Crop Landraces: Present Threats and Opportunities for Conservation

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Rakeeb Ahmad Mir, Arjun Sharma, and Reetika Mahajan

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Abstract

Crop landraces are important source of novel alleles which can be utilized for improvement of desired crops. They have variable phenology and moderate edible yield. Landraces provide traits for more efficient nutrient uptake and utilization, as well as useful genes for adaptation to stressful environments such as water stress, salinity, and high temperatures for development of improved cultivars. However, since last few decades, modern agricultural practices have resulted in decline of diversity in crop landraces. Various environmental factors like genetic erosion and local cultivation practices have threaten the landrace diversity. To overcome these threats, certain conservation methods have been adapted, and these methods have been reported to play critical role in conserving

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R. A. Mir (✉) · A. Sharma
Department of Biotechnology, School of Biosciences and Biotechnology, BGSB University, Rajouri, Jammu and Kashmir, India

R. Mahajan
Division of Plant Biotechnology, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Srinagar, Jammu and Kashmir, India

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crop landrace diversity. Furthermore, there is a need for proper documentation of the information available on remedial measures to cope up with the stress mediated by gene flow to crop landraces. Overall information generated may provide a framework to initiate different approaches for the crop improvement.

Acronyms

CRISPR	Clustered regularly interspaced short palindromic repeats
CMT3	Chromomethylase 3
DCL	DICER-like enzymes
DNA	Deoxyribonucleic acid
GM	Genetically modified
GR	Green Revolution
HYVs	High-yielding varieties
IBPGR	International Board for Plant Genetic Resources
LR	Landraces
NGOs	Nongovernmental organizations
RNA	Ribonucleic acid
RNAi	RNA interference
RISC	RNA-induced silencing complex
siRNA	Small interfering RNA
TALENs	Transcription activator-like effector nucleases
ZNFs	Zinc finger nucleases

13.1 Introduction

Agriculture is one of the oldest livelihood sources for mankind. History revealed that with the onset of civilization, agriculture had played a key role in sustainable development of mankind. From centuries, sowing of seeds saved from superior parents in next season by the farmers had led to the identification of various important traits of crops which can be used for crop improvement programme (Zeven 1998). Crop landraces are the locally adapted varieties with important traits but lack proper knowledge. Landraces have an important role in crop improvement and agricultural production, and it is for these former reasons they have been found to exist since the origin of agriculture (Zeven 1998). Modernization in agriculture and lack of information regarding the landraces possess great threat to crop landraces. Here in this chapter, we have discussed various threats and opportunities faced by crop landraces.

13.2 Crop Landraces and Their Classification

From the period since 1909 to 1974, numerous attempts have been made by scientists to define the term 'landraces' properly, but till date a well-defined definition of landraces based on knowledge of their traits, utilization, ecogeographic adaptation, cultivation and management procedures is yet to be established (Harlan 1975; IBPGR 1980; Brush 1995; Tsegaye et al. 1996; Pistorius 1997; Zeven 1998; Louette 1999; Friis-Hansen and Sthapit 2000; Saxena and Singh 2006; Berg 2009; Newton et al. 2010). Primitive cultivars, traditional varieties or conservation varieties are some of the synonyms of landraces used in literature (Camacho Villa et al. 2005). Specifically defining the seed-propagated landraces, they are the crops which have been identified and given a vernacular name. Their evolution and adaptation are restricted to the habitat they have been grown since centuries. Landraces (LR) are usually adapted to one specific geographical location, whereas cultivars are bred in remote areas being cultivated in diverse locations (Hawkes 1983). Each crop landrace has a specific local name assigned to it, highlighting its features and importance to the particular habitat and representing the class of humans inhabiting that area (Von Rünker 1908). They have been so closely associated with the particular habitat that indigenous farmers have developed a data set revealing their traditional use, knowledge of their habitat, utilization pattern and importance in several religious celebrations. Thus crop landraces can be defined as a 'dynamic population(s) of a cultivated plants that have historical origin, distinct identity and lacks formal crop improvement, as well as often being genetically diverse, locally adapted and associated with traditional farming systems' (Camacho Villa et al. 2005). In 1890, for the first time, landraces were thought to be genetic resources (Zeven 1998). Landraces are not only important for maintaining biodiversity but are also important source of superior nutritional and medicinal values. Before the invention of modern breeding technologies, every year farmers utilize their seasonally saved seeds from grown crops such that they can be used in following year for cultivation. The seeds were selected from the parent plants having best traits which evolved due to natural and non-orientated anthropogenic selections (Carvalho et al. 2012). Thus by using this selective breeding approach, various desirable traits have been developed over generations. Seed-saving method is used for the development of crops resistant to local diseases, and this method maintained the genetic diversity of the crops grown in that particular habitat, leading to the evolution of these landraces as valuable genetic resources for future generations. Crop landraces can be used to study variation in various desirable traits and to develop improved crop varieties (Table 13.1). Crop landraces has been classified into various categories as mentioned in Table 13.2. Mayr's (1934) classified landraces into five categories: autochthonous (a landrace cultivated for more than a century in the same region), autochthogenous (a landrace derived from a new genotype due to spontaneous mutations or derivative of a natural cross originating from an autochthonous landrace), allochthonous (an autochthonous landrace from one region introduced into another region and adapting itself in

Table 13.1 Showing different crop landraces used for the development of desirable trait

Crop landrace	Desired trait	Studied for	References
Barley	Plant height and crown rot disease	QTL identification	Li et al. (2009)
Triticum turgidum (*turgidum* convar. *durum*) durum wheat	Glutenin protein subunits	Genetic diversity	Moragues et al. (2006)
Durum wheat	Morphological and agronomical traits and protein	Genetic variation	Pecetti et al. (2001)
	Composition		
Ethiopian tetraploid wheat germplasm	Grain yield potential and quality traits	Genetic diversity	Teklu and Hammer (2009)
Triticum turgidum L. (tetraploid wheat)	Agronomic traits	Genetic diversity	Tsegaye et al. (1996)
Syrian durum wheat landraces	Glutenin content	Diversity	van Hintum and Ellings (1991)
Hexaploid wheat	Abiotic stress	Identification of novel germplasm resource	Trethowan and Mujeeb-Kazi (2008)
Wheat wild relatives and landraces	Drought-adaptive traits		Reynolds et al. (2007)
Barley (*Hordeum vulgare*) from Egypt	–	Genetic diversity	Sarker et al. (2008)
Rice	Drought tolerant	QTL identification	Kumar et al. (2014)
Rice	Salt tolerant	QTL identification	Ren et al. (2005), Bonilla et al. (2002), Thompson et al. (2010) and Kumar et al. (2015)

Table 13.2 Different classifications of landraces

Classification	Basis of classification	Types	References
Christiansen-Weniger's	–	Primary landrace	Christiansen-Weniger (1931)
		Secondary landrace	
Mayr's	Breeding history	Autochthonous, Autochthogenous, Allochthonous, Allochthogenous, Zucht-Landsorte'	Mayr (1934)
Mayr's	Breeding values	Primitive landrace	Mayr (1937)
		Secondary landrace	
Zeven's	Based on Christiansen-Weniger's classification	Clean multiline landrace	Zeven (1975)
		Dirty multiline landrace	

new environment), allochthogenous (a landrace being grown for a longer period in a non-native region and has been changed by this new environment although the original type is still recognizable) and Zucht-Landsorte' (improved landrace derived form a 'reversed' cultivar).

13.3 Insight into Threat Assessment of Crop Landraces

Threat is the ultimate indicator of species extinction rate, and it is the basis of this relative threat we can establish the conservation priorities. The higher the rate of threat, the higher will be the priorities for conservation. Assessment of threat, i.e. the higher probability of genetic erosion, generates the realistic data to conserve the landraces and their extinction. The loss of landraces can be assessed through 'local cultural erosion' and 'genetic erosion'. Genetic erosion can be analysed through crop loss and their varieties or allelic diversity, decrease in richness of a species and loss of genetic diversity. The local cultural erosion refers to the unending use of landraces in different cultural activities. In addition, the intervention of modern technology has drastically transformed the traditional agricultural developments into modernized agricultural practices, resulting in great impact on crop yield and diversity. This revolution has led to the global development of various stress-tolerant crops. These factors have negatively affected the landraces and in turn resulted in their extinction, whereas local cultural erosion caused loss of biodiversity by replacing local varieties by crops having desired traits, genetically uniform hybrids and improved cultivars by practicing monocropping (Ceccarelli and Grando 2000; Sarker and Erskine 2006; Rodriguez et al. 2008; Abay and Bjørnstad 2009; Frison et al. 2011). Presently, most of the population feeds on few improved cultivars of wheat, rice, maize and potato which account only 60% of diets (Esquinas-Alcazar 2010). According to World Conservation Monitoring Centre (1992), 74% rice cultivars (staple crop) of Indonesia are mainly derived from a single stock. Also in the USA, 50% wheat is derived from 9 cultivars, 75% potato is derived from 4 cultivars, and 50% soybean is derived from 6 cultivars. Genetic erosion had decreased the landrace diversity in southern Italy by 72.8% and in Albania by 72.4% (Hammer et al. 1996), and in Greece, 95% wheat landraces were lost after utilization of modern practices (Lopez 1994).

Since the advent of Green Revolution (GR) locally adapted populations of plants or 'landraces' have been replaced by HYVs (high-yielding varieties) or modern varieties, forcing farmers to leave behind the historically adapted mechanisms to conserve the landraces through seeds and other traditional conservation strategies. Out of this revolutionary process, i.e. GR, diversity of rice cultivars and other landraces decreased drastically in India and at global level. These multiple reasons lead to the threatening of landraces and it has became pretinent to asses the reasons behind erosion of landraces. Threats to landraces can be assessed (Fig. 13.1) either at individual level or at genetic level by a three-stage method which includes defining the different indicators of threat and then identifying threats to LR diversity and evaluation of the relative degree of threat (Negri 2003). Based on different

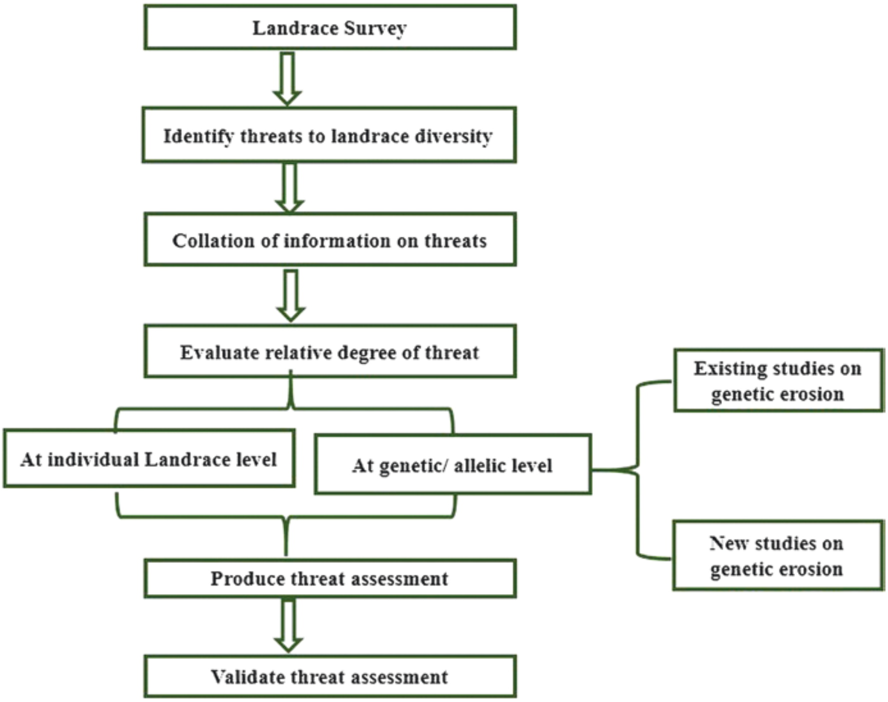

Fig. 13.1 Landrace diversity threat assessment methodology. (http://www.fao.org/fileadmin/templates/agphome/documents/POR)

categories, various alternative methods for assessing threats to landrace diversity have been developed (Joshi et al. 2004; Antofie et al. 2010; Porfiri et al. 2009). Besides a number of methods available for threat assessment not even a single method is standardized for threat assessment of erosion of landraces. Certain methodologies which rely on assessment of threat indicators include simple analysis like farmer's wealth, access to seed planting material, farming area, system of cultivation, ability of a plant material to multiply, use of plant material by local farmers, historical indicators include first time development of a landraces temporally and spatially, socio-economic indicators, conservation status of landraces, uniqueness to the habitat, familiarity of genetic diversity and data generated regarding the cataloguing of landraces. From centuries, plant breeding approaches were used by farmers for selecting superior varieties which later resulted in evolution of important landraces. But with the advancement in plant breeding approaches, there is decline in the diversity of landraces as these approaches are shifting the landraces towards a model of agriculture based on uniformity (Van de Wouw et al. 2010; Frison et al. 2011; Ceccarelli 2012). Threat to landrace diversity has direct effect on global food security. Thus, to minimize the negative effects on food security, threat identification and evaluation are of dire importance.

13.4 Approaches to Understand Impact of GM Crops on Crop Landraces

Generally speaking, gene flow is the natural incorporation of genes from one population to the other (Futuyma 1998). This unidirectional flow of genes from cultivated crops to wild species/landraces has been reported since thousands of years (Ellstrand et al. 1999). Irony to this flow of genes is that illegitimate gene flow has been further stimulated by introduction of GM crops (Snow and Moran-Palma 1997; Hall et al. 2000; Ellstrand 2001). The term genetically modified (GM) refers to the transfer of genes between organisms using a series of laboratory techniques for cloning genes, modifying DNA segments together and inserting genes into cells. The 'genetically modified' is a vague term and a potentially confusing one, in that virtually everything we eat has been modified genetically through domestication from wild species and many generations of selection by humans for desirable traits. Crop plants have been improved for different applications, and few of them are worth to mention, like to enhance the plant productivity and production of disease-resistant plants and pest-resistant plant and also to improve the quality of the plant products. Apart from being important for increasing the crop yield through the introduction of different classes of desired genes from different origins, GM crops have been found to be negatively effecting the landraces. The contamination of landraces has been reported by several studies. In Mexico, maize landraces have been found to contain genes from transgenic crop plants causing lot of controversy globally (Carpentier and Herrman 2003; Christou 2002; Kaplinsky et al. 2002; Metz and Fütterer 2002; Quist and Chapela 2001, 2002). It has raised the issue of whether the commercial introduction of transgenic maize varieties may have a deleterious effect on the diversity of maize landraces. This issue is significant because Mexico is a centre of maize domestication and maize diversity. Highlighting the negative side of GM crops, the cross contamination of local landraces of Mexican maize may serve purpose to highlight the negative effect of GM crops. Ignacio Chapela and his student David Quist collected corncobs (maize landraces) for cross-checking the contamination of Mexican maize landraces by GM maize imported from the USA where at least 40% of crops are GM based (Quist and Chapela 2001). This series of troubleshooting experimentations was famously being highlighted as 'Chapela Affair'. The duo checked the contamination through repeated amplification of CaMV promoter (a marker DNA sequence to check the transgenic plants) from crop landraces by PCR and inverse PCR (iPCR). These results showed that four maize landraces were found to be positive out of six tested maize landraces (Quist and Chapela 2001) further compounding the safety of GM crops. The maize landraces in Mexico have been conserved and bred by local farmers since centuries in small patches of agricultural fields. Out of these findings, both the investigators finally concluded that local landraces of maize have been contaminated by GM maize somehow imported from the USA. This potential of GM crops to contaminate the local landraces is alarming to eradicate the allelic diversity of wild plants. Against this backdrop of technological intervention of transgenic plants, Mexican government doesn't allow the cultivation of GM crops.

13.5 Opportunities for Conservation and Remedial Measures to Protect Diversity of Crop Landraces

Landraces play a key role in crop improvement programme as they are important source of novel alleles. Farmers from underdeveloped nations and rural areas in developing nations depend on the landraces diversity for food and seeds for next season (Joshi and Bauer 2007). The main aim of landraces conservation is to conserve the full range of genetic diversity within the LR from the threat (Negri et al. 2009). Thus, conservation of these landraces is an important task in today's world. There are various strategies for protecting the landrace diversity from the threats they face time and again mostly due to anthropogenic activities. These opportunities are divided into short- and long-term priorities. Sutherland and Woodroof (2009) reported that new threats to biological diversity and new opportunities for landrace conservation could be identified by horizon scanning. Landraces can be conserved by in situ or on-farm conservation methodologies. Various programmes have been started for conservation of landraces around the globe. These conservation methods of landraces result in establishment of biodiversity links, highlighting the need for conserving specific populations, and provide full range of ecogeographic data and genetic diversity of crop landraces. These conservation methods provide opportunities to the farmers to identify improved cultivars which can be employed for resolving food security issues globally. For conserving crop landraces, genetic reserves in secondary ecosystems (human disturbed, e.g. roadside and railroad banks) could be established. However, this approach is stringent to infrastructure and can be used as an approach to mitigate other biodiversity losses. There is a need for the development of improved national landraces inventories and prioritization of inventory on economic value, breeding demands and threat and biogeographic responsibility which are one of the significant steps towards landrace biodiversity information system. Another approach is to develop participatory management and monitoring models for landrace conservation so that it can increase emphasis on holistic approach to conservation strategies and methodologies and integration of genetic resource conservation into mainstream biodiversity conservation. Promotion of biodiversity friendly agriculture systems through NGOs could help the mankind for recognizing value of landrace biodiversity. There is an awful need of professionals and famers of traditional knowledge to timely intervene and identify the problem to chart down the strategies for protection of landraces existing in the ecosystem/s. A number of strategies have been developed to improve the crops and simultaneously protect the diversity of crop landraces. Few of them are mentioned below.

13.5.1 Strategy I: Mutational Breeding Systems

To circumvent the gene flow effect of GM crops for crop improvement, researchers recommend different alternative technologies to raise plants with desired trait. One such strategy which is beneficial to produce plants with desired traits is mutational breeding systems. These changes may be permanent or temporary. As far as

Table 13.3 Number of officially released mutant varieties in the top six countries (total 2252)

Country	Number of released mutant cultivars	Percent of total
China P.R.	605	26.8
India	259	11.5
USSR + Russia	210	9.3
Netherlands	176	7.8
USA	128	5.7
Japan	120	5.3

spontaneous mutations are concerned, they occur naturally with very low frequencies of 10^{-6} due to transposable elements which move into genome and cause alteration in DNA sequence (Wessler 2006), whereas induced mutations are caused by either chemical mutagens or other agents like X-rays, UV radiation, α-particles and β-particles. The main purpose of mutation breeding technology is the development of new and desired variation(s) through breeding programmes for crop improvement. Induced mutations can play an important role in the conservation and preservation of crop biodiversity. Induced mutations and related advanced technologies are important not only for increasing the genetic diversity of crops but also as a source for additional biodiversity enhancement of neglected and local crops/landraces (Hussain et al. 2012; Roychowdhury and Tah 2013). In this approach, mutants with desired traits were selected in the M_1 or M_2 generation after treatment with mutagens and then released as new variety for cultivation after evaluation and trials. Those mutants which are not selected as cultivars are rather used in cross-breeding programmes for tracing desired alleles (Roychowdhury and Tah 2013). More than 2000 (Table 13.3) plant varieties that contain induced mutations have been officially either released for cultivation directly as new varieties or used as parents to derive new varieties without the regulatory restrictions faced by genetically modified material (Maluszynski et al. 2000; Waugh et al. 2006). The number of mutant varieties released in China and India places Asia at the top of the list. This approach is the best alternative to transgenic biology to prevent gene flow within populations.

13.5.2 Strategy II: RNA Interference Systems

The phenomena of RNA interference is employed to produce crops having desirable traits. The process of RNAi can be triggered by the entry of small siRNA into a cell by several different ways, such as by *Agrobacterium*-mediated gene transfer, viral-mediated dsRNA transfer and particle bombardment method (Sijen and Kooter 2000). An RNAi vector is used to transform cell and produce stable dsRNA in vivo and further mediate silencing of target gene. RNA interference is an emerging tool in biotechnology for crop improvement. It has been widely used for increasing crop yield, quality and resistance against biotic and abiotic stresses. RNAi includes the sequence-specific gene silencing at post-transcription level (Kamthan et al. 2015).

Two major players of RNA interference are (endogenous) microRNA and exogenous, such as transgene and small interfering RNA (siRNA). They are produced by the breakdown of dsRNA by the ribonuclease enzyme DICER or DICER-like enzymes (DCL) (Bernstein et al. 2001; Hutvagner et al. 2001). Then a RNA-induced silencing complex (RISC) is activated by the incorporation of these single-stranded RNAs. RISC contains protein which has ribonuclease activity to degrade the mRNA- and RNA-binding domains (Hammond et al. 2000). RISC contains another important protein, Argonaute, that has been reported in *Arabidopsis thaliana*, which makes the catalytic core of RISC be involved in silencing (Vaucheret 2008). Activated RISC-RNA (antisense strand) then binds to complementary sequence and degrades the mRNA (Williams et al. 2004). siRNAs can also regulate gene expression at transcription level by regulating the chromatin modelling. siRNA maintains the transcription rate at minimal level by controlling histone modification including the cytosine methyltransferase; chromomethylase 3 (CMT3) keeps DNA into transcriptionally inactive state (Ossowski et al. 2008). Major threat of the transgenics is gene flow, which may lead to the genetic erosion. RNAi technology-based suppression of targeted expression of a gene evades this possibility and has been employed to conserve the parental crops/landraces. It can be employed to generate total sterility resulting in restriction of gene flow.

13.5.3 Strategy III: Somaclonal Variations

Australian scientists were the leaders in the field of somaclonal variations (SVs), demonstrating the efficiency in improvement of sugar cane, wheat and other crops. Somaclonal variations are genetic or epigenetic changes which are induced in plant cell and tissue culture (Fig. 13.2). The induction of somaclonal variation is an alternate approach to conventional breeding and transgenic approaches to introduce desirable genetic variability in the gene pool, thus protecting the crop landraces from selection pressure and extinction. The efficiency of developing disease-resistant SVs is accomplished with the imposition of an appropriate in vitro selection pressure. Selection agents that have been applied include pathogen elicitors, pathogen culture filtrates and purified pathotoxins. This method of SV selection has been successful in enhancing disease resistance in several crops, and it is an accepted biotechnological approach with tremendous potential for crop improvement. The Biotechnology Centre at the Indian Agricultural Research Institute (IARI) has standardized protocols for plant regeneration of *Brassica carinata* and is isolating somaclonal variants. Useful somaclonal variants for earliness, maturity, plant height, etc. have been induced in *B. juncea* and *B. napus*.

13.5.4 Strategy IV: Total Sterility

Total sterility involves the deletion of a portion of the gene involved in the production of pollen or flower or ovule. So this strategy forces the farmers to propagate the plant vegetatively, thus preventing the possibility of gene flow (Sharma et al. 2013).

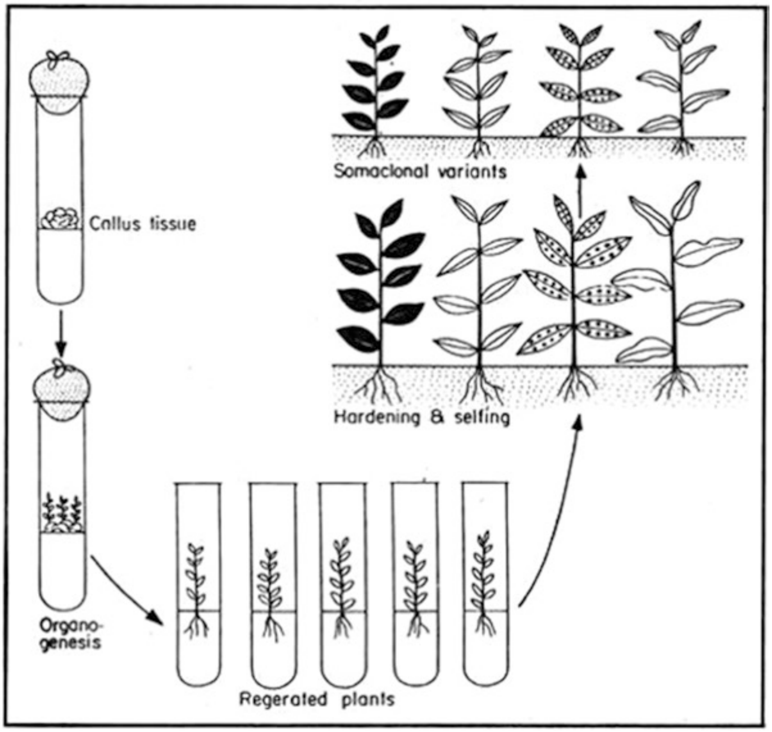

Fig. 13.2 Steps involve in induction and selection of somaclonal variation

This technique would be restricted to the plants which can be propagated through bulb propagules, leafy vegetable crops and forest plants. Due to high metabolic energy cost of sexual processes in plants, there will be higher yield of vegetative part of the plant, increasing the biomass production.

In addition to above strategy for preventing gene flow, the total sterility can be achieved by different genome-editing technologies like zinc finger nucleases (ZNFs), transcription activator-like effector nucleases (TALENs) (Christian et al. 2013) and CRISPR-Cas systems (Shan et al. 2013) to easily remove the target gene.

13.6 Conclusion

In fact, most of the threats to crop landraces need to be explored and documented for further fortification and conservation purpose. But it is evident from the above-mentioned literature that crop landraces are important to be focused for food security and diversity. In addition, crop landraces provide genetic resources that can be used for meeting current and new challenges of farming in stressful environments. However, proper knowledge of the crop landrace threats and opportunities are yet to be explored. Thus, we need to study these threats and opportunities so that crop landraces could be protected from extinction and could be used as a source for improvement of crops and to enhance production to meet the increased food demand throughout the globe. Research programmes need to be initiated to develop a stringent regulatory system to disseminate the knowledge regarding the prime importance of crop landraces and their threats and systemic application of specific transgenic approaches to prevent gene flow.

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