320	Nakagomi *et al.* (2006)[116]
213	Nikomaru	Kinumusume*	Hokuriku 174 gou**	*A descendant of cv. Kinuhikari; **A descendant of cv. Kinuhikari through cv. Dontokoi	NARO Kyushu Okinawa ARC	2005	2008	16611			Sakai *et al*. (2010)[140]

No.	Cultivar Name	Maternal Line	Paternal Line	Origin of Parental Line	Institution of Development	Dev. Year	Reg. Year	Reg. No.[a]	Mutant Characteristics Transferred	IAEA ID[b]	Reference
214	Hikarikko	Koshihikari	Reimei*	*cf. cv. Reimei (Appendix 1); A mutant cultivar induced through a gamma ray irradiation to cv. Fujiminori	Mr. Masayuki MURAI		2009	18110	Semi-dwarf		
215	Nangoku-sodachi	Kouiku 30 gou*	Kou-kei 265**	*A descendant of cv. Reimei through cv. Hayahikari; **A descendant of cv. "Katsura-wase", cf. cv. "Katura-wase"	Kochi PARC		2009	18117	Semi-dwarf		Takata *et al*. (2005)[166)]
216	Satsuma-yuki-mochi	Mine-no-yuki-mochi*	KG Mochi 102	*A descendant (the 3rd generation) of cv. Reimei through cv. Hayahikari (the 1st generation)	Kagoshima Prefectural Institute for Agricultural Development		2009	18117	Semi-dwarf		Wakamatsu *et al*. (2007)[200)]
217	Mine-no-yuki-mochi	Ouu 302 gou*	Himeno-mochi	*A descendant (the 2nd generation) of cv. Reimei	Hokuriku NAES	1991	1995	4231	Semi-dwarf		Shimizu *et al*. (1993)[151)]
218	Massigura	Ouu 341 gou	Yamagata 40 gou*	*A descendant (the 4th generation)of cv. Reimei through cv. Akihikari	Aomori Prefectural Industrial Technology Research Center		2009	18348	Semi-dwarf		
219	New Hikari	Etsunan 148 gou	Milky Queen (Kanto No. 168)*	*cf. cv. "Milky Queen" (Appendix 1)	Fukui PAES		2009	18349	Low amylose content		Tomita *et al.* (2007)[181)]
220	Hoshimaru	Kami-iku 428 gou	Kuiku 159 gou*	*A descendant (the 4th generation) of cv. Hayamasari through cv. Ishikari	Hokkaido Prefectural Kamikawa Agricultural Experiment Station		2009	18350			
221	Moe-minori	Nankai 128 gou	Haenuki*	*A descendant (the 4th generation) of cv. Reimei through "Shonai 29 gou"	NARO Tohoku ARC		2009	18351	Semi-dwarf		Kataoka *et al*. (2007)[62)]
222	Tachi-aoba	Ha-kei 906*	An original line**	*A descendant (the 3rd generation) of cv. "Mine-asahi" through cv. Matsuribare; **A descendant (the 3rd generation) of cv. Kinuhikari	NARO Kyushu Okinawa ARC		2009	18352			Sakai *et al*. (2009)[139)]
223	Yuyake-mochi	Tatsuko-mochi*	Benigoromo**	*A descendant (the 2nd generation) of cv. Reimei through cv. Akihikari; **A descendant of cv. Reimei through cv. Fukuhibiki (the 4th generation)	NARO Tohoku ARC		2009	18353	Semi-dwarf	3356	Kataoka *et al*. (2007)[61)]
224	Kareimai	Miyan 23 gou	Akihikari*	*A descendant (the 1st generation) of cv. Reimei	NARO Hokuriku ARC		2009	18473	Semi-dwarf		Shigemune *et al*. (2011)[150)]
225	Koyuki-mochi	Wataboushi	Yamagata mochi 55 gou*	*A descendant (the 4th generation) of cv. Reimei through cv. "Kaguya--mochi"	Yamagata PAES		2009	18546	Semi-dwarf		Chuba *et al*. (2007)[9)]
226	Sue-akari	Aoi-no-kaze	Milky Queen (Kanto No. 168)*	*cf. cv. "Milky Queen" (Appendix 1)	Mr. Jiro OZEKI		2008	16008	Low amylose content		
227	Ayanatsuki	Aya*	An original line	*cf. "Aya" (NM391/Ishikari); (the 2nd generation of a gamma ray induced endosperm mutant "NM391"	Kagoshima PAES		2008	16010	Low amylose content		Wakamatsu *et al*. (2005)[199)]

No.	Cultivar Name	Maternal Line	Paternal Line	Origin of Parental Line	Institution of Development	Dev. Year	Reg. Year	Reg. No.[a]	Mutant Characteristics Transferred	IAEA ID[b]	Reference
228	Mizuhonoka	LGC1*	Hyogo-kitanishiki**	*cf. cv. "LGC 1" (Appendix 1); **A descendant (the 4th generation) of cv. Reimei through cv. Nadahikari	NARO Kinki Chugoku Shikoku ARC		2010	19409	Low glutelin content in the grain; semi-dwarf		Iida *et al*. (2009)[40)]
229	Manpuku-mochi	Etsunan 144 gou	Fukuhibiki*	*A descendant (the 4th generation) of cv. Reimei	Fukui PAES		2010	19053	Semi-dwarf		Tomita *et al.* (2008)[179)]
230	Yukimusubi	Hatajirushi*	Higashi 810**	*A descendant (the 3rd generation)of cv. "Mine-asahi"; **A descendant (the 2nd generation) of cv. Reimei	Miyagi Prefectural Furukawa Agricultural Experiment Station		2010	19502	Tolerance to cold; semi-dwarf		Nagano *et al*. (2008)[109)]
231	Koujyu-muryou	Yume-gokochi*	Yume-kahori**	*cf. cv. "Yume-gokochi" (Appendix 1); **cf. cv. "Yume-kahori" (Appendix 1)	Katayama Kometen Co.		2010	18775			
232	Seto-no-niji	Hinohikari	Matsuribare*	*A descendant (the 1st generation) of cv. "Mine-asahi"	Yamaguchi Technology Center for Agriculture and Forestry		2010	19691			Hajima *et al*. (2010)[16)]
233	Aki-matsuri	Yamahikari	Matsuribare*	*A descendant (the 1st generation) of cv. "Mine-asahi"	Yamaguchi Technology Center for Agriculture and Forestry		2010	19692			Hajima *et al*. (2012)[15)]
234	Yume-sorara	Koshihikari	Akihikari*	*A descendant (the 1st generation) of cv. Reimei	Tottori PAES		2010	18780	Semi-dwarf		
235	Tenryu-otome	Inahikari*	Matsuribare**	*, **A descendant (the 1st generation) of cv. "Mine-asahi"	Nagano PAES		2010	19267			
236	Takane-murasaki	Kaguya-mochi*	Tohoku mochi 149 gou	*A descendant (the 4th generation) of cv. Reimei	Nagano PAES		2010	19045	Semi-dwarf		
237	Kinuhikari-Saitama SBL	Kinuhikari*	Sai-no-kagayaki**	*cf. cv. Kinuhikari; ** A descendant of cv. "Mine-asahi"	Saitama PAES		2010	19049	Good taste; lodging resistance		Arakawa *et al*. (2008)[6)]
238	Mine-no-murasaki	An original line	Asamurasaki*	*A descendant (the 5th generation) of cv. Reimei through cv. Fukuhibiki	Aichi PAES		3010	19055	Semi-dwarf		Saka *et al*. (2007)[137)]
239	Beko-gonomi	An original line*	Fukuhibiki**	*A descendant (the 4th generation) of cv. Reimei; **A descendant (the 4th generation) of cv. Reimei	NARO NARC Tohoku Reg.		2010	19355	Semi-dwarf		Nakagomi *et al.* (2008)[117)]
240	Yume-matsuri	Asahi-no-yume*	Daichi-no-kaze**	*, **A descendant of cv. "Mine-asahi"	Aichi PAES		2010	19357			Kato *et al*. (2008)[65)]
241	Ishikawa Sake 52 gou	An original line	Ippon-jime*	*A descendant (the 2nd generation) of cv. Reimei through cv. Houhai	Ishikawa PAES		2010	19695	Semi-dwarf		
242	Tomi-no-kaori	Yamadanishiki	Oyamanishiki*	*A descendant (the 2nd generation) of cv. "Miyama-nishiki", that was induced through gamma ray irradiation to cv. Takanenishiki (Appendix 1)	Toyama PAES		2010	19696			Ebitani *et al.* (2009)[10)]
243	Mini-hikari	Hikari-shinseiki*	An original line	*A descendant (the 3rd generation) of "Kanto 79 gou", that was induced through gamma ray irradiation (200 Gy) to the seed of cv. Koshihikari	Mr. Motonori TOMITA		2010	19985			

No.	Cultivar Name	Maternal Line	Paternal Line	Origin of Parental Line	Institution of Development	Dev. Year	Reg. Year	Reg. No.[a]	Mutant Characteristics Transferred	IAEA ID[b]	Reference
244	Sai-no-minori	Yumematsuri (Aichi 108 gou)*	Sai-no-kagayaki**	*A descendant of (G4 and G5, respectively) a gamma ray induced line "Kanto 79 gou" through cv. "Mine-asahi" and cv. Matsuribare; **A descendant (the 3rd generation) of "Kanto 79 gou" through cv. Matsuribare , a descendant (the 4th generation) of cv. Reimei	Saitama Pref. Agr. Forest. Res. Ctr.		2010	20027	Semi-dwarf		Ooka *et al* . (2009)[136)]
245	Koshi-no-kaori	Kinuhikari*	An indica-japonica hybrid back-crossed to Kinuhikari**	*, **cf. cv. Kinuhikari	NARO		2011	20349	Good taste; lodging resistance		Sasahara *et al* . (2013)[142)]
246	Shikibu-mochi	Asamurasaki (Ouu mochi 349 gou)*	Fu-kei mochi 170 gou	*A descendant (the 4th generation) of cv. Reimei through cv. Fukuhibiki	Aomori Prefectural Industrial Technology Research Center		2010	20030	Semi-dwarf		
247	Murasaki-no-kimi	Asamurasaki (Ouu mochi 349 gou)*	Fu-kei 176 gou	*A descendant (the 4th generation) of cv. Reimei through cv. Fukuhibiki	Aomori Prefectural Industrial Technology Research Center		2010	20031	Semi-dwarf		
248	Ake-no-murasaki	Asamurasaki (Ouu mochi 349 gou)*	Silky Pearl (Ouu 354 gou)**	*A descendant (the 4th generation) of cv. Reimei through cv. Fukuhibiki; **cf. cv. "Silky Pearl"	Iwate ARC		2011	20710	Semi-dwarf		Takakusagi *et al.* (2008)[162)]
249	Gin-sayaka	Syun-yo (Hokuriku 183 gou)*	Gin-ginga (Iwate minami sake 13 gou)**	*A descendant (the 1st generation) of cv. "LGC1" (Appendix 1); **A descendant of cv. Reimei (Appendix 1) and cv. "Miyama-nishiki"	Iwate ARC		2011	20711	Semi-dwarf		
250	Aki-sakari	Awaminori (Hokuriku 159 gou)*	Etsunan 173 gou**	*A descendant (the 1st generation) of cv. Kinuhikari; **A descendant (the 1st generation) of both cv. Kinuhikari and a descendant (the 3rd generation) of cv. Reimei	Fukui PAES		2011	20431	Semi-dwarf		Tomita *et al* . (2009)[180)]
251	Kita-aoba	Yume-aoba (Hokuriku 187 gou)*	cv. "Hatsushizuku" and cv. "Nanatsuboshi"	*A descendant (the 4th generation) of cv. Reimei through cv. Fukuhibiki	NARO		2011	20615	Semi-dwarf		
252	Ushi-yutaka	Yume-akari (Ao-kei 125 gou)*	Kanto PL 12 (Tsu-kei 995 gou)**	*A descendant of cv. Reimei; **A descendant of cv. Reimei through cv. "Musashi-kogane"	Aomori Prefectural Industrial Technology Research Center		2011	20530	Semi-dwarf		Maeda *et al* . (2008)[87)]
253	Murasaki-koboshi	Kanto 195 gou	Asamurasaki*	*A descendant (the 4th generation) of cv. Reimei through cv. Fukuhibiki	NARO NARC Tohoku Reg.		2011	20714	Semi-dwarf		Kataoka *et al* . (2010)[63)]
254	Nebari-yuki	Takitate (Tohoku 172 gou)*	Ao-kei 134 gou**	*A descendant (the 2nd generation) of cv. Reimei through "Ouu 343 gou"; **A descendant (the 3rd generation) of cv. Reimei through cv. Akihikari	Aomori Prefectural Industrial Technology Research Center		2011	20533	Semi-dwarf		Kon *et al* . (2008)[80)]

No.	Cultivar Name	Maternal Line	Paternal Line	Origin of Parental Line	Institution of Development	Dev. Year	Reg. Year	Reg. No.[a]	Mutant Characteristics Transferred	IAEA ID[b]	Reference
255	Saga-biyori	Tenshi-no-uta*	Aichi-no-kaori SBL**	*A descendant of both cv. "Mine-asahi" (the 3rd generation) and cv. Kinuhikari (the 2nd generation); **A descendant (the 3rd generation) of cv. "Mine-asahi"	Saga PARC		2011	20775			Hirota *et al*. (2012)[29)]
256	Genki-tsukushi	Tsukushi-roman (Chikushi 46 gou)*	Tsukushi wase**	*A descendant (the 2nd generation) of cv. Kinuhikari; **A descendant (the 2nd generation) of cv. Kinuhikari	Fukuoka PAES		2011	20744	Good taste; lodging resistance		Wada *et al.* (2010)[198)]
257	Tsubu-yutaka	An original line	Fukuhibiki*	*A descendant (the 4th generation) of cv. Reimei	Iwate ARC		2011	20716	Semi-dwarf		Abe *et al.* (2009)[1)]
258	Akidawara	Mirenishiki (Kanto 188 gou)	Ikuhikari (Etsunan 176 gou)*	*A descendant (the 2nd generation) of cv. Kinuhikari through cv. Dontokoi	NARO National Institute of Crop Science		2011	20717	Good taste; lodging resistance		Ando *et al.* (2011)[5)]
259	Milky Star	Tohoku 168 gou*	Milky Princess (Tohoku 194 gou)**	*A descendant (the 4th generation) of cv. Reimei through cv. Akihikari; **A descendant (the 1st generation) of cv. "Milky Queen" (Appendix 1)	NARO National Institute of Crop Science		2011	20718	Low amylose content		Ishii *et al.* (2012)[44)]
260	Milky Summer	Wa-kei 243	Milky Queen (Kanto No. 168)*	*cf. cv. "Milky Queen" (Appendix 1)	NARO National Institute of Crop Science		2011	20745	Low amylose content		
261	Kinefuri-mochi	Mine-no-yuki-mochi*	Kokonoe-mochi	*A descendant (the 3rd generation) of cv. Reimei through cv. Hayahikari	Gifu PAES		2011	20945	Semi-dwarf		Hirose *et al.* (2010)[27)]
262	Mina-yutaka	Fuyu-geshiki*	Fu-kei 186 gou**	*A descendant (the 4th generation) of cv. Reimei through cv Akihikari; **A descendant (the 3rd generation) of cv. Reimei through cv. Akihikari	Aomori Prefectural Industrial Technology Research Center		2011	20913	Semi-dwarf		Ono *et al*. (2009)[135)]
263	Maki-mizuho	Hoshi-aoba*	Kusa-yutaka**	*A descendant (the 1st generation) of cv. Oochikara; ** A descendant of cv. Oochikara	NARO Kyushu Okinawa ARC and JIRCAS		2011	21175	Semi-dwarf		
264	Mogu-mogu-aoba	Hoshi-aoba*	Mizuho-chikara**	*A descendant (the 1st generation) of cv. Oochikara; **A descendant (the 3rd generation) of cv. Reimei through cv. Akihikari	NARO Kyushu Okinawa ARC and JIRCAS		2011	20915	Semi-dwarf		
265	Hime-gonomi	Milky Queen*	Chugoku 169 gou	*cf. cv. "Milky Queen" (an NMU induced mutant cultivar) (Appendix 1)	NARO NARC for Western Region and JIRCAS		2012	21717	Low amylose content		Iida *et al*. (2011)[39)]
266	Yamadawara	Izumi 348*	Kanto 192 gou**	*A descendant (the 5th generation) of cv. Reimei through cv. Akihikari; **A descendant (the 3rd generation) of cv. Kinuhikari through cv. Dontokoi	NARO National Institute of Crop Science and JIRCAS		2014	23197	Semi-dwarf		
267	Kita-aoba	Yume-aoba (Hokuriku 187 gou)*	Nanatsuboshi (Kuiku 163 gou)	*A descendant (the 5th generation) of cv. Reimei through cv. Fukuhibiki	NARO Hokuriku ARC		2011	20615	Semi-dwarf		
268	Tsukuba SD2 gou	An original line	Milky Queen*	*cf. cv. "Milky Queen": an NMU induced mutant cultivar (Appendix 1)	Plant Genome Center Co. Ltd.		2012	21431	Low amylose content		
269	Torihime	Kan-no-mai*	Gyokuei	*A descendant (the 1st generation) of cv. "Miyama-nishiki"	Tottori PAES		2012	21383			

No.	Cultivar Name	Maternal Line	Paternal Line	Origin of Parental Line	Institution of Development	Dev. Year	Reg. Year	Reg. No.[a]	Mutant Characteristics Transferred	IAEA ID[b]	Reference
270	Yuki-asobi	An original line	Yume-akari*	*A descendant (the 5th generation) of cv. Reimei	Aomori Prefectural Industrial Technology Research Center		2012	21433	Semi-dwarf		Kobayashi *et al*. (2010)[74)]
271	Natsu-aoba	Yume-aoba (Hokuriku 187 gou)*	Akichikara**	*A descendant (the 5th generation) of cv. Reimei through cv. Fukuhibiki; **A descendant (the 2nd generation) of cv. Reimei	NARO Hokuriku ARC		2012	21434	Semi-dwarf		Nagaoka *et al*. (2013)[112)]
272	Jyugemu	Yume-ikkon*	Yamadanishiki	*A descendant of both cv. Reimei and cv. Kinuhikari	Mr. Norimitsu KAWAMURA		2012	22025	Semi-dwarf		
273	Niigata-Jiro	Akihikari*	Niigata 11 gou	*A descendant (the 1st generation) of cv. Reimei	Niigata PAES		2013	22426	Semi-dwarf		Ishizaki *et al*. (2014)[48)]
274	Kin-no-megumi	Okini-iri*	Asominori	*A descendant (the 4th generation) of cv. Reimei	NARO, Toyo Rice Co. Ltd.		2013	22530	Semi-dwarf		Kaji *et al.* (2013)[55)]
275	Harumi	Koshihikari	Kinuhikari*	*cf. cv. Kinuhikari	Japan Agricultural Co-operatives (JA)		2014	22985	Good taste; lodging resistance		
276	Rakufumai	Dontokoi*	Gohyaku-mangoku	*A descendant (the 1st generation) of cv. Kinuhikari	NARO ARC		2014	23198	Good taste; lodging resistance		
277	Tachi-ayaka	Hoshi-aoba*	An original line	*A descendant (the 2nd generation) of "BG1" through cv. Oochikara	NARO Kinki Chugoku Shikoku ARC		2014	23275	Semi-dwarf		
278	Haigokoro	Milky Princess*	An original line	*A descendant (the 1st generation) of cv. "Milky Queen"	NARO Kinki Chugoku Shikoku ARC		2014	23276	Low amylose content		Ishii *et al*. (2013)[45)]
279	Sato-no-shirayuki	Hokuriku mochi 175 gou*	Aneko-mochi**	*,**A descendant (the 3rd generation) of cv. Reimei	NARO ARC		2014	23429	Semi-dwarf		
280	Yume-no-mai	Koimusubi (Tohoku 160 gou)*	Syu 6084**	*A descendant (the 3rd generation) of "Kanto 79 gou" through cv. "Mine-asahi"; ** A descendant (the 2nd generation) of cv. Kinuhikari	NARO Agricultural Research Center		2014	23320	Good taste; lodging resistance		
281	Tochigi-no-hoshi	Tochigi 11 gou	Nasuhikari (Tochigi 7 gou)*	*A descendant of both "Kanto 79 gou" through cv. "Mine-asahi" (the 5th generation) and cv. Reimei (the 4th generation)	Tochigi PAES		2015	24269	Semi-dwarf		Yamazaki *et al.* (2012)[211)]
282	Kazusa 1 gou	Koshihikari Kazusa 9 gou	Milky Queen (Kanto No. 168)*	*cf. cv. "Milky Queen" (Appendix 1)	Honda Motor Co., Ltd.		2015	24336	Low amylose content		
283	Koshi-izumi	Hikari-shinseiki*	Yutaka-Koshihikari	*A descendant (the 5th generation) of "Kanto 59 gou"	Tottori University and Shizuoka University		2015	23807			
284	Pikamaru	Kanto 221 gou*	Nikomaru (Saikai 250 gou)**	*A descendant of cv. "Milky Queen" through cv. "Milky Princess"; **A descendant of cv. Kinuhikari	NARO Kyushu Okinawa ARC		2015	24270	Low amylose content; good taste; lodging resistance		

No.	Cultivar Name	Maternal Line	Paternal Line	Origin of Parental Line	Institution of Development	Dev. Year	Reg. Year	Reg. No.[a]	Mutant Characteristics Transferred	IAEA ID[b]	Reference
285	Konadamon	Hinohikari	Houiku 5 gou*	*A hybrid between an EI induced mutant cv. "LGC1" and a gamma ray induced mutant line "89WPKG30-433)	NARO Kyushu Okinawa ARC		2015	24337	Low digestible protein content (low glutelin content; low globulin content) and high non-digestible protein (prolamine) content		
286	Seto-no-kagayaki	Kinumusume (Saikai 232 gou)*	Yumematsuri (Aichi 108 gou)**	*cf. cv. Kinumusume; **cf. cv. Yumematsuri	NARO Kinki Chugoku Shikoku ARC		2015	24361	Good taste with lodging resistance		
287	Emi-no-aki	Mine-haruka (Chubu 111 gou)*	Moeminori (Ouu 382 gou)**	*A descendant of "Kanto 79 gou" through cv. Mineasahi; **A descendant (the 5th generation) of cv. Reimei	NARO Tohoku ARC		2015	24271	Semi-dwarf		
288	Yume-fuwari	Takitate (Tohoku 172 gou)*	LGC-Katsu**	*A descendant (the 2nd generation) of cv. Reimei; **A descendant (the 1st generation) of cv. "LGC1"	NARO Tohoku ARC and JIRCAS		2015	24272	Semi-dwarf		
289	Tachi-hayate	An original line*	Hoshi-aoba (Chugoku 146 gou)**	*A descendant (the 1st generation) of cv. "Odoroki-mochi" (Appendix 1); **A descendant (the 3rd generation) of Taihou through cv. Oochikara	NARO National Institute of Crop Science		2015	24364			
290	Yamagata mochi 110 gou	Tatsuko-mochi (Akita mochi 45 gou)*	Oochikara**	*A descendant (the 2nd generation) of cv. Reimei through cv. Akihikari; **A descendant (the 2nd generation) of cv. Taihou	Yamagata PAES		2015	24457	Semi-dwarf		
291	Kiraho	Milky Princess*	Iwate 61 gou	*A descendant (the 1st generation) of cv. "Milky Queen" (Appendix 1)	Iwate ARC		2015	24582	Low amylose content		
292	Kin-no-ibuki	Takitate (Tohoku 172 gou)*	Mebae-mochi**	*A descendant (the 3rd generation) of cv. Reimei; **A descendant (the 2nd generation) of a NMU induced mutant line from cv. Kinmaze	Miyagi Prefectural Furukawa Agricultural Experiment Station		2015	24378	Semi-dwarf		
293	Yamagata 95 gou	Yamagata 59 gou*	Chura-hikari (Ouu 366 gou)**	*A descendant of cv. Reimei; **A descendant (the 4th generation) of "Kanto 79 gou" through cv. "Mine-asahi"	Yamagata PAES		2015	24454	Semi-dwarf		
294	Iwai-dawara	Ouu shi 394 gou	Beko-gonomi (Ouu shi 395 gou)*	*A hybrid between 2 descendants (both the 5th generation) of cv. Reimei	NARO National ARC for Tohoku Region		2015	24363	Semi-dwarf		
295	Hana-sayaka	Kuro 1900*	Gin-ginga (Gannan sake 13 gou)**	*A descendant of cv. Reimei; **A descendant of both cv. Reimei and cv. "Miyama-nishiki"	Aomori Prefectural Industrial Technology Research Center		2015	24456	Semi-dwarf		
296	Mine-no-hoshi	Akita-komachi*4/Mine-asahiRF*	Akita-komachi*4/(Chubu 111	*,**cf. cv. "Mine-asahi"	Aichi PAES		2015	24365			
297	Ginsan	Iwate 75 gou	Akita 63 gou*	*A descendant (the 3rd generation) of cv. Taihou through cv. Oochikara	Akita PAES		2015	28538			

No.	Cultivar Name	Maternal Line	Paternal Line	Origin of Parental Line	Institution of Development	Dev. Year	Reg. Year	Reg. No.[a]	Mutant Characteristics Transferred	IAEA ID[b]	Reference
298	Mineharuka	Chubu 100 gou*	cv. "Chiyo-nishiki" X "Kumo14252"	*A descendant (the 1st generation) of cv. "Aichi-no-kaori"	Aichi PAES		2010	19054			
Wheat		*Triticum aestivum* L.									
1	Akebono-mochi	Kinu-iroha	Tani-kei A6099*	*A mutant from EMS treatment to "Kanto No. 107"	NARC	2000	2000	8363	Extremely low amylose content	3129	Yamaguchi *et al*. (2003)[215]
2	Ibuki-mochi	Kinu-iroha	Tani-kei A6099*	*A mutant from EMS treatment to "Kanto No. 107"	NARC	2000	2000	8364	Extremely low amylose content	3130	Yamaguchi *et al*. (2003)[202]
3	Tama-izumi	Kan-kei w364	Kan-kei w361*	*A descendant (the 2nd generation) of gamma ray induced mutant cv. "Shiro-wase-komugi"	NARO (National Institute of Crop Science)	2002	2005	12962		3131	Fujita *et al*. (2004)[13]
4	Urara-mochi	Bandou-wase	Akebono-mochi *	*A descendant (the 1st generation) of EMS induced mutant line "Tani-kei A6099" from "Kanto 107 gou"	NARO (National Institute of Crop Science)		2009	18434			Fujita *et al.* (2007)[12]
5	Yume-shiho	Tamaizumi (Kanto w421)*	An original line	*A descendant (the 3rd generation) of gamma ray induced mutant cv. "Shiro-wase-komugi"	NARO (National Institute of Crop Science)		2010	19418			Kiribuchi-Otobe *et al*. (2009)[69]
6	Yume-akari	Haru-ibuki	Tamaizumi*	*A descendant (the 3rd generation) of gamma ray induced mutant cv. "Shiro-wase-komugi"	Aichi PAES		2014	23409			
Barley		*Hordeum vulgare* L.									
1	Nirasaki Nijo 8	Gamma No. 4*	34r127	*Gamma ray irradiation to "Kirin-cyoku No. 1"	Barley Research Center, Kirin Brewery Co., Ltd.	1967				1119	
2	Kawamizuki	U-kei H-83*	U-kei H-79**	*Gamma ray irradiation to cv. "Kanto-nakate-gold"; **Gamma ray irradiation to "Asahi No. 5"	Kyushu NAES	1979			Early maturing; short and tough culm; constantly high-yielding	1118	Tsuru *et al*. (1981)[184]
3	Tone-nijo	M4-66*	Nitta-kei 1	*Gamma ray irradiation to "Nitta-nijo No. 1"	Sapporo Breweries, Ltd.	1989	1989	1972		1164	
4	Masakado-mugi	Ea52*	Kanto-kawa No. 53	*Gamma ray irradiation to the plant of "Takebayashi-Ibaraki No. 1"	NARC	1989	1991	2688	Early maturing; resistant to stripe virus disease	1154	Makino *et al.* (1992)[91]
5	Komaki-nijo	(Nitta-kei 1×Tochi-kei 85)F2	M4-66*	*Gamma ray irradiation to "Nitta-nijo No. 1"	Sapporo Breweries, Ltd.	1996	1996	5066		3132	
6	Sayakaze	Kanto-kawa No. 70*	Kanto-kawa No. 68 (Suzukaze)	*"Ea52"×"Kanto-kawa No. 60"; "Ea52": Gamma ray irradiation to the plant of "Takebayashi-Ibaraki No. 1"	NARO (National Institute of Crop Science)		2003	14301	Stripe virus disease resistance	3133	Yoshioka *et al*. (2005)[214]
7	Sakitama nijo	Tone nijo (Nitta-kei 25)*	Yasu-kei 58	*A descendant (the 2nd generation) of gamma ray induced "M4-66" through cv. "Tone nijo"	Sapporo Breweries, Ltd.		2003	11235			
8	Kashima-goal	Sayakaze (Kanto kawa 78 gou)*	Kanto hadaka 78 gou	*A descendant (the 2nd generation) of Gamma ray induced disease resistant mutant "Ea52"	NARO Kinki Chugoku Shikoku NARC		2012	21880	Stripe virus disease resistance		

No.	Cultivar Name	Maternal Line	Paternal Line	Origin of Parental Line	Institution of Development	Dev. Year	Reg. Year	Reg. No.[a]	Mutant Characteristics Transferred	IAEA ID[b]	Reference
Soybean		*Glycine max* (L.) Merr.									
1	Nanbu-shirome	10kR-3-7 (Raiden)*	Kitami-nagaha	*cf. cv. Raiden (Appendix 1)	Tohoku NAES	1977			Medium-maturing	1593	Matsumoto *et al*. (1979)[95)]
2	Tomo-yutaka	Tohoku No. 52*	Kari-kei No. 102	*Raiden/"Toiku No. 109"	Tohoku NAES	1990	1991	2878		3134	Watanabe *et al*. (1990)[201)]
3	Ryuhou	Suzu-yutaka	Kari-kou 343*	*A descendant (the 2nd generation) of cv. Raiden	Tohoku NAES	1995	1997	5859		3135	Nakamura *et al.* (1996)[113)]
4	Suzu-no-ne	Kari-kei No. 244*	Kari-kei No. 221**	*A descendant (the 2nd generation) of cv. Raiden; **Named as cv. Kosuzu: cf. cv. Kosuzu (Appendix 1)	Tohoku NAES	1995	1998	6206		3136	Nakamura *et al*. (1996)[114)]
5	Eru-star (L-star)	Fuku-yutaka/Kyu-kou 506*	Mura-yutaka**	*Named as cv. Ichihime: cf. cv. Ichihime (Appendix 1); **cf. cv. "Mura-yutaka" (Appendix 1)	Kyushu NAES	2000	2001	8646		3137	Takahashi *et al.* (2003)[165)]
6	Suzu-sayaka	Suzu-yutaka	Kyu-kou 365F2(γ)-M4*	*A mutant line induced through Gamma ray irradiation to a hybrid between "Kanto 102 gou" and "Kan-kei 1 gou (later named as cv. Yumeyutaka)"	NARO (NARC for Tohoku Region)	2003	2006	14042	Complete absence of lipoxygenases	3138	Yumoto *et al.* (2006)[217)]
7	Suzu-kaori	Kari-kou 778F5*	Kosuzu**	*A progeny of cv. Kosuzu and "Kitsurin No. 13"; **cf. cv. Kosuzu	NARO (NARC for Tohoku Region)	1995	2007	15131		3139	Kono *et al.* (2006)[81)]
8	Kanto 100 gou	Enrei	En6500*	*A mutant line induced through EMS treatment to cv. Enrei	NARO (NARC)	2002	2005	13531	Supernodulating character	3412	Akao & Kouchi (1992)[3)]; Takahashi *et al*. (2003)[164)]
9	Olerich50	M23*	LOLL**	*A high oleic acid mutant line induced through X-ray irradiation to cv. Bay;**A hybrid of M5 x M24, both of which are low linoleic acid content mutant through X-ray irradiation to cv. Bay	Saga University	1996	2008	16459			
10	Kinu-sayaka	Karikei 508 gou*	Developed line	*A lipoxygenase free mutant induced through a gamma ray irradiation	NARO (NARC for Tohoku Region)	1995	2008	16460	All lipoxygenase free		Kato *et al*. (2007)[67)]
11	Kyo-shirotanba	Murasaki-zukin*	Tama-daikoku	*Gamma ray irradiated mutant cultivar: cf. cv. "Murasaki-zukin"	Kyoto Prefecture		2013	22491			
12	Satohonoka	Kanto 100 Gou*	Nanbu-shirome**	*EMS treated mutant: cf. "Kanto 100 gou"; **derived from cv. Raiden (Appendix 1)	Iwate University and Akita Prefectural University		2014	23737			
13	Takamaru	Fukuibuki	Kanto 100 gou*	*EMS treated super-nodulating mutant: cf. "Kanto 100 gou"	Iwate University and Akita Prefectural University		2014	23738	Supernodulating character		
14	Murasaki-zukin 3 gou	Murasaki-zukin 2 gou	Murasaki-zukin*	*Gamma ray induced mutant cultivar	Kyoto Prefecture		2015	23850			
15	Kogane-sayaka	Eru-star*	Sachi-yutaka	*cf. cv. Eru-star	NARO (National Institute of Crop Science)		2016	24955			
Rush		*Juncus effusus* L. var. *decipiens* Buchenau									
1	Hinomidori	Shimomasuda-zairai	Seto-nami*	*cf. cv. "Seto-nami" (Appendix 1)	Kumamoto PARC	1998	2001	9034	Long and many stems	3141	Nakazawa *et al.* (1999)[119)]

No.	Cultivar Name	Maternal Line	Paternal Line	Origin of Parental Line	Institution of Development	Dev. Year	Reg. Year	Reg. No.[a]	Mutant Characteristics Transferred	IAEA ID[b]	Reference
2	Suzukaze	Hinomidori*	An original line	*cf. cv. Hinomidori	Kumamoto PARC		2015	23967			Fushimizu *et al.* (2015)[14]
Tomato		*Solanum lycopersicum* L.									
1	Kyoryoku-oogata-reikou	IRB301-31*×Sekai-ichi	(Anahu×Ichihara)×Sekai-ichi	*Gamma ray irradiation to a wild relative species	Musashi Breeding Station Co.	1984			Resistance to both TMV and crown and root rot	2222	
2	Kagyoku	Noh PL No. 4*	Noh PL No. 3	*Gamma ray irradiation to a wild relative species	National Institute of Vegetables	1984	1986	964	Resistance to crown and root rot	2223	Yamakawa *et al.* (1987)[205]
3	Ryugyoku	Noh PL No. 5*	Noh PL No. 4**	*, **Gamma ray irradiation to a wild relative species	National Institute of Vegetables	1984	1986	965	Resistance to fusarium crown and root rot	2224	Yamakawa *et al* . (1987)[205]
Egg plant		*Solanum melongena* L.									
1	Daijiro	Mutant of Daitaro*	Hiranasu	*Selected from anther culture	Kochi PARC	2000	2004	1185	Fruit shape; green skin color	3142	
Snapdragon		*Antirrhinum* L.									
1	Fuji Sweet Pink 1	A mutant of cv. Touen*	cv. Yukihime	*Colchicine treatment	Nihon Nohyaku Co., Ltd.	1993	1998	6398	Doubled chromosome number	3143	
Job's tear		*Coix ma-yuen* Roman.									
1	Hato-yutaka	Tohoku No. 1*	Oou No. 4**	*A progeny of a gamma-ray induced mutant line "TS-kei" from a foreign cultivar; **Gamma ray irradiation to "Okayama-zairai"	NARO（NARC for Tohoku Region）		2004			3144	Kato *et al.* (2007)[66]
Japanese lawn grass		*Zoysia japonica* Steud.									
1	FLATZ	An original line	COPROS*	*A descendant (the 1st generation) of a somaclonal mutant through x-ray irradiation to a meristem callus	Kaisui Chemical Industry Co. Ltd.		2006	13648			

Note: Paternal and maternal line written in red are mutant lines or cultivars

[a]Reg. No. is the registration number of The Plant Variety Protection System in Japan

[b]IAEA ID is the variety ID number of the Joint FAO/IAEA Mutant Variety Database (https://mvd.iaea.org/#!Home)

Abbreviations:

ARC: Agricultural Research Center
ARI: Agricultural Research Institute
JIRCAS: Japan International Research Center for Agricultural Sciences
NAES: National Agricultural Experiment Station
NARC: National Agriculture Research Center
NARO: National Agriculture and Food Research Organization
PAES: Prefectural Agriculture Experiment Station
PARC: Prefectural Agriculture Research Center

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