Indigenous Seeds, Seed Selection and Seed Bank for Sustainable Agriculture

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Abstract
Indigenous seeds are grown by the farmers over the years with a strong influence from local natural factors. Such seeds have a higher level of intrapopulation variations and the capacity of buffering the adverse factors. Understanding indigenous seeds along with their diversity are useful to diversify their uses, to assess conservation status, to know the factors making farming areas red zone, and to improve their performance. Selection is the simplest and most common method for the improvement of crop varieties. The variation must be created and maintained to impose selection. Different types of selection can be considered depending on the mode of reproduction of crops. Response to selection and correlated response are estimated to make the selection process more effective. Many different selection approaches can target either developing monomorphic or polymorphic varieties. There are five selection units and can be applied in five crop stages. Farmers’ criteria need to be considered during selection process. Based on the genotypic classes, there are three types of selection namely stabilizing selection, directional selection, and disruptive selection. The most simple and common selection methods are pure lines, mass selection, and class-bulking selection. Orthodox seeds in short, medium, and long-term storage facilities are conserved as a seed bank. Major types are household seed banks, community seed banks, national seeds, natural seed banks, and global seed banks. A seed bank is for assuring the availability of crop diversity for research, study, and production. The common works in seed banks are diversity collection, regeneration, characterization, multiplication, and distribution along with online database management.

Keywords
Conservation; Endangered; Native seed; Red zone; Selection method; Workflow
Introduction

Seed is the heart of agriculture and a major source of energy for living beings on the Earth. Thousands of native seeds of different crop species are being created and maintained by farmers (Dwivedi et al., 2016; Joshi et al., 2018). Before the agricultural green revolution, localized Indigenous seeds were grown for grain production, and were produced at the same locality. Diverse and robust local seed systems which involve many native crop landraces are central to sustainable food systems that are renewable, resilient, equitable, diverse, healthy, and interconnected (Global Alliance for the Future of Food, 2016). But after the establishment of international research centers, crop diversity is being stored in the room and very few uniform varieties are grown widely. This has resulted in the loss of many native seeds (Joshi, 2017; Roy, 2000). Seeds and grain products are now in different domains. Seeds are produced in one site and transported to other sites for cultivation. Seeds grown in new areas sometimes do not perform well and there are many cases of crop failure across the world. Selection is the main method of shaping diversity, developing new uniform varieties, and narrowing the genetic base of newly developed varieties (Roy, 2000; Singh and Chaudhary, 1977; Sthapit et al., 2019). Modified selection methods are needed so that this method could develop a variety with high intra level genetic diversity as well site-specific polymorphic variety. Commercialization of agriculture and negligence of native seeds are the major drivers leading to loss of a large number of native crop landraces. Realizing the importance of native crop diversity and a higher rate of genetic erosion, many different kinds of seed banks have been established (FAO, 1994; IRRI, 2000; Joshi et al., 2020b, 2017). Indigenous seeds, selection, and conservation are the key players in agriculture for sustainable food and nutrition security. This paper elaborates on the importance of Indigenous seeds, selection methods for developing polymorphic varieties, and conservation methods.

Indigenous Seeds

Seeds are planting materials produced by sexual reproduction. They are capable of reproduction and act as source of energy for many living beings in the world. Over the years, many different types of seeds of plant species have been evolved. Indigenous seeds are those that are produced, grown, or living naturally in a particular location. They are selected and managed by local people in the local environment, and they possess a high-level intra diversity. Therefore, they are heterogenous, polymorphic in nature (Joshi, 2017; Marone et al., 2021; Shiva, Ramprasad and Bhar, 1994). They are well adapted to the growing areas, and they produce high nutrition yield (Joshi et al., 2020c) and health index yield. Farmers have a crucial role in maintaining and improving such seeds (Global Alliance for the Future of Food, 2016). Seeds produced from the same production areas (seeds are well familiar with the production and environmental factors) are far better for a sustainable production system. They are the sources of many different genes and the foundation of agricultural science.

Types of Seeds, Features and Uses

Seeds are of many different types based on breeding, conservation, and botanical perspectives. Types of seeds along with their features are explained in table 1. Indigenous seeds are used mainly for production and in research studies. This is the basis of developing modern high-yielding varieties (Dwivedi et al., 2016; Marone et al., 2021). Green revolution in agriculture is because of their role in contributing specific genes. Any different types of varieties are possible only using such indigenous seeds. As an example, a

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1 Earlier many farmers produce themselves seeds for theirs need to produce grains. But trend is now increasingly changing from single producers of seeds and grains in to two different types of producers, one is seed producer and another one is grain producer. They are generally from different areas, districts, provinces or countries. This resulted in the production of seeds from other than grain production areas, called grain production domain.
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A popular rice variety, called Khumal-4 in Nepal, has been developed using 13 different landraces originated in 8 countries (namely USA, India, Indonesia, Taiwan, China, Pakistan, Thailand, and Nepal (Joshi et al., 2017).

Table 1. Types of seeds and varieties based on different criteria

<table>
<thead>
<tr>
<th>S.N.</th>
<th>Types (seed or variety)</th>
<th>Feature</th>
<th>Synonym</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Indigenous seed</td>
<td>Landrace of a particular site where this was originated</td>
<td>Native seed</td>
</tr>
<tr>
<td>2.</td>
<td>Local variety</td>
<td>Landrace not introduced from other areas, if introduced, localized after growing several generations</td>
<td>Heirloom</td>
</tr>
<tr>
<td>3.</td>
<td>Landrace</td>
<td>Genotype not altered by breeders but grown continuously by farmers over years</td>
<td>Traditional, farmer’s variety</td>
</tr>
<tr>
<td>4.</td>
<td>High yielding variety</td>
<td>Developed by selecting and following principles of genetics</td>
<td>Improved, modern variety</td>
</tr>
<tr>
<td>5.</td>
<td>Hybrid seed</td>
<td>Produced by crossing two different parents</td>
<td>F1 seed</td>
</tr>
<tr>
<td>6.</td>
<td>Genetically modified seed</td>
<td>Seeds of genotype having distantly related genes</td>
<td>GMO seed</td>
</tr>
</tbody>
</table>

Based on the conservation perspective

| 1     | Orthodox seed         | Successfully dried to moisture contents <12% without injury and can tolerate freezing | Desiccation tolerant seed |
| 2     | Recalcitrant seed     | Do not tolerate drying tent below 12% without injury and are unable to tolerate freezing | Desiccation sensitive seeds, unorthodox seed |

Based on the botanical perspective

| 1     | Monocot seed         | A single (mono) embryonic leaf or cotyledon | Albuminous seed |
| 2     | Dicot seed           | Two embryonic leaves or cotyledons           | Symmetrical seed |

Status Assessment

The status of landraces concerning trends in their population size over sites and years is called conservation status. Among many different methods of status assessment, five cell analysis (also called landrace distribution analysis) is practically simple and very useful (Joshi and Gauchan, 2017). This method is based on areas and the number of growers which are measured through focus group discussion. Another approach is trait distribution analysis which helps identify rare and unique landraces based on the distribution of a particular trait in different landraces (Joshi and Gauchan, 2017).

Endangered (red-listed) landraces

The size and distribution of many native landraces are decreasing rapidly due to many factors (Shrestha et al., 2005). Landraces that are expected to be extinct in the near future from a particular site are called endangered landraces. In general, all landraces from the red zone are defined as endangered. Red zones are those areas where native technologies and germplasm are at the risk of being lost due to both natural and human-made factors e.g., earthquakes, changes in land use, distribution of modern variety, commercialization, etc. (Figure 1). All landraces that are endangered and rare are defined as a red list. Many different approaches can be used to assess the status of crop diversity called conservation status.
How to conserve

Crop diversity can be conserved in three different ways. The first one is growing landraces or diversity continuously. Continued cultivation, harvesting, storing, and using are the dynamic process of conservation of crop diversity. The second method is using landraces in a breeding program. Use in breeding helps conserve some portion of the genome of landraces. The third one is conserving seeds in a seed bank. This is a long-term approach for the conservation of seeds. All three methods should be adopted for sustainable agricultural research and development (Joshi et al., 2020b).

Seed Selection

Basis of selection and mode of reproduction

Genetic variation within species, varieties or population is the basis of selection. Major events for creating variation are meiosis, mutation, and cross-pollination. Heritability of specific traits is very important to estimate the response to selection. The genetic variation depends on the mode of reproduction e.g., the evolutionary rate is higher in sexually propagated genetic resources as compared to asexually propagated species. Seed selection applies only to self and cross-pollinated plant/crop species. Depending on the mode of reproduction, the selection target may be either homogenous or heterogeneous (Figure 2). In autogamy species, the selected populations are homogenous and homozygotes, whereas, in allogamy, the selected populations are heterogeneous and heterozygotes. Selection always favors increasing the frequency of favorable alleles, genes, traits, and genotypes.

Response to selection and correlated response

Selection is the main and simple method for the genetic improvement of an individual or a population. Response to selection is how much gain we achieved in a particular trait (e.g., grain yield) from choosing some individuals over the original population. Response to selection is also called genetic gain (ΔG) or genetic progress. Based on the performance of the base population, selected individuals, and progeny of selected individuals, the following different parameters related to response to selection can be calculated (Figure 3) (Roy, 2000; Singh and Chaudhary, 1977).

\[ S (\text{selection differential}) = \text{Mean of selected individuals} - \text{mean of the base population} \]

For prediction of selection differential \( (S') \),
\[ S' = (Z/p); \text{where } Z \text{ is the height of the ordinate, } p \text{ is the proportion of selected individuals, and } \sigma_p \text{ is phenotypic standard deviation} \]

Figure 1: Possible causes of making agricultural land to the red zone and ultimately agricultural genetic resources endangered. (Source: Joshi and Gauchan, 2017)
R (response to selection) = Mean of the progeny of selected individuals – mean of the base population
For prediction of response to selection (R’), R’ = i.h^2. σp; where i is standardized selection differential, h2 is heritability.

Figure 2: Mode of crop reproduction and selection targets

Figure 3: Different selection parameters associated with response to selection

During selection of an individual based on a particular trait, it also affects other traits. Many traits are correlated with each other. The change in one character (say ‘y’) through indirect selection on an
associated character (say 'x') is called correlated response (CRy), which is estimated using the following formula (Singh and Chaudhary, 1977),

$$CR_y = i_x \cdot h_x \cdot h_y \cdot r_g \cdot \delta_p y$$

where $i_x$ is standardized selection intensity of x character, $h_x$ and $h_y$ are the square roots of heritability of x, and y, respectively, $r_g$ is a genetic correlation between x and y, $\delta_p y$ is the phenotypic standard deviation of y character.

**Selection approaches**

Six different selection approaches are in practice. Anyone or a combination of more than one approach can be adopted. These are: a) participatory vs. non-participatory selection approach; b) on-farm vs. on-station selection; c) native vs. exotic variety selection; d) natural vs. artificial crossing-based selection; e) population vs. individual selection, and f) direct vs. indirect selection. On-farm selection is generally carried out in a participatory way, whereas on-station selection is non-participatory. Genetic diversity can be collected either from within a country or from a foreign country. Selection based on this material, it may be native seed selection, which is found more effective in term of its adaptability and consistence performance over the years. Naturally, almost all seed-bearing species cross at least few percentages among genotypes. Selection can be pressured on such a naturally crossed population or a human-assisted crossed population. In general, the population is considered as a selection unit in cross-pollinated species and an individual selection is in self-pollinated species. Direct selection is a very common approach that considers the target trait during selection (Joshi, 2017; Sthapit et al., 2019). Indirect selection is effective based on correlation and path coefficients.

**Selection target: Monomorphic vs. polymorphic**

The selection target is always to develop better variety at least for a target trait. In many cases, selection output is to get monomorphic and genetically uniform variety. Genetic uniformity leads to genetic vulnerability to both biotic and abiotic stresses and decreases intra level diversity. In contrast, polymorphic variety has a higher level intra varietal diversity, poly genotypes, and, therefore, is called heterogeneous population. Increased diversity reduces losses from pests and diseases, keeps evolving from generation to generation, decreases vulnerability to both biotic and abiotic stresses (Joshi et al., 2020a). Therefore, the selection target should be to develop a variety with a higher level of intra varietal diversity.

**Selection units and crop stages**

Selection is a continuous process, and there are five selection units. These are crop fields, a specific area within a crop field, plant or hill (all tillers emerged from the same point) from within a selection area, flower or spikelet within a plant, fruit or seed within an inflorescence. All units should be selected based on pre-defined criteria and targets. Selection then should be carried out in five different stages of the crop, namely seedling stage, vegetative stage, flowering stage, maturity stage, and storage stage. In many cases, one-stage selection (i.e., at the maturity stage) is very common but five stages selection is more effective, and genetic gain is relatively high.

**Selection tools and aids**

Selection involves many different factors, and it is complex in terms of getting significant genetic gain. To accelerate the selection process more effectively and efficiently, many different tools and aids should be considered. Some of them are correlation coefficients, heritability, path coefficients, check variety, control variety, yield, yield components, selection index, criteria and objective, target environment, and software.
The software, which are useful for the selection of genotypes, are:

**GGEBiplot**: It is a graphical tool for breeders, geneticists, and agronomists for conducting biplot analysis of research data. It is available from http://ggebiplot.com/.

**GGEBiplotGUI**: It is an R package that provides a graphical user interface for the construction of, interaction with, and manipulation of GGE biplots. It is available from https://cran.r-project.org/web/packages/GGEBiplotGUI/index.html.

**Agrobase**: It is a plant breeding software with selection index estimation. It is available from https://www.agronomix.com/AGROBASE.aspx.

**Selection index**: It is an R package for analysis of selection index in plant breeding. It is available from https://cran.rstudio.com/web/packages/selection.index/index.html.

**RIndSel**: It is an R package with a graphical unit interface that uses selection index theory to select individual candidates. It is available from https://data.cimmyt.org/dataset.xhtml?persistentId=hdl:11529/10854.

**SI-R**: This is a collection of R codes to compute several selection indices in R. It is available from https://data.cimmyt.org/dataset.xhtml?persistentId=hdl:11529/10352.

**ViTSel**: It is R-based software to visualize results of multi-environmental multi-trait analysis for selection in plant breeding. It is available from https://data.cimmyt.org/dataverse/cimmytswdvn.

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**Generalized selection traits (farmers’ criteria)**

Farmers always consider multiple traits in any variety. However, many researchers target to increase grain yield. Nutrition yield and health index yield are also very important and need to be considered during the selection of varieties. Farmers’ criteria are high yielding without external inputs, early maturity, good cooking and eating quality, pest resistance, medium height, drought-resistance, strong stem, good tillering capacity, erect leaves, large seed sizes, non-shattering, cost benefits and fodder value (Shiva et al., 1994).

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**Types of selection based on classes**

In diploid species, there are three types of genotypes, e.g., AA, Aa, and aa, for a particular trait and can also be called three classes (in one locus with two alleles systems) (Roy, 2000). Genotypes of AA and aa represent extreme types and Aa represent the intermediate type. Almost all quantitative traits follow a normal distribution. In such a normally distributed curve, two tails are representing the two extreme expressions of a trait, and the third represents the average expression of a trait. Depending on the favoring of such classes during selection, there are three types of selection, as given in figure 4. Stabilizing selection includes individuals with mean equal or close to population means. The selection of individuals with either higher mean or lower mean is called directional selection. Disruptive selection includes individuals from more than one class and the progeny of selected individuals make two picks. In the majority of crop breeding, directional selection is very common and effective.

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**Simple Selection methods**

Many specific selection methods have been developed for self and cross-pollinated and vegetatively propagated crops. Selection methods are applicable to both segregating population and farmers’ varieties. The simple methods among other complex selection procedures are pure line selection, mass selection, and class-bulking selection methods. The pure line selection method involves the selection of a single best genotype for several generations until a pure line of a variety with desired characters is established. This method is more applicable to self-pollinated and clonally propagated crops. Mass selection is the oldest method of crop improvement in which many different individual plants are selected based on phenotypic performance, their seeds are bulked and used to grow in next generation.
This cycle is repeated until the desired population is established.

Figure 4: Types of selection based on different genotypic classes

Another modified bulk selection method is the class-bulking selection (CBS). In this CBS, individuals are selected from different classes, categories, or groups of varieties or landraces or within cultivar and mix them. This mixture or bulked materials are grown, and selection pressure is imposed. These processes are repeated for getting a heterogenous population having desired characters. Such variety is relatively more resilient to climate changes and less vulnerable to both abiotic and biotic stresses. A better result can be obtained if selection and bulking could be done based on the mixing ability (general mixing ability and specific mixing ability) of different selected genotypes.

**Seed Bank**

Seed bank is a place where the orthodox seeds of many different crops are stored to preserve genetic diversity along with information for present and future use. Orthodox seeds are long-lived seeds and can be successfully dried to moisture contents as low as 5% without injury and can tolerate freezing e.g., rice, maize, and soybean. Non-orthodox (recalcitrant) seeds cannot be stored for a long term and, therefore, seed bank is associated with only orthodox seeds. Some features of general seed banks are banking of different kinds of seeds, making access to all stakeholders and long-term security. Seeds from such banks are only used for reproduction, multiplication, and research, and not for consumption (FAO, 1994; IRRI, 2000; Joshi et al., 2020b, 2018, 2017; Rao et al., 2006; Rao and Paula, 2000).

**Types of a seed bank**

Seed banks are of three types based on conservation strategies, they are on-farm seed banks, *ex-situ* seed banks, and *in-situ* seed banks (Figure 5) (Joshi et al., 2017; Joshi and Upadhya, 2019). The on-farm seed bank is where seeds are stored for few months to few years in a man-made store or house e.g., community seed bank (Shrestha, Vernooy and Chaudhary, 2013), household seed bank, and village level seed bank. The whole life period of seeds does not get a chance to interact with natural factors. Seeds are stored at normal room temperature and for a short term. In village level seed bank, each household maintains different specific crop seeds, and, in aggregate, all households i.e., the village, conserve the maximum...
crop diversity. *Ex-situ* banks may be national, regional, or global, and seeds stored in such banks do not get a chance to interact with natural factors. Seeds are stored in an advanced structure with a controlled environment targeting medium and long terms. If seeds and all their stages interact with natural factors, such a system of storage is called as *in-situ* seed bank. Seeds of crop’s wild relatives are stored in such conditions and called natural seed banks. Similarly, the domesticated crop can be kept all the time in a certain field, called agro gene sanctuary. In such sanctuary, crop seeds are grown in the field and their matured seeds remain in the same field in natural condition.

![Image of seed banks and storage environment](image)

**Figure 5:** Types of seed banks and storage environment (not colored box)

### Storage condition

Community seed banks and household seed banks are being maintained at room temperature and natural relative humidity (RH) (Joshi et al., 2018). Seeds can be stored either in air-tight containers or in any local containers. The *ex-situ* seed bank is maintained with two systems, one is called active collection where seeds are kept in air-tight containers at 0-10°C temperature and 35-45% RH (FAO, 1994; IRRI, 2000). Second is a base collection, which is maintained at -20°C and seeds are generally kept in vacuum-sealed aluminum foil. In many cases, RH is not considered to maintain in base collection. Everything in a natural seed bank is naturally maintained. Therefore, it is also called ‘seeds in the soil’, ‘soil seed bank’, etc.

### Workflow in the seed bank

Genebank handles different types of genetic materials e.g., orthodox seeds, recalcitrant seeds, and vegetatively propagating materials. For conserving all such types of materials, genebank consists of the seed bank, field genebank, and tissue bank. The work and germplasm flows are given in figure 6. The major works in seed banks are exploration and collection, registration, seed testing and processing, conservation, regeneration and multiplication, viability monitoring, characterization, evaluation, genotyping, screening and pre-breeding, distribution and exchange of materials, and database management.
Seeds flow, regeneration and distribution

Seeds flow in seed bank is given in figure 7. Seed quality and amount are major considerations during the storage process in the seed bank. Germination should be more than 80% for storing seeds in the seed bank. If both quality and quantity do not meet the standard of the seed bank, then regeneration and multiplication are carried out at suitable locations. Regeneration should be done in a similar environment to that of the original collection site. During seed multiplication and regeneration, sample size (more than 40 seeds) should be maintained to minimize the loss of genetic diversity within an accession. Small amounts of seeds are distributed to researchers and farmers from ex-situ seed banks especially from the active collection.

Figure 6: Works and germplasm flows in genebank. (Source: Engels and Visser, 2003; FAO, 1994; IRRI, 2000; Joshi et al., 2017; Rao et al., 2006; Rao and Paula, 2000)
Seed database and online access

The details of seeds materials along with the availability of seeds of many global and country-level genebanks are searchable online. Some searchable platforms are given below.

- **Genesys**: This is an online platform where one can find information about plant genetic resources conserved in genebanks worldwide. Its website is https://www.genesys-pgr.org/.
- **GRIN-Global (USDA)**: This is a database application that enables genebanks to store and manage information associated with plant genetic resources (germplasm). Its website is https://npgsweb.ars-grin.gov/gringlobal/search.
- **NIAS Genebank**: This is the main repository of genetic resources of plants, animals, and microorganisms of agricultural importance in Japan. Its website is https://www.gene.affrc.go.jp/databases_en.php.
- **Svalbard Global Seed Vault**: This is a long-term seed storage facility representing the world’s largest collection of crop diversity. The official website is https://seedvault.nordgen.org/.
- **EURISCO**: It is an online platform that provides information at the accession level of PGR conserved in European genebanks or other collections. Its website is https://eurisco.ipk-gatersleben.de/apex/f?p=103:55.

**Conclusion**

Localized seed diversity performs consistently over a long period. These Indigenous seeds are the sources of many genes and the foundation of agricultural science. Due to the high level of intra landrace diversity, Indigenous crop varieties respond well to selecting with the specifically targeted trait. Participatory selection following the class-bulking method is more effective for developing nature-responsive varieties. Crop diversity is generally being conserved in human-made buildings and a single uniform variety is grown in wider areas. This resulted in the loss of a higher percentage of genetic diversity. Crop diversity should also be maintained in the field not only in static conditions for sustainable agriculture. Different conservation strategies, as well as types of seed banks, should be considered for conservation and utilization of nature-gifted diversity over a longer period.

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References


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