Review Article

PLANT BREEDING IN NEPAL: PAST, PRESENT AND FUTURE

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ABSTRACT

Research in agriculture has been started since 1950 in Nepal. Plant breeding works started with the introduction and evaluation of rice, wheat and maize genotypes in 1951 in Agronomy Farm, Kathmandu. Crossing, first in Nepal was done in potato in 1964. Variety recommendation system was first initiated after evaluation and simple mass selection of genotypes by recommending CH-45 rice variety in 1959 followed by Lerma-52 wheat variety in 1960. There are about 45 plant breeders and 80% of them are cereals breeders. Contribution of breeding on total production is about 60%. Mass selection is most commonly used breeding method for both self and cross pollinated crops. Pedigree method is common for self-pollinated crops and recurrent selection for cross-pollinated crops. Among the total 275 released varieties, 16% were developed through crossing, 71% were developed through introduction and 13% were developed simply by selection of landraces. Most popular varieties of rice, wheat and maize are Masuli, RR21 and Rampur Composite, respectively. The varietal development period can be grouped into three phases such as pre-breeding, breeding and post breeding. There are three main strategies for developing a variety through plant breeding. They are wide vs site specific adaptation, evolutionary vs non-evolutionary, and diversity vs uniformity. Before 2005, breeders had developed varieties focusing on wide adaptability and non-evolutionary with uniform phenotype. After 2010, plant breeding is more science based, business oriented and less art. In addition to conventional plant breeding, anther culture, shoot tip culture, mutation breeding and marker assisted selection have been increasingly applied to breed the varieties. Plant breeding is not so advanced in Nepal and need to develop many competitive plant breeders and to invest more on it, giving due emphasis on local landraces.

Keywords: Breeding method, breeding phases, history, Landrace, trials

INTRODUCTION

Major factors for increased production in agriculture are acreage, management practices, inputs, and variety. Plant breeding has been playing significant role in developing high yielding varieties and suitable to diverse environments. Global food security relies on intelligent use of crop genetic resources which contain the essential building blocks that are critical to food security. Their availability is a fundamental requirement for achieving further productivity increase and higher nutritional values through plant breeding. About half of the average global production increase in cereals that were achieved under the Green Revolution in 1960s was attributable to plant breeding utilizing agricultural plant genetic resources (APGR). The productivity increment over 25 years in Nepal is more than 50% in rice, wheat and potato, which were possible through the intensive research on agriculture. This gain is mainly due to the breeding and its contribution on total production is about 60%. On an average, 75% of corn yield improvement was attributed to genetic gain from

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breeding in US and the remainder was generally attributed to improved farming practices (Tollenaar and Lee 2006).

Plant breeding has been practiced for thousands of years, since near the beginning of human civilization. Science based breeding was started worldwide after the re-discovery of Mendel's law of segregation and law of independent assortment in 1900. Breeding is important for ensuring food security by developing new varieties that are higher-yielding, nutritious, resistant to pests and diseases, drought-resistant or regionally adapted to different environments and growing conditions. Plant breeding is science, business and art of developing new varieties with traits of interest. Breeders always consider farmers (growers) with the objectives of providing varieties with high yield, disease resistance, early maturity, lodging resistance, etc; processor (industrial user) as it relates to efficiently and economically using the cultivar as raw materials for producing new product (e.g. canning qualities, fiber strength, etc) and consumers for their preference (e.g. taste, high nutritional quality, shelf life, etc).

In Nepal, plant breeding started since 1951 using many different techniques ranging from simply selecting plants with desirable characteristics for propagation, to more complex crossing and selection. Mass selection is the very common breeding method for both self and cross pollinated crops in Nepal. Pedigree method is common for self-pollinated crops and recurrent selection for cross-pollinated crops. Most popular varieties of rice, wheat and maize are Masuli (Shahi, 1885), RR21 and Rampur Composite, respectively. These are the varieties that brought green revolution in Nepal in late 1960s. Among the released varieties, 16% were developed through crossing, 71% were developed through introduction and 13% were developed simply by selection of landraces. Investment in plant breeding is negligible in comparison to the investment on other Agri-disciplines. About 25% of the total cost on research was on plant breeding (Shrestha & Gaire, 2016; Paudyal & Khatiwada, 2015; Morris et al., 1994). Many different trials, methods and steps of plant breeding have been introduced in Nepal and its contribution has been recognized on food and nutrition security and on making agriculture a profitable business. This paper has documented historical development of plant breeding, analyzed the progress made on productivity and described the plant breeding practices in Nepal. It is expected that information will be very useful for advancing plant breeding as well as developing policy and guidelines in the country.

History of plant breeding in Nepal

In Nepal, agricultural research was initiated since 1950 and plant breeding from 1951, but the systematic research in major cereals started from 1972 when major commodity programs (rice, wheat, maize, sugarcane and potato) were established in different agro-ecological domains of the country. Rice breeding began with the introduction of indica type semi-dwarf Taiwanese varieties in lower plain- Tarai and intermediate types for Kathmandu valley (NRRP, 1997). Variety recommendation system was first initiated after evaluation and simple mass selection of genotypes by recommending CH-45 rice variety in 1959 followed by Lerma 52 wheat variety in 1960. Plant breeding initiatives along with name list of breeders and breeding institutes are given in Table 1. Major milestones are introduction, collection and evaluation of local landraces, crossing, heterosis breeding, anther culture, DNA marker technology, and National genebank (Figure 1). Before 1990, plant breeding in Nepal was more art based and after 1990, breeding was more science (i.e. crossing, genetics study, use of selection aids, etc.) and less art based. After 2010, plant breeding is based on science, business and art.

Table 1. Historical events and activities of plant breeding and name list of pioneer breeders in Nepal

SN	Trial/method/ activity	Start date	Breeder/ organization	Crop	Remarks/Reference
1	Introduction	1850	Rana Dynasty	Fruits	Acharya & Atreya, 2012
2	Plant exploration	1937	Herrlich (Germany)	Wheat, barley	Upadhyay & Joshi, 2003
3	First breeder in Nepal	1951	Netra B. Basnyat	Rice	Primary introduction of rice from Japan, Mallick, 1981
4	Rice collection and evaluation	1951	Netra B. Basnyat	Rice	Mallick, 1981
5	First introduced recommended variety and crop	1958	Netra B. Basnyat	CH-45, rice	From India; Mallick, 1981
6	Variety recommendation	1959	Parwanipur Agriculture Station	Rice (CH-45)	NARC, 1997; Mallick, 1981
7	FFT	1960	Parwanipur Agriculture Station	Rice and wheat	www.narc.gov.np
8	First hybridization	1964	Gopal R. Rajbhandary	Potato	Kamlesh L. Rajbhandry (Pers. Comm.)
9	First university degree holder in plant breeding	1964	Gopal R. Rajbhandary	Brinjal	From Philippines Gopal R. Rajbhandary (Pers. Comm.)
10	CVT	1966	Amresh M. Pradhananga	Rice, wheat, maize	Mallick, 1981
11	First maize breeder (crossing)	1966	Amresh M. Pradhananga	Maize	Kamlesh L. Rajbhandry (Pers. Comm.)
12	IET	1966	Amresh M. Pradhananga	Rice, wheat, maize	Mallick, 1981
13	Observation nursery	1966	Amresh M. Pradhananga	Rice, wheat, maize	Mallick, 1981
14	Start of crop breeding	1966	ABD	Rice	Basnyat, 1999
15	First barley breeder (crossing)	1967	Shiva N. Lohani	Barley	Madhusudan P. Upadhyay (Pers. Comm.
16	First rice breeder (crossing)	1968	Bal B. Shahi	Rice	Kamlesh L. Rajbhandry (Pers. Comm.)
17	First wheat breeder (crossing)	1968	Badri N. Kayasta	Wheat	Gopal R. Rajbhandary (Pers. Comm.)

SN	Trial/method/ activity	Start date	Breeder/ organization	Crop	Remarks/Reference
18	Commodity based research program	1972	NARC	Rice, wheat, maize, potato, sugarcane	www.narc.gov.bp
19	Seed classes	1972	ABD	Rice, wheat, maize	Mallick, 1981
20	Minikit	1972	NRRP, NMRP, NWRP	Rice, wheat, maize	www.narc.gov.np
21	Plant breeding and genetic courses	1976	Krishna P. Sharma, IAAS, TU	Cereals	Rampur
22	Tissue culture	1976	National Herbarium and Plant Laboratories (KATH, DPR)	Indian snakeroot (Sarpaghandha)	Rajbhandary, 2000
23	Maintenance breeding	1980	NRRP, NWRP, NMRP	Rice, wheat, maize	Mallick, 1981
24	Hybrid (Commercial cultivation)	1985	Private sector	Vegetables, maize	SQCC, 2013
25	First variety released	1985	ABD	Wheat (NL-297)	Kamlesh L. Rajbhandary (Pers. Comm.)
26	Genebank (medium term ex-situ conservation)	1986	Bharat R. Adhikary	Cereals	Madhusudhan P. Upadhyay (Pers. Comm.)
27	First horticulture breeder (crossing)	1988	Indra R. Pandey	Radish and cauliflower	Dhruba Bhattarai (Pers. Comm.)
28	Hybrid research	1988	NMRP, Rampur	Maize	Dil B. Gurung (Pers. Comm.)
29	Sand rooting	1988	Saman B. Rajbhandary	Tobacco, potato, sweet potato	Rajbhandary, 1989
30	Tissue culture (breeding perspective)	1989	NPRP	Potato	Shambu P. Dhital (Pers. Comm.)
31	IRD	1990	LARC	Rice	Joshi & Sthapit, 1990
32	PPB	1993	Bhuwon R. Sthapit	Rice	Sthapit et al. 1996
33	Community seed bank	1994	Bal K. Joshi	Cereals and vegetables	Dalchowki, Lalitpur; Joshi, 2013
34	FAT	1995	Devendra Gauchan	Rice, wheat, maize	Devendra Gauchan (Pers. Comm.)
35	Department of plant breeding	1986	IAAS, TU	Cereals	Rampur, Led by Krishna P. Sharma
36	PVS	1996	Krishna D. Joshi	Rice	Joshi et al., 1997

SN	Trial/method/ activity	Start date	Breeder/ organization	Crop	Remarks/Reference
37	Heterosis breeding (vegetable)	1998	Kedar P. Budathowki	Tomato	Dhurba Bhattarai (Pers. Comm.)
38	Application of isozyme markers	1998	ABD	Barley	Bajracharya et al., 2000
39	Master degree in plant breeding	1998	IAAS, TU	Cereals	Rampur
40	Heterosis breeding (CMS based)	1999	Bal K. Joshi	Rice	Joshi, 2003; Joshi et al., 2003
41	Application of DNA marker (SSR)	2000	ABD	Rice	Bajracharya et al., 2003
42	Anther culture (double haploid)	2001	Bal K. Joshi	Rice, wheat	Joshi and Bimb, 2003a, 2003b
43	Mother baby trial	2001	CIMMYT, Nepal	Maize	Tiwari, 2001
44	Wide hybridization	2001	Raj K. Niroula	Rice	Interspecific cross, Niroula et al., 2002
45	PCR based diagnosis	2002	NAST	Citrus (HLB)	Shrestha et al., 2003
46	PhD in Plant Breeding	2002	IAAS, TU	Cereals	Rampur
47	GMO testing lab	2005	SQCC	Maize	Dila R. Bhandari (Pers. Comm.)
48	Mutation breeding	2006	Sabin Basu	Rice	Master Thesis, IAAS, Rampur
49	Emasculation (hot water method)	2008	Bal K. Joshi	Tite buckwheat	Joshi et al., 2009
50	Gene tagging by DNA markers	2010	Bal K. Joshi	Tomato	Joshi et al., 2013
51	National genebank	2010	Madhusudan P. Upadhyay	Cereals	Genebank, 2014
52	Protected variety and royalty system	2010	HRD	Tomato (parental lines of Srijana F1 hybrid)	Dhruba Bhattarai (Pers. Comm.)
53	Field genebank and community field genebank	2012	Bal K. Joshi	Taro, Ginger, Chayote, mango	Genebank, 2014
54	Pre-breeding	2012	Bal K. Joshi	Rice	Joshi et al., 2013
55	DNA bank and Tissue bank	2013	Bal K. Joshi	Potato, chayote, rice, wheat	Genebank, 2014

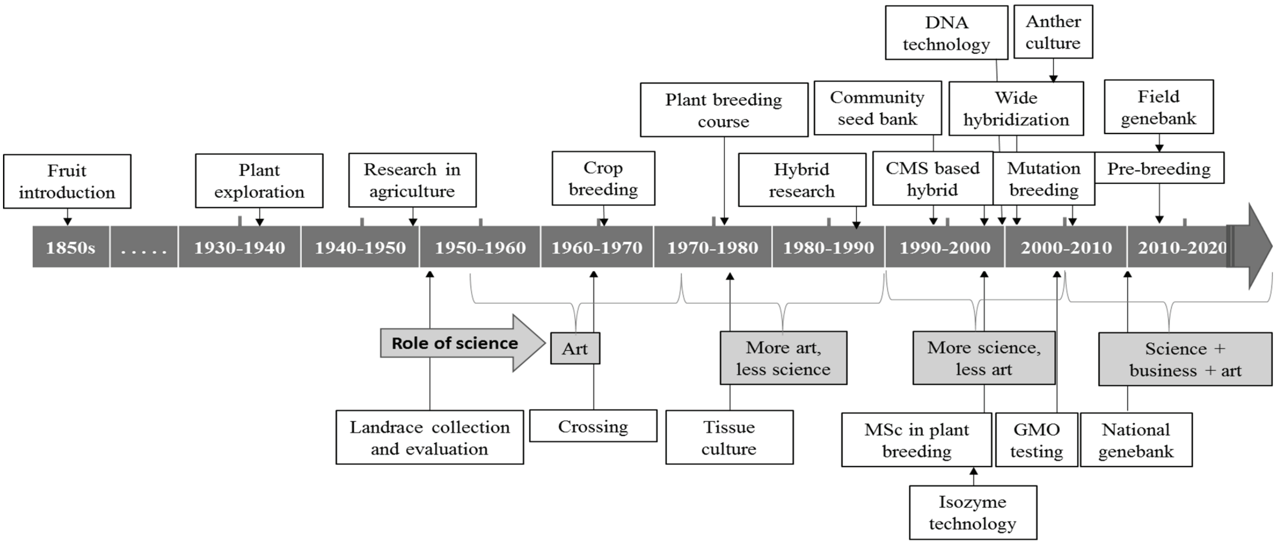

Figure 1. Major historical events of plant breeding in Nepal.

Plant breeding objectives

In early period (1960-1985), the main objective was to increase yield of main stable crops i.e. rice, wheat and maize. At the end of this period, some breeding activities were also started in sugarcane, potato, some vegetables, oilseed crops, millets, buckwheat, pulses (Sharma 1982) and fruits with the objective of yield improvement. In mid period (1985-2005), priority was given to developing biotic stresses, mainly disease resistant variety, followed by yield. Rice blast and wheat rust were the main diseases in the country from very beginning to current period of breeding history. In late period (2005-2015), abiotic stresses mainly drought and quality aspects got priority in the breeding programs. All the time, breeding objectives were looked on the foreign materials, and genetics of specific traits in the local germplasm were not studied. There is very limited use of local knowledge and germplasm in research and development. Nepal has very diverse climate and breeding strategies were, however, developing widely adapted varieties using foreign germplasm. Target remains only to the farmers in most of the breeding programs. Scientific information generated during research should be integrated to education system and during policy formulation.

Breeding institutes

There are more than 100 organizations involved in breeding activities in Nepal (Joshi et al., 2016). Main research organizations related to plant breeding are Nepal Agricultural Research Council (NARC) established in 1991, and its research stations and disciplinary divisions; National Academy of Science and Technology (NAST), established in 1982; Local Initiatives for Biodiversity, Research and Development (LI-BIRD), established in 1995, Forum for Rural Welfare and Agricultural Reform for Development (FORWARD Nepal), established in 1997; Center for Environment and Agricultural Policy Research, Extension and Development (CEAPRED), established in 1991; Seed Entrepreneurs' Association of Nepal (SEAN), established in 1989. International research organizations are Bioversity International, started linking with Nepal since 1984, IRRI, started collaborating in Nepal since 1985, CIMMYT started working in Nepal since 1970 and International Centre for Integrated Mountain Development (ICIMOD), established in 1983. Three university institutions, namely IAAS of TU, established in 1972; Department of Genetics and Plant Breeding, AFU, established in 2010, and HICAST of PU, established in 2000 are responsible for teaching and research on plant breeding. Department of Agriculture, established in 1951 is the main organization to disseminate the varieties. Formal introduction and evaluation of rice, maize and wheat were begun after the establishment of Agronomy Division in 1954 under the Department of Agriculture. Agriculture Botany Division started the preliminary plant breeding works mainly on rice, wheat and maize since 1966. Extensive plant breeding started after the establishment of five commodities (rice, wheat, maize, potato and sugarcane) research programs in 1972. IAAS, Rampur started degree course on plant breeding since 1998. There are about 45 plant breeders in Nepal. Main plant breeding organizations in Nepal are Department of Plant Breeding (established in 1986) of IAAS, Department of Genetics and Plant Breeding, Agriculture and Forestry University (established in 2010) and Agriculture Botany Division (established in 1966) of NARC.

Food security, agro-biodiversity and plant breeding

Food security is the prime goal of all research programs and organizations involved in plant breeding. Currently, nutrition security is also considered. Among the three approaches, i.e., increase cropped area, better inputs and management, and genetic enhancement or plant breeding, for increased food production; plant breeding is the better option and sustainable method (Figure 2). Figure 3 explains the percent increment in area, production and productivity of some important crops over last 25 years in Nepal. The increment in grain yield of major food crops during the last 25 years shows significant achievement in production. The highest productivity increment was of wheat (76.4%) followed by potato (69.9%) and maize (53.7%). Though, the statistics indicated that country is importing food grains and other agricultural commodities, domestic production has also significantly increased. In Nepal, about 60% of total production increment is due to contribution of plant breeding. The impact of breeding in wheat crop was remarkable, as there were 10 and 2 folds increment on production and productivity, respectively, in the period from 1965 to 2000. During 1990-2014, production of potato, sugarcane, wheat, maize and rice were increased by 319.4%, 235.5%, 122.3%, 90.1% and 48.9%, respectively.

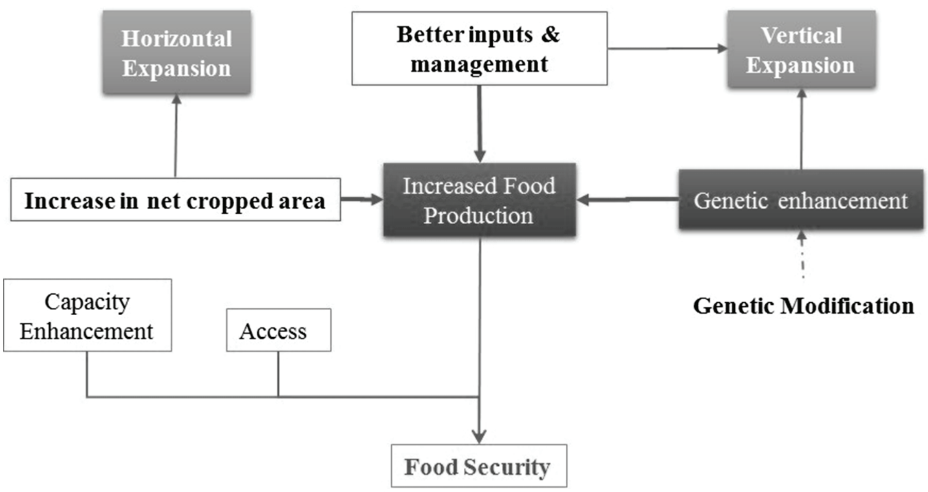

Figure 2. Three approaches for increased food production and food security

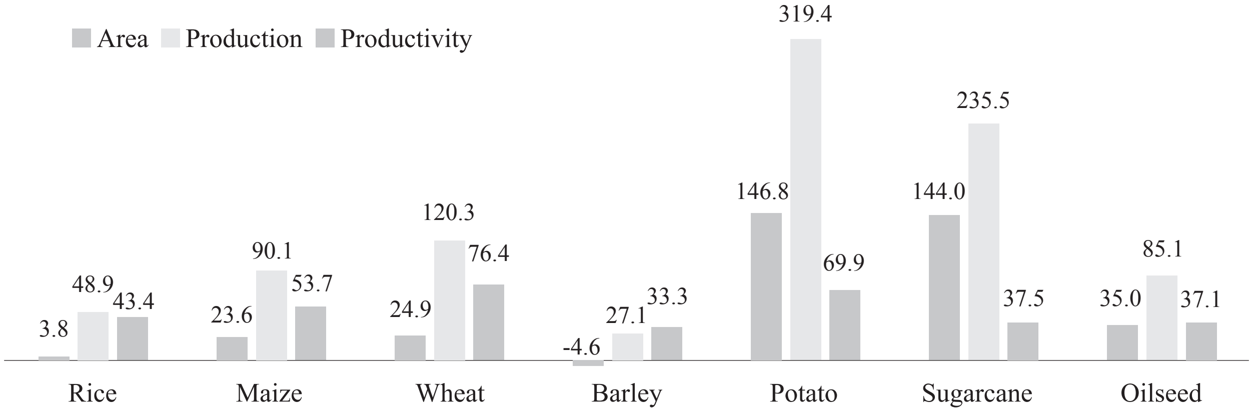

Figure 3. Percent increment in area, production and productivity of important crops over 25 years (1990-2014) in Nepal. Source: MoAD 2014

About 30,000 landraces of 250 cultivated crop species exists in Nepal. Landraces are the early cultivated forms of a crop species, evolved from a wild population and not manipulated by plant breeders. Varieties are developed by breeders. Cultivars include both landraces and varieties. Contribution of landraces on food security and plant breeding are often underestimated and it is reported that the area covered by improved varieties of rice, maize and wheat in Nepal is more than 90% (MoAD, 2014). Many crop landraces have very important and useful genes (Table 2) however, their use is negligible. Some of the globally important landraces are 'Bhate Phaper' of tartary buckwheat (Joshi et al., 2009), 'Jumli Marshi' and 'Anadi' of rice and 'Akabare' of chili pepper. Nepal is considered agro-biodiversity rich country (Shahi, 1995, 1999; Shrestha & Shrestha, 1999; Basnyat, 1999; Upadhyay & Joshi, 2003), however, among 275 released varieties, only 25% are origin to Nepal (Figure 4). The highest number of varieties originated from India. Around 80% of total released varieties of wheat, all of the potato and lentil varieties originated outside the country.

Foreign genetic materials are used for breeding research, as parental lines in crossing program, for testing across the locations, and partly for production. Free and easy access of advanced lines are the major factor that influence the germplasms flows from outside the country. Pedigree analysis reveals that 13 landraces originated in 8 different countries were used to develop Khumal-4 rice variety (Figure 5). A total of 47 ancestors (landraces) originated in 12 different countries were used to develop 20 mid and high hills rice cultivars and a total of 35 ancestors originated in 11 different countries were used to develop 28 rice cultivars for Tarai. Exotic ancestors were used to develop 35 modern wheat varieties. A total of 89 ancestors originated in 22 different countries were used to develop these wheat cultivars. The origin of most of the ancestors for Nepalese wheat cultivars were from USA (13%), India (13%), France (12%), Argentina (6%), and Italy (6%). Only exotic parents have been used to develop all the eight modern potato varieties. The highest numbers of ancestors used in developing these potato varieties were from Germany. Eleven varieties of lentil have been released so far and only one variety was bred in Nepal. Nepal is dependent about 95 to 100% on foreign germplasms for varietal development. Dependency will increase further on outsourcing APGR because of climate change impacts, e.g., heat, drought, submergence, cold and diseases of major economic importance.

Table 2. Some of the important and unique crop landraces in Nepal

Crop	Genotype	Uniqueness
Buckwheat	Bhate Phaper	Loose husk
	Kagpani Phaper	Highest rutin content
Cauliflower	Garve Cauli	Very large head, perenniality gene, vegetatively propagated
Chilly	Akbare Khursani	Medicinal value, very hot and does not have burning sensation on stomach
	Jire Khursani	All year round fruiting
Finger millet	Dailekh Local	High yielder and adapted to low fertility land
Maize	Pani Makkia	Tolerant to water logged condition
Rice	Amaghauj	Multiple spikelets per node
	Anati Dhan	Festival rice/ sticky rice
	Bhati	Deep water rice
	Ekle Rice	Zn deficiency tolerance
	Gamadi Dhan	Matured panicle remained within flag leaf
	Jumli Marshi	Cold tolerance rice
	Mansara	Adopted to very marginalized land
	Pakhe Masino, Lahure Sahila, Goi Sahila, Makar Kandhu	Hiunde (winter, boro) rice
	Samundaphinj	Swampy land rice
Sarson	Gorlikhorka	Highest oil content
Wheat	Dabde Local	For low fertility and moisture deficient land
	Mudule Gahun	Very sweet taste, awnless
	Pauder Local	Cold induced sterility tolerance

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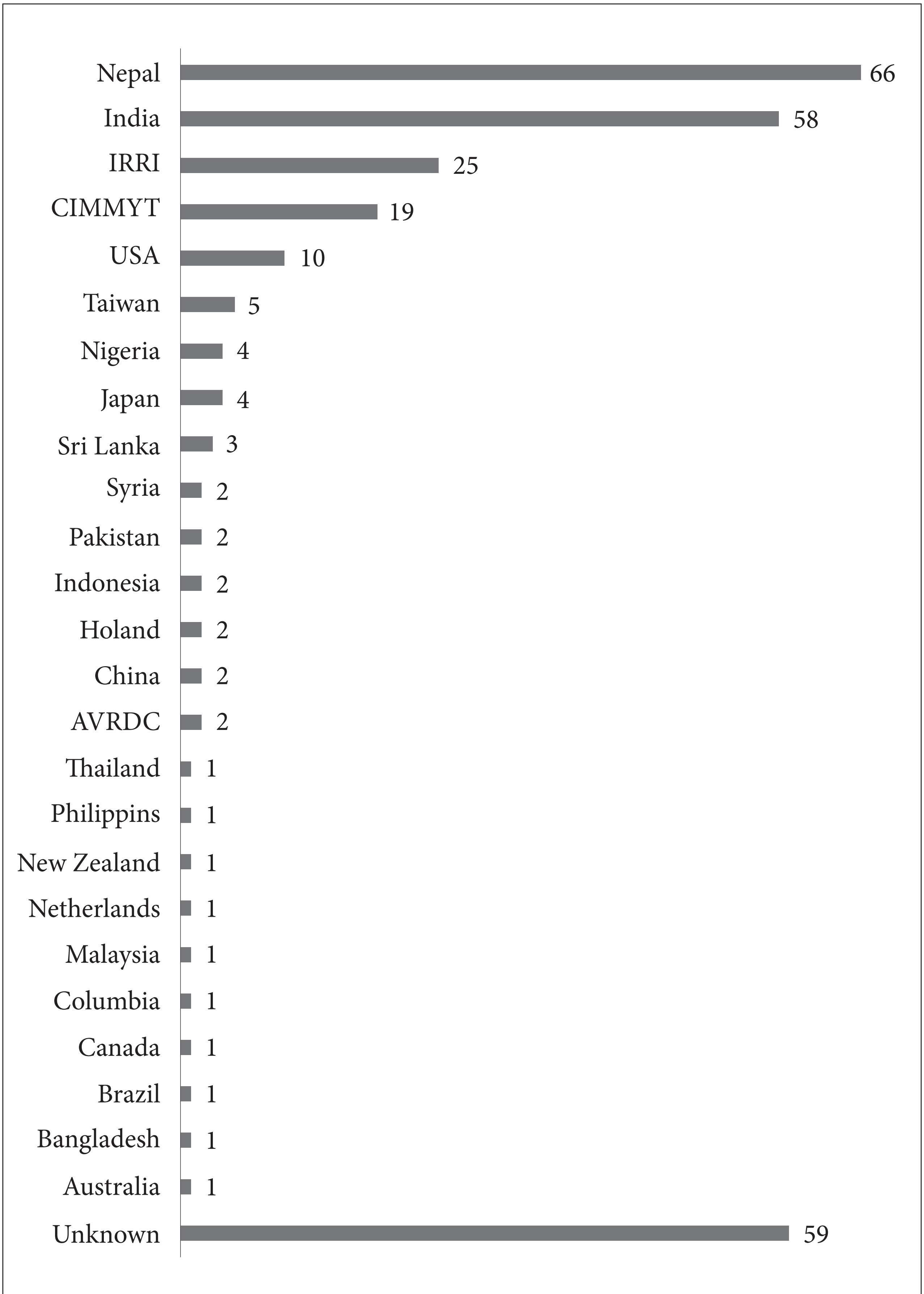

Figure 4. Origin of crop varieties released in Nepal

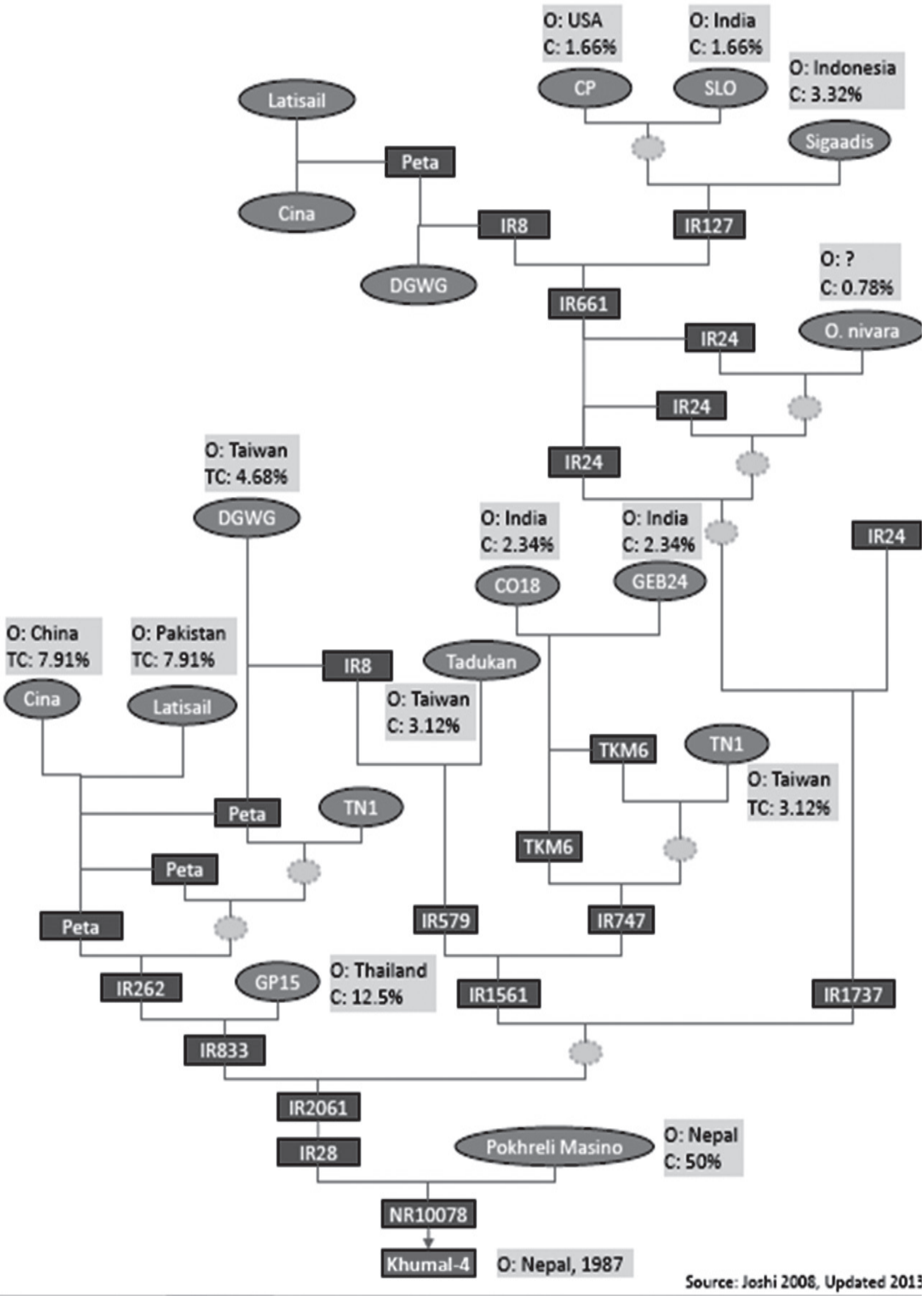

Figure 5. Complete pedigree tree and ancestral contribution to Khumla-4 rice variety

ACHIEVEMENTS

Total released and registered varieties in Nepal are 605 of 65 crops. Among them 241 are released varieties of 51 crops, 364 are registered varieties of 37 crops and 35 are denotified varieties of 6 crops. The number of released varieties is the highest for Tarai area (Figure 6) followed by for Mid Hill. Twenty seven varieties are recommended for all agricultural domains i.e. Tarai, Mid and High Hills. CH-45 rice variety was the first variety recommended in Nepal in 1959 for general cultivation and second variety recommended in 1960 was of wheat variety called Lerma-52. The highest numbers of varieties were released during 1990-1999. In recent years, release of varieties is increasing in number.

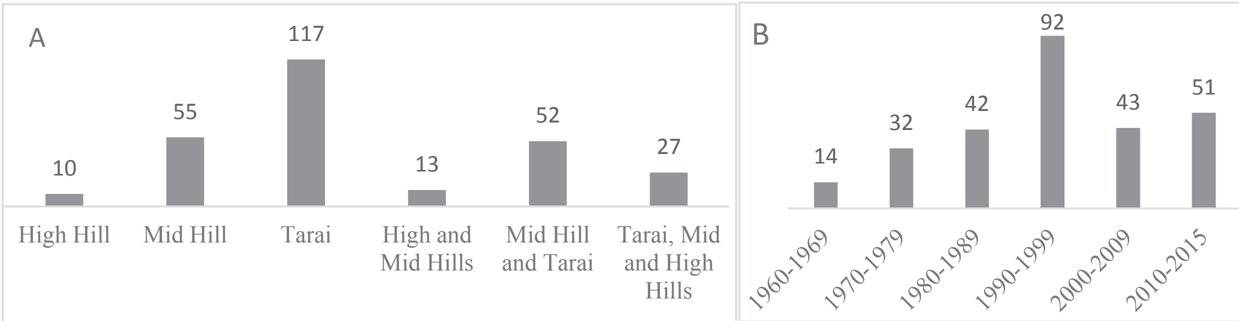

Figure 6. Number of released varieties based on the recommended zones (A) and over the 10 years interval (B)

Trend on yield potential of released varieties of rice, wheat and maize over five decades are presented in Figure 7. The productivity increment over the years was 0.016, 0.0033 and 0.065 (t/ha/year) for rice, wheat and maize, respectively. The coverage of improved variety in rice, maize and wheat is above 90% (MoAD, 2013). The production and productivity of the crops has not been achieved as expected. However, production increases have been experienced in major crops. The yield potential of improved rice varieties in Tarai and inner Tarai is 5-6 t/ha and 8-9 t/ha in the hills. However these potentialities could not be exploited at farm level.

Regmi (2014) stated the 1% average per year increase in rice production and 0.35% area increase based on the last 60 years of rice statistics. Gauchan et al (2012) analyzed the growth in area, yield and production of rice. The trend of area, yield and production was positive during the early 1980's (1.37%, 2.08% and 3.46% per annum in area, yield and production respectively) and 1990's (0.94%, 1.06% and 1.99% per annum in area, yield and production respectively but no remarkable increase occurred in other decades. Rice production from 1961 to 2008 grew at 1.7% per annum. The area under wheat increased by more than 6 folds, the production by 10 folds and the productivity by 2 folds in the span of 35 years- 1965 to 2000 (NARC & CIMMYT, 2001). In the same period, the area and production of maize got double (NARC & CIMMYT, 2001). Khatiwada and Manandhar (2012) mentioned the increase in production of various crops in 20 years of time span- 1990 (1990-1992, average three years as base) to 2009/10 (2008-2010, averaged of three years). The increase in production in three major crops rice, maize and wheat were around 40%, 57% and 97% respectively (Khatiwada and Manandhar, 2012). The increase in production was 11% for legume, 70% for oil seed crops and 101% for sugarcane and it was negligible for barley and millet. The increase in crop area was the highest for sugarcane (65%) followed by millet with 34% and oilseed crops with 24.7%. The area increase was 9.8% in rice, 16.2% in maize and 23.4% in wheat during this 20 year's period.

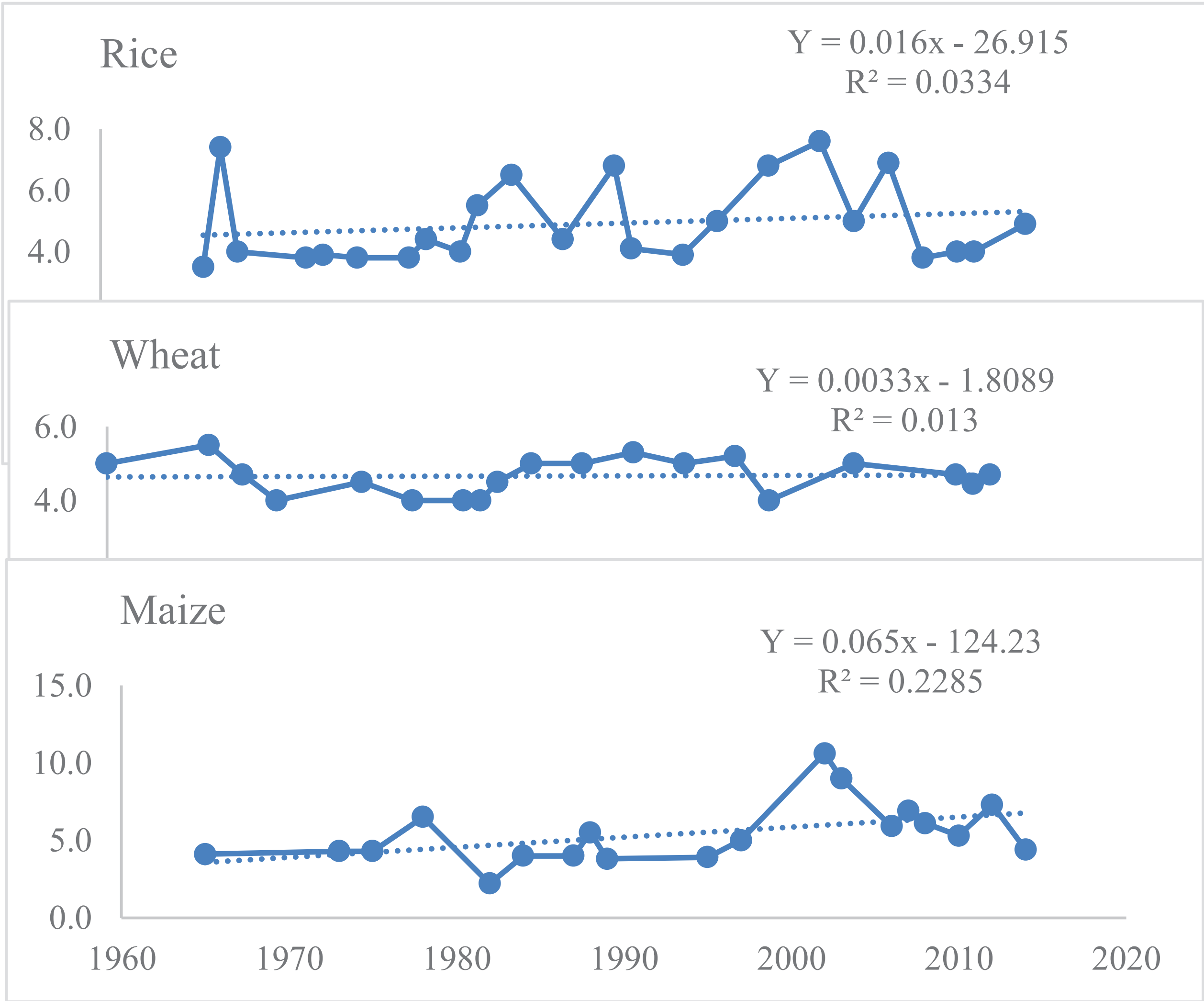

Figure 7. Yield potential of released varieties of rice, wheat and maize over the years (Years: 1960 to 2015 in X-axis and yield, t/ha in Y-axis).

Local landraces of 19 crops have been used to develop 41 varieties (Table 3). Among them 14 varieties were developed by crossing local landraces with exotic varieties. Landraces were genetically enhanced either through pureline or mass selection method. To complement the conventional breeding, tissue culture has been started since 1989 in Potato Research Program, Khumaltar. There are research efforts to extend the tissue culture technique to other crops e.g. rice, sugarcane, banana, buckwheat, wheat, cardamom, etc. In recent years, many research stations in Nepal have started using DNA technology, especially in crop breeding program (Gurung et al., 2009; Sharma et al., 2007). Major focus in the past was on genetic diversity assessment (Bajracharya et al., 2003, 2012; Joshi et al., 2005; Joshi, 2007) and now marker assisted selection is being practiced in major crops. Some of the released rice varieties e.g. Swarna Sub-1, Sukha Dhan, in Nepal are the contribution of DNA technology.

Table 3. Crop varieties developed by using local landraces and breeding method

SN	Crop	Variety	Landrace used	Breeding method	Year released
1	Asparagus Bean	Khumal Tane	Local landrace	Pureline selection	1994
		Sarlahi Tane	Local landrace	Pureline selection	1994
2	Barley	Solu Uwa	Landrace from Solukhumbu	Pureline selection	1990
3	Black Gram	Kalu	Local landrace	Mass selection	1989
4	Broad Leaf Mustard	Khumal Broad Leaf	Local landrace	Mass selection	1989
		Khumal Rato Pat	Local landrace	Mass selection	1994
		Marpha Broad Leaf	Local landrace	Mass selection	1994
5	Cauliflower	Kathmandu Local	Local landrace	Mass selection	1994
6	Chickpea	Dhanush	Local landrace	Mass selection	1979
		Trishul	Local landrace	Mass selection	1979
7	Cowpea	Akash	Local landrace	Pureline selection	1990
8	Cucumber	Kusle	Local landrace	Selection	1994
9	Egg Plant	Sarlahi Green	Local landrace	Pureline selection	1994
10	Finger Millet	Okhale-1	Landrace from Okhaldhunga	Mass selection	1980
		Kabre Kodo-1	Landrace from Surkhet	Mass selection	1990
11	Lentil	Sindur	Local landrace	Mass selection	1979
12	Maize	Ganesh-2	Local landrace	Exotic / Local cross, composite	1989
		Hetauda Composite	Local landrace	Exotic / Local cross, composite	1973
		Manakamna-1	Local landrace	Exotic / Local cross, composite	1987
		Manakamna-5	Local landrace	Exotic / Local cross, composite	2010
		Manakamna-6	Local landrace	Exotic / Local cross, composite	2010
		Rampur-2	Local landrace	Exotic / Local cross, composite	1989
		Resunga Composite	Local landrace	Composite	2014
13	Niger	Nawalpure Jhuse Til-1	Local landrace	Mass selection	2000
14	Pigeon Pea	Bageswori	Local landrace	Pureline selection	1991
		Rampur Arahar-1	Local landrace	Pureline selection	1991
15	Radish	Pyuthane Rato	Local landrace	Selection	1994

SN	Crop	Variety	Landrace used	Breeding method	Year released
16	Rice	Khumal-2	Jarneli	Landrace /exotic genotype crossing and selection	1987
		Khumal-4	Pokhreli Masino	Landrace /exotic genotype crossing and selection	1987
		Palung-2	Pokhreli Masino	Landrace /exotic genotype crossing and selection	1987
		Khumal –5	Pokhreli Masino	Landrace /exotic genotype crossing and selection	1990
		Chhomrong	Ghandruk local	Pureline selection	1991
		Machhapuchhre-3	Chhomrong	Variety /exotic genotype crossing and selection	1996
		Pokhreli Jethobudho	Jethodbudho landraces	Mass selection	2006
		Khumal-8	Jumli Marshi	Landrace /exotic genotype crossing and selection	2006
		Lalka Basmati	Local Lalka Basmati	Mass selection	2010
		Lekali Dhan-3	Chhomrong	Variety /exotic genotype crossing and selection	2014
		Lekali Dhan-1	Chhomrong	Variety /exotic genotype crossing and selection	2014
17	Sesame	Nawalpure Khairo Til-1	Local landrace	Mass selection	2000
18	Soybean	Lumle Bhatmas-1	Local landrace	Mass selection	1996
19	Sponge Gourd	Kantipure	Local landrace	Selection	1994

Plant breeding strategies, phases and activities

There are three main strategies on developing a variety through plant breeding. They are wide vs site specific adaptation, evolutionary vs non-evolutionary and diversity vs uniformity. Before 2005, breeders had developed varieties focusing on wide adaptability and non-evolutionary with uniform phenotype. This strategy resulted in the expansion of cultivation areas with mono-genotype and loss of many landraces. In Nepal, such strategy is not appropriate due to varied climates and needs of farmers, where single variety could not perform equally well all over the country. Current trends on plant breeding strategy is now shifting from non-evolutionary to evolutionary, uniformity to heterogenous and heterozygotes, and wide adaptation to site specific (Joshi et al., 2016).

The varietal development activities can be grouped into three phases, namely pre-breeding, breeding and post breeding in Nepal (Figure 8). Pre-breeding is targeted to accelerate the breeding work with the focus of making diverse elite lines available to breeders. Major activities under pre-breeding are collection and characterization of crops diversity, introgression, and genetic base broadening. The breeding phase is the central one with more resources demanded. New genotypes are created in this phase and different crossing techniques, tools and selection methods are applied. Different kinds of breeding trials are conducted and most of the activities are implemented on-station (i.e. trials and sites managed and controlled by breeder). Statistical genetics and computer software are applied to understand the genetics of particular traits and to accelerate the selection process and advance the segregating populations. After making the genotypes stable, it enters next phase called post-breeding, which is generally linked with on-farm activities (may be on-farm trial led by researchers or on-farm trial led by farmers) along with some part of activities in on-station. Major activities are multi-location trials, farmers' field trials, variety release and dissemination (Figure 8). Different research and development partners should be involved in close collaboration in these three phases to make the plant breeding works more effective and efficient.

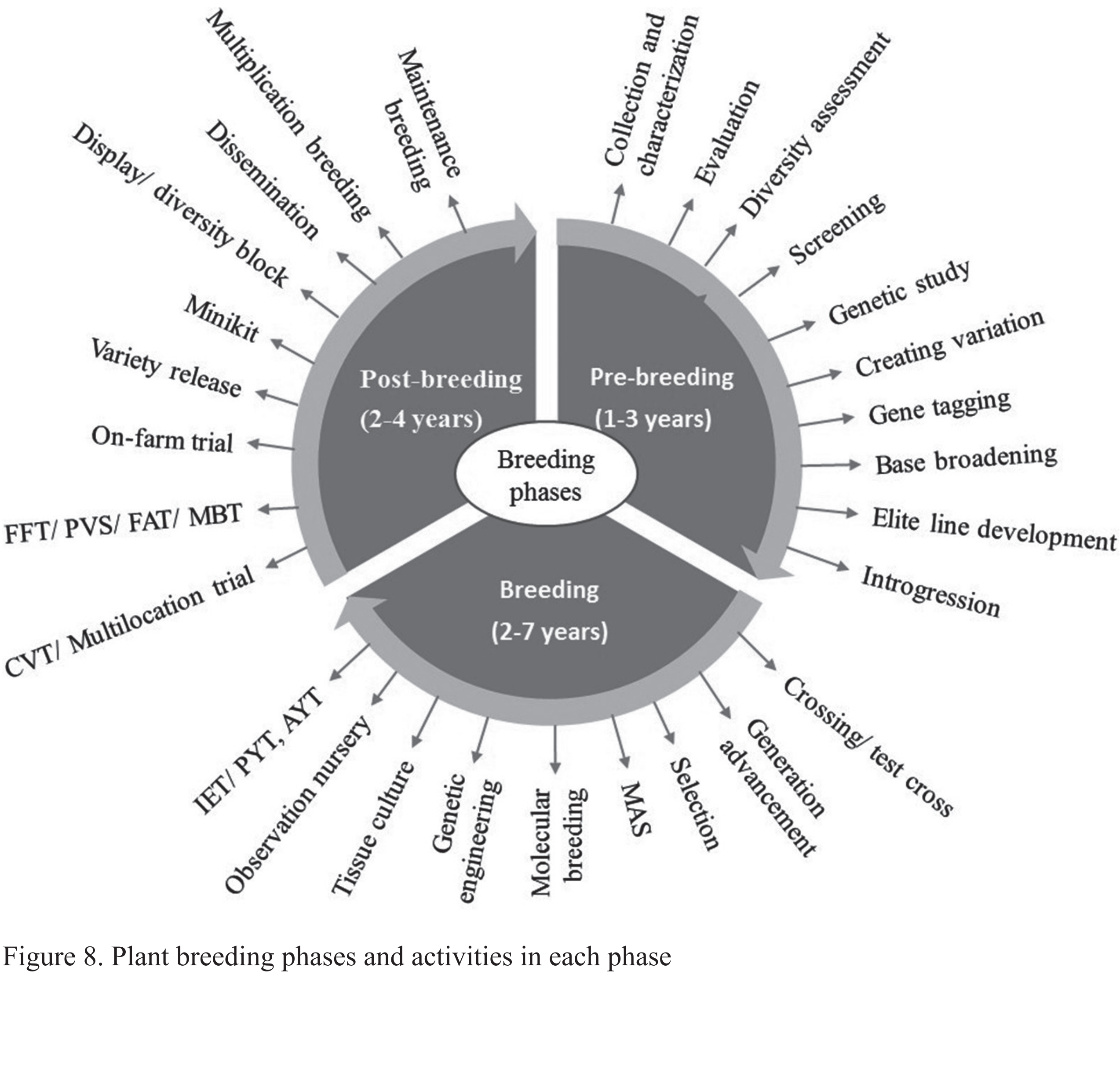

Figure 8. Plant breeding phases and activities in each phase

Plant breeding techniques and methods

Breeding technique is the method of reproduction i.e. production of progeny. It may be either controlled pollination (selective mating) or open pollinated (random mating). Plant breeding methods can be grouped into three categories. First is conventional or classical plant breeding methods, which were developed during the early plant breeding era and are commonly practiced in most of the breeding institutes. These methods are dominant in Nepal. For self-pollinated crops, classical methods are introduction (primary and secondary), mutation breeding, landrace enhancement, maintenance breeding, back crossing, mass selection, pure line selection, bulk method, heterosis breeding, cultivars mixture (varietal blend), pedigree method and single seed descent method. Breeding methods for cross pollinated crops are introduction (primary and secondary), mass selection, heterosis breeding, maintenance breeding, synthetic variety, recurrent selection, population improvement. Introduction, clonal selection and heterosis breeding are three methods practiced for vegetatively propagated crops in Nepal. Shuttle breeding is also in practice. It is the technique of rapidly advancing segregating generations by growing contra-season nurseries at distant locations, utilizing the agro-climatic diversity. The objective is to obtain at least two crop cycles in a year.

Second is participatory plant breeding method, which involves farmers and plant breeders during selection as well as advancing segregating generations. These methods mostly conducted in farmer's field, e.g. participatory plant breeding (PPB), participatory varietal selection (PVS), farmer's field trial (FFT), mother baby trial (MBT) and landrace enhancement. PPB is the selection of segregating lines by farmers in collaboration with breeders in their target environments using their own selection criteria. Regular interaction among farmers and plant breeders and growing breeding materials in target environment are supposed to speed up the adoption process of newly developed varieties.

Third category is modern plant breeding methods and generally includes application of biotechnological tools. Broadly there are three methods under modern plant breeding, namely 1. Molecular marker technology, 2. Plant tissue culture and 3. Genetic engineering. Molecular marker technology includes markers (e.g. DNA markers, isozyme markers) linked to important traits and are used to select genotypes more effectively and efficiently. Selection is possible any time and at any crop stages. Molecular marker based selection accelerates the conventional plant breeding. Markers are useful for characterization, fingerprinting and identification; screening; diversity study; population structure; linkage map construction and gene tagging; marker assisted selection (MAS) and marker assisted backcrossing (MAB). Plant tissue culture is the regeneration of whole plant from any parts (cell, tissue, organs, meristem, anther, ovule, etc) of plants in artificial media. There are different techniques under tissue culture e.g. anther culture (double haploid production), meristem culture, in-vitro fertilization, somatic hybridization, embryo rescue, protoplast fusion, etc. Genetic engineering is a technique to introduce distant genes into a genotype. Through this technique, though not in practice in Nepal, genotype carrying new genes are developed e.g., Golden rice.

Selection is the only method that have been used from the very beginning of plant breeding and equally applicable to self-pollinated, cross pollinated and vegetatively propagated crop species. To aid the selection, three kinds of markers have been practiced in Nepal (Figure 9). Comparative features of these markers are explained in Figure 9. Breeders had used biochemical markers for about 5 years mainly for assessing genetic diversity in rice, taro, barley, buckwheat. DNA based markers mainly SSR and RAPD are increasingly used for selection of desired genotypes and diversity assessment.

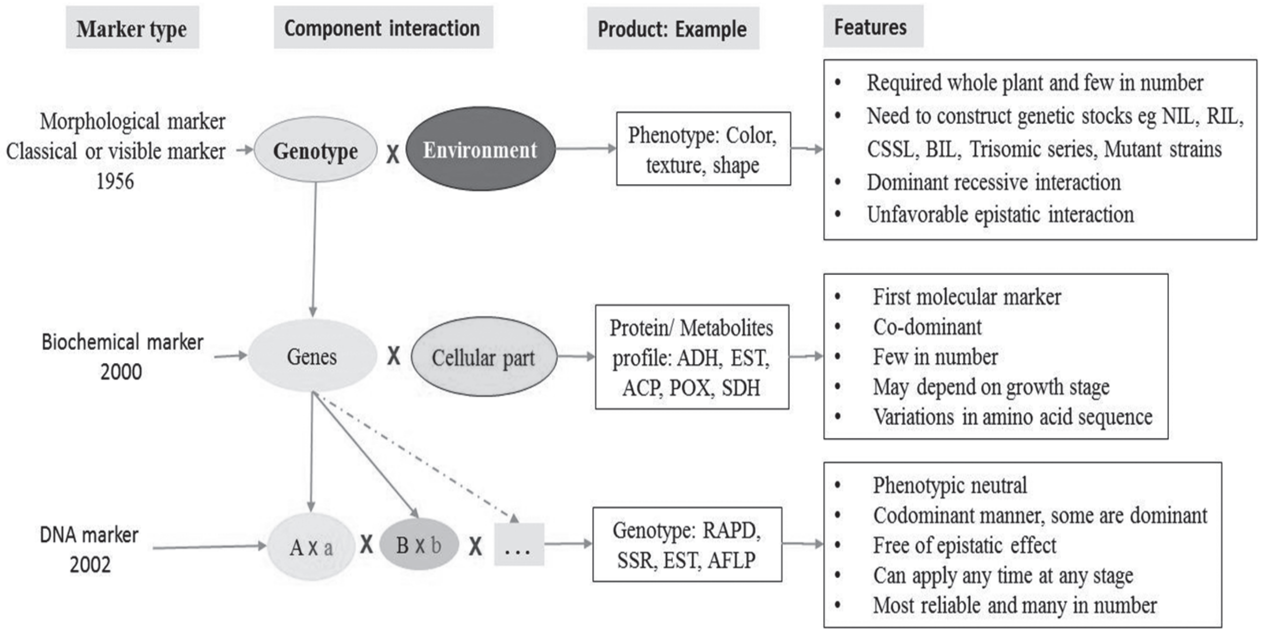

Figure 9. Markers system used in plant breeding in Nepal.

General breeding scheme adopted for self and cross pollinated crops are sketched in Figure 10. This is conventional breeding method consisted of pre-breeding, breeding and post breeding phases and takes almost 12 years to release a variety for general cultivation. After variety release, breeding station involved in the variety development should maintain and produce breeder seeds. There are mainly four classes of seeds (Figure 10). Because of long process in conventional plant breeding system, fast track breeding is necessary to adopt by removing or merging some steps (Figure 10) and using biotechnological tools. For commercialization of any cultivars, they need first either released or registered in National Seed Board. Any cultivar can be registered with single season agro-morphological data. There is also provision to register variety developed outside Nepal. Both types of varieties i.e. released and registered have same status, even though many efforts and years are necessary to get variety released.

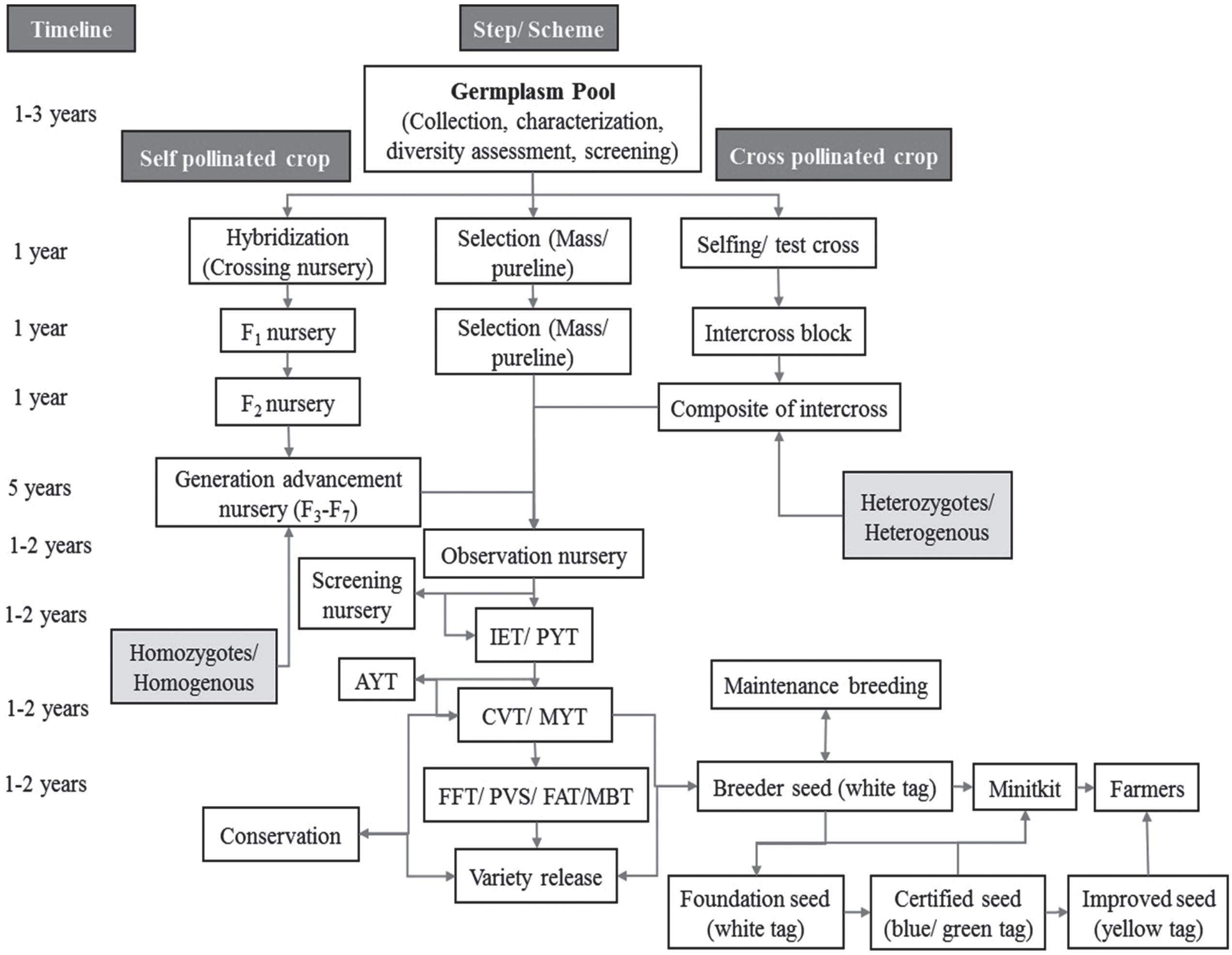

Figure 10. Generalized plant breeding scheme for self and cross pollinated crops in Nepal.

Experiment designs used by plant breeders are RCBD, CRD, augmented design, alpha lattice, split plot, multi-locations/ years trial, un-replicated trial, rod row design (solid seeded lines). Most common statistical tools are stability analysis (AMMI, GGE biplot), multivariate analysis (cluster, PCA), descriptive statistics (frequency, CV, mean, SE), test statistics (F-test, t-test, LSD, DMRT), ANOVA, correlation, regression and genetic parameters. Most common software are GGEBiplot, Agrobase, R, SAS, Minitab, MSTAT-C, NTSYS, SPAR, Indostat, Diva-GIS (Joshi et al., 2008a, 2008b), IRRIStat, GenStat, and Alphagen (Joshi & Shrestha, 2003; Joshi et al., 2005). Software used for genetics and biotechnological data analysis are MapMaker, WinQTLCartographer, PopGene, PHYLIP, KIN, Genestat, GDA, PowerMarker and GenAlex, etc.

Plant breeding trials and generation

Followings are the commonly used breeding trials in Nepal. These are designed to meet different objectives (Figure 10) and conducted either on-station or on-farm. In addition to these, there may be target/objective specific trial e.g. blast screening nursery, drought screening nursery, seed multiplication nursery, maintenance breeding, etc. In most of the trials check varieties are included. They are of two types, one called local check which is the best variety under cultivation in target environment, and second is standard check which is the best variety under cultivation at national level.

- **Crossing nursery**: Growing of male and female parental lines in glasshouse or field for hybridization.
- **Generation advancement nursery (GAN)**: Heterozygotes generations after F_1 and grown in field either for developing homozygotes or making selective crossing among themselves.
- **Observation nursery (ON)**: Un-replicated trial of newly developed or received genotypes in on-station for observing the expression of economic traits in particular environment.
- **Initial evaluation trial (IET)**: On-station replicated yield trial of newly developed genotypes including check in one location for testing their overall performance. Also known as preliminary yield trial (PYT).
- **Advanced yield trial (AYT)**: On-station replicated yield trial of newly developed genotypes including check in one location for further verification of IET over the years on their general performance.
- **Coordinated varietal trial (CVT)**: Replicated yield performance trial where varieties and checks are evaluated on more than one location for testing their adaptability and stability. It is also called multi-location yield trial (MYT).
- **Farmer's field trial (FFT)**: On-farm evaluation trial of newly developed pipeline varieties in farmer's management practices and in target environment for getting response from farmers on them, generally farmer is considered as single replicate. Also known as farmer acceptance test (FAT).
- **MINIKIT**: A small seed kit of modern cultivars distributed free by the formal research system to promote the newly released varieties under farmers' management conditions.
- **Participatory varietal selection (PVS)**: Selection of fixed lines (released or pre-released or advance lines or landraces) by farmers in collaboration with breeders in their target environments using their own selection criteria.
- **Mother baby trial (MBT)**: A baby trial is a one-on-one comparison under farmers' management. In mother trial all new varieties tested in baby trials are grown together as a single replicate. The varieties comprising the baby trials come from the mother trial. Each mother trial is composed of 6-10 varieties.
- **On-farm trial**: Trial in farmer's field either managed and controlled by farmer or researcher. Generally particular technology or variety is tested in comparison with local one in farmer's management practices.
- **On-station trial**: Trial managed by researchers on-station where most of the agricultural practices are controlled and suitable environment for particular varieties are created.
- **Diversity kit**: Also called seed kit, which includes more than one variety either released, pipelines or landraces in a pack to distribute to the farmers. This is particularly targeted to increase diversity along with making farmers access to new varieties.

- **Diversity block**: A number of plots either in on-station or on-farm with many types of cultivars (varieties and landraces) and pipelines, grown for displaying the available diversity along with preliminary observation on their yield performance.
- **Display block**: A number of plots on-station with all released varieties, pipelines, elite lines, rare and unique landraces maintained providing the visitors an opportunity to see potential of different varieties at a single location.
- **Informal research and development (IRD)**: Distribution of many small packets of seed of released and pipelines varieties without fertilizer or pesticides, the only additional input being a description of varietal characteristics on an enclosed leaflet. This approach emphasized increased varietal adoption rather than data collection for research and was particularly suitable for increasing the flow of new genetic materials to areas lacking an effective formal seed supply system.
- **Demonstration plot**: Growing newly released varieties including local landrace in farmer's field or in area accessible to many farmers with the objective of showing potential of new varieties to the farmers at their own location.

Different kinds of generations are developed and advanced for developing varieties. Cultivars (varieties and landraces) and genotypes in farmers' fields and breeding stations are open pollinated variety (OPV), clonal lines, pure lines, inbreds, bulk population, high yielding varieties, modern varieties, composite population, segregating generations, fixed genotypes, partial hybrid, F_1 hybrids, mutants, multilines, near isogenic lines, differential lines, pipeline varieties, synthetic population, polyploidy, genetically engineered organism (GMO), organ transplanted organism (OTO) and Cytoplasmic male sterile line (CMS) lines.

Advances in plant breeding and adoption

Horizon of crop breeding is drastically expanded after the advancement in genomics. I Crop improvement is possible within a short period of time using genomics and biotechnological tools, e.g., double haploid crops, cybrids, hybrids, somaclonal variants, virus free plants and GMOs.

The unconventional approach i.e. using biotechnological tools, to breeding entails the use of cutting edge technologies for creating new variability that it is sometimes impossible to achieve with conventional methods. The advent of recombinant DNA (rDNA) technology gave breeders a new set of powerful tools for genetic analysis and manipulation. Gene transfer can now be made across natural biological barriers, circumventing the sexual process. For example,. the Bt products that consist of bacterial genes transferred into crops to confer resistance to the European corn borer. Molecular markers are available to aid the selection process to make the process more efficient and effective. Even though two breeding approaches (conventional and modern) have been described, it should be considered as complementary rather than independent approaches.

Usually, the molecular tools are used to generate variability for selection, or to facilitate the selection process. After genetically modifying plants using molecular tools, it may be used as a parent in subsequent crosses, using conventional tools, to transfer the desirable genes into adapted and commercially desirable genetic backgrounds. Different approaches used in crop breeding worldwide are given in Table 4.

Table 4. Breeding tools for crop improvement and genetic studies

Breeding tool	Application
Classical tool	
Emasculation	Removing male parts from a complete flower; preparation for crossing
Hybridization	Crossing genetically different plants to transfer genes or achieve re-combinants
Wide crossing	Crossing of distantly related plants
Selection	The primary tool for discriminating among variability
Chromosome doubling	Manipulating ploidy level, mainly for fertility
Male sterility	To eliminate need for emasculation in hybridization
Triploidy	To achieve seedless varieties
Linkage analysis	For determining association between genes
Mutagenesis	To induce mutations to create new variability
Tissue culture	For manipulating plants at the cellular or tissue level
Haploidy	Used to create extremely homozygous diploid
Isozyme markers	To facilitate the selection process
GIS and CAT	To accelerate the adaptability of genotypes
Advanced tool developed in recent time	
Molecular markers	For effective selection and gene tagging and mapping
Marker assisted selection	Facilitate the selection process
DNA sequencing	Ultimate physical map of an organism
Plant genomic analysis	Studying the totality of the genes of an organism
Bioinformatics	Computer-based technology for prediction of biological function from DNA sequence data
Microarray analysis	To understand gene expression and for sequence identification
Phenomics	For physical and biochemical traits
Plant transformation	For recombinant DNA work

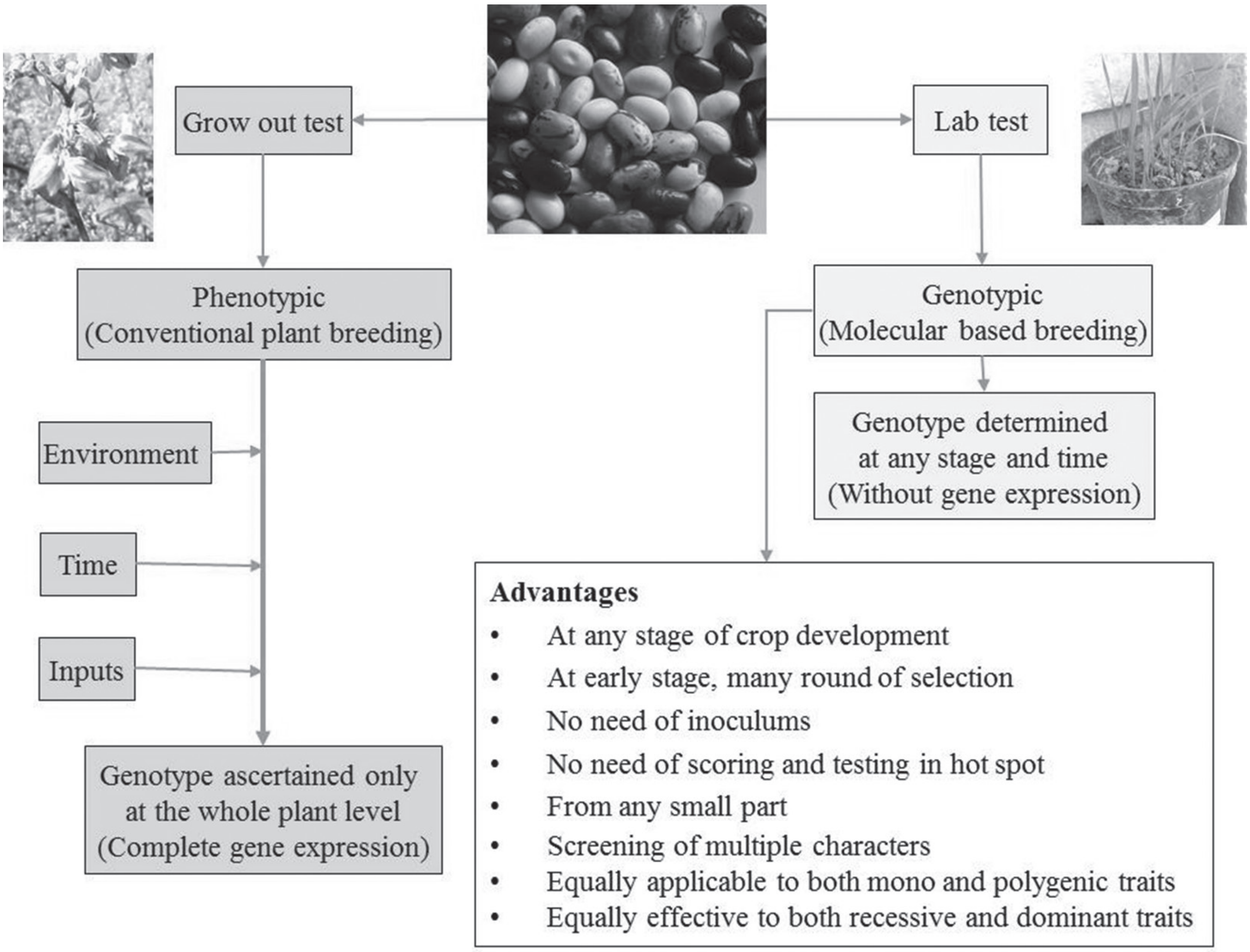

Figure 11. Comparative process and advantages between grow out test and lab test in selection or identification of genotype

Lab test method of selecting genotypes (i.e. use of biotechnology in the breeding) has many advantages compared to grow out test (i.e. phenotype based selection) (Figure 11). However, only 8 out of 60 research and education organizations have used lab test method.

Several molecular marker systems are available now making the crop selection more efficient and effective. Nepal Agricultural Research Council has also initiated biotechnological research for crop improvement (Joshi and Bimb, 2001, 2002, 2003a, 2003b; Bajracharya et al., 2003; Joshi 2007; Joshi et al., 2009; Bhatta & Amgai, 2012). Biotechnological products mainly in rice have been tested and evaluated in collaboration with IRRI, CIMMYT and CIP. After the extensive testing, IRRI bred rice varieties tolerant to submergence (Swarna Sub-1 and Samba Masuli Sub-1) and drought tolerant varieties (Sukha Dhan 1 to 6) have been released in Nepal.

Genetic modification using recombinant DNA technology (Figure 12) is the method of gene transfer horizontally making it possible to manipulate genes, theoretically without any biological limits. On this approach research has not been initiated in Nepal.

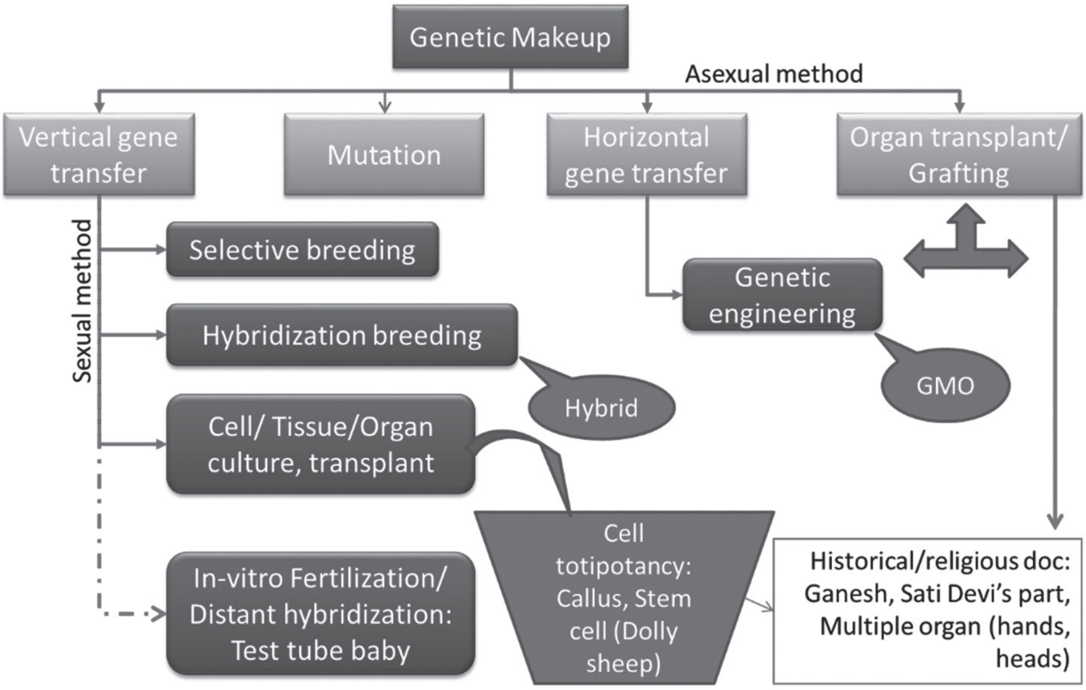

Figure 12. Approaches for genetic modification of crop species. GMO, Genetically modified organism.

Current policy on plant breeding

There is no specific policy for plant breeding and genetics in Nepal. Some of the relevant policy, act or regulations are Plant Protection Regulations 1975, Seed Act 1988 AD (Amendment 2008 AD), Seed Regulations 1997, National Seed Policy 1999, National Agriculture Policy 2004, Biotechnology Policy 2006, Plant Protection Act 2007, Agro-biodiversity Policy 2007 (amendment 2014), National Biosafety Framework 2007, National Seed Vision 2013-2025, National Biodiversity Strategy and Action Plant 2014-2020 and Agriculture Development Strategy 2015-2035. Relevant draft documents are Access and Benefit Sharing Bill 2002, Plant Variety Protection and Farmers' Rights Bill 2005 and NARC Vision 2011-2030.

Genetic improvement of crop species including hybrids and high yielding varieties with sustainable use of APGRs are the prime concern of National Agriculture Policy and Agro-biodiversity Policy. ADS focuses on improvement of local landraces through breeding for base value addition (e.g. PVS, PPB). Seed vision has given emphasis on strengthening plant breeding works in the country. By 2025, the cumulative number of released crop varieties is expected doubled, from 232 in 2010 to 423 in 2025. Establishment of Hybrid Research Unit (HRU) under National Commodity Programs and Divisions are proposed. By 2025, it is envisaged that 40 hybrids comprising, 20 in vegetables, 12 in maize and 8 in rice will be developed and promoted. In addition, 20 hybrids comprising 10 in vegetables, 5 in maize and 5 in rice are expected to be developed and promoted by private sectors.

NARC vision emphasizes the use of biotechnological tools in plant breeding with the target of developing high yielding varieties with tolerant/ resistant to abiotic and biotic stresses. Biotechnology Policy has also provision on using biotechnology for varietal development. GMOs or their product may be released one after another in the environment by taking due precaution. Prior to releasing GMO or products thereof in the environment, it is to be ensured that no adverse effect to the human health or environment is observed at each stage of the risk assessment (Biosafety Guidelines 2005). Registration of GMO is possible only after biosafety report (risk assessment).

Two major international agreements that Nepal is a party, are the Convention on Biological Diversity (CBD) 1992 and International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) 2004 which cover conservation, sustainable use and fair and equitable benefit sharing of biological diversity. CBD states that countries have sovereign rights to legislate, manage, exploit and control access to their natural resources, including APGR. Nepal has been a signatory to the CBD in June 1992 and ratified it in November, 1993. ITPGRFA focuses on conservation, sustainable use and fair and equitable sharing of benefits. Nepal ratified ITPGRFA on 2 January, 2007 and became party to it on 19 October, 2009.

Opportunities and challenges

Huge agricultural biodiversity, about 30,000 crops landraces, evolved and grown across the diverse climates is the major opportunity for breeders and crop scientists in Nepal (Baniya, 2001; Bajracharya et al., 2003; Upadhyay and Joshi, 2003; Joshi, 2004, 2008, 2007; Sharma et al., 2007; Gurung et al., 2009; Joshi et al., 2010; Joshi et al., 2013; Genebank, 2014). National breeders, farmers and researchers can have access to more than 46,00,000 accessions of different crop species (Figure 13). University students have chances to develop knowledge and skill on modern plant breeding including biotechnology. There is a need of developing breeders and crop scientists with expertise on different crops and cross-cutting disciplines. Germpalsm/genes with global importance can be used to expand the agricultural business.

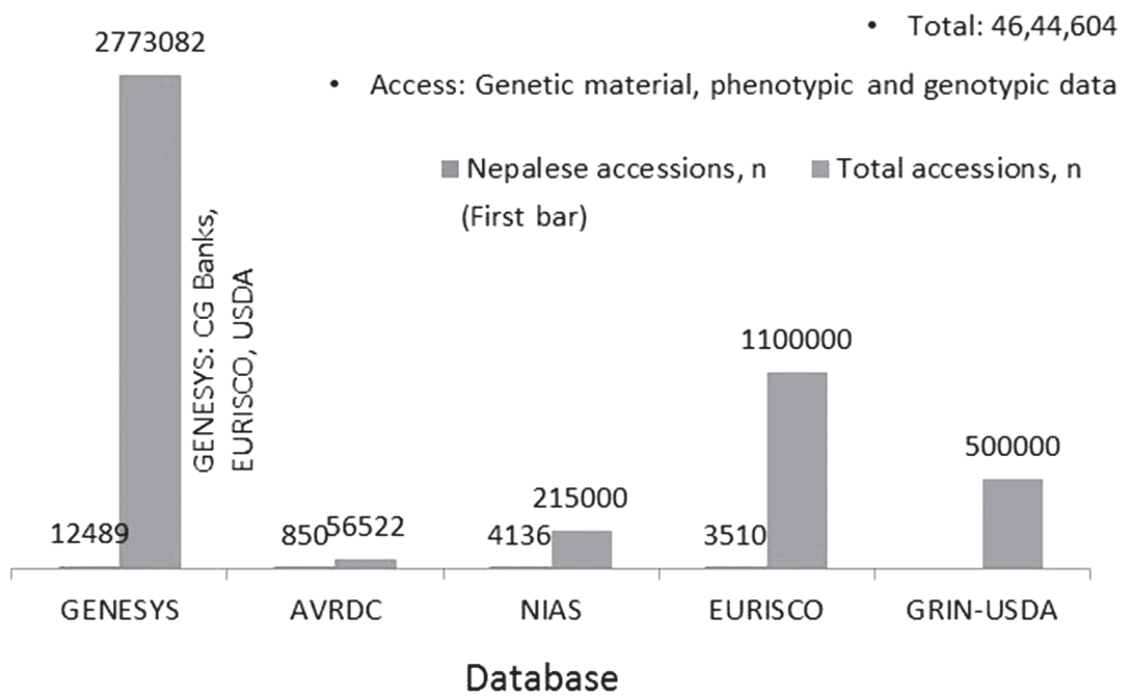

Figure 13. Number of accessions in global gene pool that are accessible to Nepalese plant breeders.

According to the World Population Reference Bureau (PRB, 2014), population of Nepal in mid-2030 is projected to rise to 31.7 million and 35.2 million in mid-2050 from that of the present population of 27.1 million. To meet the future food demands agriculture production must be increased by 70%. This is a big challenge as there is no possibility of bringing more land into cultivation. The increased production must come from increased productivity in major cereals, vegetable and fruit crops. This will only be possible through genetic gain in crop yield along with improved agronomy and favorable agriculture policies. The genetic gain can only be obtained through technological breakthrough by using biotechnological tools as complementary to the conventional breeding.

Climate change is a serious challenge for domestic and global agriculture. Nepal is highly vulnerable and ranked 4th in the world from this perspective. High and mid hills are more vulnerable and the impact will be more severe compared to Tarai region. Breeders need to develop many varieties to meet the diverse needs of farmers and consumers, and to suit at varied production climates with enhanced tolerance to various biotic and abiotic stresses.

Many technological advances have been made on plant breeding in the world; however, Nepal could not adopt these advances for crop improvement. The lack of financial investments and limited number of breeders are the major constraints on advancing the plant breeding in the country. In the past, thousands of genotypes of different crop species were introduced for evaluation and now there is a restriction on germplasm flow, especially after Nepal becoming the party to CBD in 1993. Breeders now have to manage, create and use diversity available within country at least for some crop species. Research and education systems need to advance and private sectors should be encouraged and facilitated for plant breeding entrepreneurship.

Way forward

Of the two approaches i.e. horizontal and vertical expansion for increased production, genetic enhancement is the most preferred and effective means through which farmers and environment friendly varieties can be developed. Huge diversity available in the country should be explored for better designing genotypes suitable for different conditions with biotic and abiotic stresses tolerance. Harvesting the economically important genes is now possible within a short period of time through biotechnological tools. Still, Nepal is very far behind exploiting heterosis in most of the crops and using the biotechnological tools to enhance the conventional crop breeding. Therefore, focus should be given to explore the potential of Nepalese genetic resources and heterosis. To speed up the varietal development process, biotechnological tools should be considered in most of the crop improvement programs e.g. crop breeding, plant pathology, and entomology. Most of the Nepalese have poor access to balanced foods. This can be tackled through biofortifying the landraces or varieties.

Public and private stakeholders, research and education sectors must be harnessed to drive the pace of plant breeding. As the new, well-tested technologies emerge, especially molecular tools like MAS, plant breeding will become more efficient at a fast rate, perceived as fast track breeding. This should principally speedup breeding progress, starting with the more efficient use of genetic resources to a reduction of multi-location trials as genotypic selection becomes more precise Gene technology can additionally solve problems related to quality and resistance within and across the species. Conclusively we should think of giving more space to science in agriculture research and crop breeding and should consider following points.

- Although the improved varieties coverage is high in major crops, niche specific and stress tolerant varieties are lacking. The diverse crop genetic resources should be used to develop crop varieties of specific adaptation.
- Germplasm collection, conservation, characterization, including tagging and mapping of genes and QTLs in Nepalese landraces and genetic enhancement must be fully strengthened using conventional as well as molecular techniques.
- Emphasis should be given for incorporation of molecular breeding like marker aided selection along with conventional breeding system for breeding tolerance to biotic and abiotic stresses and for quality traits.
- Regional and location specific or niche based germplasm adaptation should be duly considered in varietal improvement.
- Heterosis breeding should get priority in research and education.
- Education system should be based on the research findings pertinent to agriculture production problems in the country.
- Strong linkage is necessary between research and education institutions.
- Adoption of fast-track breeding strategy.

ACKNOWLEDGEMENTS

Historical activities and breeders name were documented in consultation with Madhusudan P. Upadhyay, Devendra Gauchan, Mina N. Paudel, Dili R. Bhandari, Dhruba Bhattarai and Madan R. Bhatta. Special thank goes to Gopal R. Rajbhandary, Kamlesh L. Rajbhandary, Krishna P. Sharma and Bal B. Shahi for sharing history and specific data on plant breeding works in Nepal.

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