PARTICIPATORY DIAGNOSTIC TOOLKITS AND CROP IMPROVEMENT APPROACHES: PARTICIPATORY METHODS TO ASSESS AND USE PLANT GENETIC DIVERSITY IN THE FIELD

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TABLE OF CONTENT

ACRONYMS

BoA	Bureau of Agriculture
CBPR	Community Based Participatory Research
CCI	Crowdsourcing Crop Improvement
CCP	Cross Composite Population
CPB	Conventional Plant Breeding
CPGR	Conservation of Plant Genetic Resources
CSB	Community Seedbank
EPB	Evolutionary Plant Breeding
FCA	Four-Cell Analysis
FGD	Focus Group Discussion
FTC	Farmers' training center
ha	hectare
IFAD	International Fund for Agricultural Development
ISSD	Integrated Seed System Development
MoA	Ministry of Agriculture
NAMA	National Meteorological Agency
NGO	Non-Governmental Organization
PCI	Participatory Crop Improvement
PGR	Plant Genetic Resources
PPB	Participatory Plant Breeding
PVS	Participatory Varietal Selection
S4N	Seeds for Needs
TRICOT	Triadic Comparisons of Technologies
WLE	Water Land and Ecosystem
WMA	World Meteorological Agency

Participatory variety selection in Ethiopia (photo: *Dejene K. Mengistu*)

ACKNOWLEDGEMENTS

The authors would first like to acknowledge all participating farmers, not only for their direct and indirect efforts and contributions to this manual, but also for their vital role in conserving genetic diversity and contributing to building resilient production systems. We would also like to thank the various scholars for the wealth of knowledge accessed for the preparation of this manual. The manual is one of the outputs of the project "Use of genetic diversity and Evolutionary Plant Breeding for enhanced farmer resilience to climate change, sustainable crop productivity, and nutrition under rainfed conditions" funded by the International Fund for Agricultural Development (IFAD), and hence the authors are grateful for IFAD for generously financing the project. Finally, the authors gratefully acknowledge Vincent Johnson (consultant contracted to the Alliance of Bioversity International and CIAT Science Writing Service) for his copy editing and technical inputs in this manuscript.

FOREWORD

This *Manual on participatory diagnostic toolkits in participatory research* is based primarily on the authors' personal experiences gained from several years of implementing participatory research programs, and from several training courses, as well as on relevant scientific literature. The Manual is structured in three parts. Section one presents four methods used to collect baseline information in participatory research: interviews, focus group discussion, snowball sampling, and secondary data analysis. Section two describes the methods used in participatory crop genetic resources assessment, including transect walk, diversity kit, and four-cell analyses. Section three addresses crop diversity deployment methods, such as participatory varietal selection (PVS), crowdsourcing crop improvement (CCI), participatory plant breeding (PPB) and evolutionary plant breeding (EPB).

The manual brings together information presented in various material sources including books, journal articles, project reports and websites, and hard facts taken from these sources have been duly acknowledged. The most-referred sources have been listed in the bibliography for further reference by readers. In developing this manual's contents, some source materials/websites have not been cited due to lack of details needed for citation (e.g. author name, publication year, etc.), and the publisher and authors deny any deliberate plagiarism. Arguably, information accessed from websites is less trusted, but still useful for developing materials, particularly when information in reputable sources is scarce. The authors believe that this manual provides useful guidance for experts working in plant genetic resources characterization and utilization using participatory approaches.

EXECUTIVE SUMMARY

In both developing and developed countries, there is increasing interest in adopting more inclusive and problem-solving participatory research methods. While there is a wealth of methods and toolkits for conducting participatory research in the form of scientific articles, books, and manuals, this manual aims to provide a source of information on available toolkits used in conducting participatory research around plant genetic resources (PGR). The manual aims at all those involved in the characterization and utilization of PGR, information collection from participant farmers, and conservation of PGR. The users could be from research centers, universities, farmers' organizations, government extension agents, and non-governmental organizations (NGOs).

The manual presents participatory information gathering tools, diversity assessment, and deployment tools and diversity conservation approaches. Each toolkit has been described in enough detail to enable readers, at different levels, to understand and use them. The manual's major merit is in presenting different toolkits in one document that are otherwise scattered in several different sources. Different toolkits used to gather information on status of PGR in participatory varietal deployment methods are presented to the readers. These readers are encouraged to submit their comments, corrections, or criticisms to improve future versions of the manual.

The manual aims at:

– Compiling different participatory toolkits in a single document for easy access by users.

– Introducing the readers to the wealth of participatory toolkits used in agrobiodiversity assessment, characterization, and utilization.

– Providing sufficient description on each participatory toolkit to improve the knowledge of 'apprentice' scholars in the field of agrobiodiversity.

– Taking the readers through the main steps in methods of PGR deployment for the betterment of target farming communities.

The Manual draws heavily on the experiences of distinguished scientists in participatory plant breeding and participatory varietal selection[1] to develop content on diversity kit, Four-cell analysis (FCA), PVS, PPB, EPB and others. Inputs from interested readers are welcome at d.mengistu@cgiar.org or dejenekmh@gmail.com.

1 such as Bhuwon Sthapit and Ceccarelli Salvatore, amongst others,

1. PART I PARTICIPATORY RESEARCH

1.1 *Introduction: What is participatory Research?*

Community-based participatory research (CBPR) has gained momentum over conventional research in many types of development research. In a nutshell, CBPR is an approach in which researchers and members of the target community make joint decisions and share common responsibilities at every level of the research process. All research stakeholders work together to enhance the understanding of their working environment and integrate that knowledge with action, to realize positive outputs from the research and thereby improve target communities' well-being. The level of community participation in participatory research ranges from passive participation, where people participate by being told what is going to happen or has already happened, to self-mobilization, where people participate by taking initiatives independent of external instructions to change systems (Pimbert, 2011). To help readers easily access and understand the different typologies of participation for visualizing and clarifying the roles, rights, and responsibilities of the different actors (researchers, farmers, etc), the seven levels of participation are listed below (adopted from Pretty, 1994 with slight modification):

1. *Passive participation:* – People participate by being told what is going to happen or has already happened. It involves a unilateral announcement by an administration or project management without listening to people's responses. The information being shared belongs only to external professionals.

2. *Participation in information giving:* – People participate by answering questions posed by extractive researchers and project managers using questionnaire surveys or similar approaches. People do not have the opportunity to influence proceedings, as the findings of the research or project design are neither shared nor checked for accuracy.

3. *Participation by consultation:* – People participate by being consulted, and external agents listen to views. These external agents define both problems and solutions and may modify these in light of people's responses. Such a consultative process does not concede any share in decision-making, and professionals are under no obligation to take on board people's views.

4. *Participation for material incentives:* – People participate by providing resources, for example labor, in return for food, cash, or other material incentives. Much of the participation in *in-situ* research and environmental protection work falls into this category, as rural people provide their labor but are not involved in the experimentation or the process of learning. This is commonly called participation, yet people have no stake in prolonging activities when the incentives end.

5. *Functional participation:* – People participate by forming groups to meet predetermined objectives related to the project, which can involve the development or promotion of externally initiated social organization. Such involvement does not tend to be at the early stages of project cycles or planning, but rather after major decisions have been made. These institutions tend to be dependent on external initiators and facilitators but may become self-dependent.

6. *Interactive participation:* – People participate in joint analysis, which leads to action plans and the formation of new local groups or the strengthening of existing ones. It tends to involve interdisciplinary methodologies that seek multiple perspectives and make use of systematic and structured learning processes. These groups take control over local decisions, and so people have a stake in maintaining structures or practices.

7. *Self-mobilization:* – People participate by taking initiatives independent of external institutions to change systems. Such self-initiated mobilization and collective action may or may not challenge existing inequitable distributions of wealth and power.

These forms of participation are used in different disciplines of scientific investigation. In demand-driven crop improvement programs, participation types 3 to 7 are used together or separately. Participatory crop improvement has numerous potential ways to empower farmers to influence the development of technologies in ways that are informed by their specific needs, agroecological environments and cultural preferences, incorporate their indigenous knowledge and hence influence the decision-making process (Halewood et al., 2007). An ideal form of participation gives farmers an opportunity to make decisions throughout from defining the breeding goals and priorities to multiplying and commercializing the seeds of the selected varieties. However, in most conventional approaches, the role played by farmers is largely undermined. Instead of ensuring farmers' participation from the beginning, conventional approaches set up farmers' field trials to collect their opinions on already-developed varieties. Usually the characteristics, inputs, and management requirements are included as mini-kits during variety extension. The consequences of such consultative types of primary end-users of the developed technologies are either complete rejection of the technologies or low adoption as farmers evaluate the technologies according to their own needs and perspectives. The degree of technology rejection or lower adoption is greater by smallholder farmers in marginal growing conditions (Witcombe et al., 1998) and such farmers continue to grow traditional varieties along with decades-old cultivars (Sthapit et al., 2019). To encourage greater adoption, decentralized and participatory approaches were gradually introduced, and the number of methods to deploy diversity in agricultural production has increased (Sperling et al., 2001; van Etten et al., 2016; Fadda et al 2020).

Now the advantages of participatory approaches over conventional ones is widely recognized and appreciated by farmers, international organizations such as Bioversity, and donors such as the World Bank (WB) and the International Fund for Agricultural Development (IFAD). For instance, in its world development report, WB stated that "*decentralized and participatory approaches allow farmers to select and adapt technologies to local soil and rainfall patterns and to social and economic conditions, using indigenous knowledge as well*." The report also acknowledged the role of participatory plant breeding and variety selection to decrease the time taken for varietal development and dissemination to half the time taken by conventional breeding programs (World Bank, 2008). Despite the approach being widely recognized by scientists and funding bodies, numerous participatory research methods have not been well-institutionalized at the local level. Conceptual confusions when considering such methods have made it difficult to choose an appropriate method and communicate results consistently (Sthapit et al., 2017).

This manual provides briefs on types, use, and pros and cons of the various methods of crop diversity assessment and diversity deployment, to help practitioners and enumerators distinguish between methods and choose the most appropriate for their needs. Additionally, the manual catalogues the participatory methods used in crop genetic resource assessment and deployment as well as agrobiodiversity assessment globally.

1.2 *The Participatory Toolkit and some baseline information collection tools*

The goal of this toolkit is to support emerging researchers who would like to learn more about CBPR approaches, particularly in the context of domestic violence. While much of the content is aimed at researchers, there is much here that will help advocates and other community partners understand the CBPR approach and its benefits. This section presents four methods used to collect baseline information in participatory research: interview, focus group discussion, snowball sampling, and secondary data analysis.

1.2.1 *In-depth individual interview*

Situation analysis of the target area(s) is very important in participatory plant breeding. In-depth interviewing is a qualitative research technique that involves conducting intensive individual consultations with a small number of respondents to explore their perspectives on a few issues related to a specific subject matter. It is a type of information acquisition method in one-on-one conversation mode. Interviews help assess interviewees' knowledge and perceptions regarding the subject under investigation. In participatory research, interviews are usually conducted with selected individuals who are thought to be knowledgeable about the subject, to get firsthand information before involving more people in the process. Researchers may seek participants' basic information including: i) their experiences of growing the target breeding crop, ii) existing varietal genetic diversity of that particular crop, iii) the crop's local importance, production potential and constraints, and iv) the crop's adaptation to local climatic conditions, amongst other things. Through interviews, researchers can assess ideas on participatory approaches *vis-a-vis* conventional approaches, and any changes they bring as the result of their involvement in the participatory study.

1.2.1.1 *Selection of interview participants*

In participatory plant breeding it is customary to involve men and women, and the old and young to represent the full range of social segments. Moreover, some types of participants, such as crop genetic resource custodian farmers, model farmers in the area, traditional breeder farmers, and woman-headed households, are deliberately sampled and included among the participants. Smolders and Caballeda (2006) have established some of the following criteria to select participants for interviews, trainings, and surveys associated with participatory plant breeding and genetic resource assessment. The participant should be:

a) living in the target village and involved in farming.

b) an active farmer with a keen interest in participatory research.

c) willing to share his/her indigenous knowledge during interview and subsequent processes.

d) experienced in cultivating the target priority crop (s).

e) between 18 and 60 years old, preferably with some basic education.

f) willing to be involved in the research process over the full duration of the project.

1.2.1.2 *When to use an in-depth interview?*

When detailed information about participants' perspectives is needed, interview is the right data collection method. Interviews are often used to provide context to existing information/data because they offer a more complete picture of what happened and why. For instance, a researcher may have observed that traditional crop varieties have been rapidly replaced by a few improved varieties. Through an interview (s) he can find out, for example, that the national extension system incentivizes planting improved varieties over traditional varieties. (S)he may discover that traditional varieties are less productive compared to improved varieties and that the local community has lost interest in conserving these traditional varieties. In this case, (s)he may also need to interview experts from the extension system, policy makers, and local governance to find out their perspectives on this issue.

In-depth interviews should be used in place of focus group discussions (FGD) where potential participants may not be included or comfortable talking openly in a group, or when distinguishing individuals' opinions (as opposed to those of a group) on any issue (Boyce and Neale, 2006).

1.2.1.3 *Advantages and disadvantages of the interview method*

There are associated advantages and disadvantages in using any given method in quantitative and qualitative research. The main advantages and disadvantages of interview are summarized below.

Advantages:

– Provides much more detailed information.

– Provides a much more relaxed atmosphere between the interviewer and the interviewee.

– Provides easier information flow for the interviewee compared with completing questionnaires

Disadvantages:

– The response might be biased due to interviewee's personal support or objection to the issue under investigation.

– The probing capacity of the interviewer might bias the response of the interviewee.

– It is time-intensive compared to FGD because of the time it takes to conduct interviews, transcribe them, and analyze the results to link with the next interview question or relate with previously-asked questions.

– Results obtained may not be easily generalizable to the whole population because of the sample size and sampling method, as random sampling is seldom used.

1.2.2 *Focus group discussion (FGD)*

Focus group discussion is a frequently-used qualitative research approach to gain an in-depth understanding of pertinent matters. FGD gained popularity due to the rise of participatory research, which requires active participation of groups of people (Morgan, 2002). It is conducted to obtain data from a purposely-selected group of individuals rather than from a statistically-representative sample of a broader population (Nyumba et al., 2018). The application of FGD in participatory research including PPB, PVS and conservation of plant genetic resources (CPGR) has been extensive. The main purpose of the FGD is to explore and understand farmers' knowledge, perceptions, beliefs, and practices (Jarvis and Campilan, 2006). It gives an opportunity for the research team to listen and learn from community members about a specific matter rather than lecturing or providing their perspective interpretation on the matter, the major problem reflected in conventional research.

1.2.2.1 *Why FGD?*

There are reasons for choosing FGD over interview in participatory research. Some of the benefits of FGD over interviews are:

1. It is a cost-effective and promising alternative in participatory research (Morgan 1996)
2. It offers a platform for exploring differing paradigms or worldviews (Guba and Lincoln, 1994)
3. FGD can minimize the effect of the researcher in controlling the discussion dynamics unlike during interview (Hohenthal et al., 2015; Bloor et al., 2001). The research role is 'facilitation' or 'moderation' and his/her lobbying power is significantly reduced.

1.2.2.2 *Designing FGD*

Focus group discussion is designed carefully to address several important components (Fig.1). It should be designed to address the key research objectives involving the right participants. While designing FGD, the following elements should be considered.

1. Identify the main study aim and define key research objectives that should be addressed during the discussion.
2. Prepare list of questions that address the research objectives as a guidance for each FGD sessions.
3. Seek ethical clearance for conducting the FGD. In research involving humans and animals, signing ethical clearance is usually mandatory.
4. Identify FGD participants whilst considering group dynamics and synergistic relationships among participants that lead to generation of intended data (Green et al., 2003).
   a. Participants should be disaggregated by sex and age.
   b. Participants should be from similar social-class backgrounds.

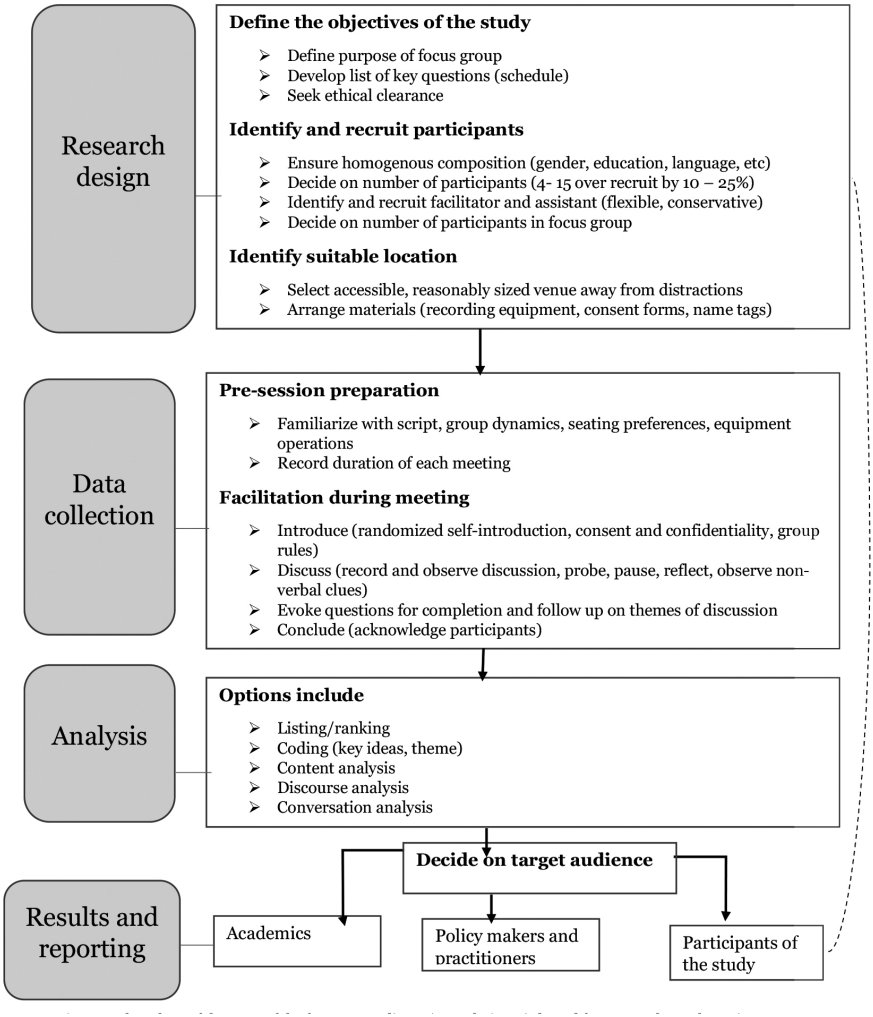


Figure 1: Flow chart of the steps of the focus group discussion technique (adapted from Nyumba et al 2018).

c. Consider involving participants with differing levels of subject matter experience and knowledge, especially where the FGD entails a knowledge transfer component, as in the case of plant genetic resource conservation and utilization.

d. Secure participants' willingness (prior informant consent obtained) to fully engage in the discussion to generate useful data/information.

e. Engage diversified FGD participants to obtain honest and spontaneous views by overcoming pre-existing relationships and patterns of leadership (Thomas et al., 1995). The moderator should keep the balance of the discussion by regulating domination and encouraging participation of all participants.

1.2.2.3 *Recruitment of participants*

Recruit participants considering their impact on the discussion outcomes. Use a purposive sampling method to ensure the ability and capacity of participants to provide relevant information is well-captured. For example, if the purpose of the FGD is to assess the conservation of traditional crop varieties in a certain area, the FGD participants are mainly custodian farmers with the presence of others disaggregated by sex, age, and education level. The inclusion of others is important to inform them on the need for conserving genetic resources and where they can access the conserved resources if needed. On the other hand, if the purpose of the FGD is to start a new participatory plant breeding program that aims to improve local crops for certain traits such as adaptation to changing climatic conditions, disease resistance, or grain yield enhancement, participation of men and women farmers is equally important. Additionally, the presence of experts from the local agricultural office, such as extension, crop production, and protection experts, is critical to capturing a comprehensive range of perspectives.

1.2.2.4 *Number of participants per FGD*

The number of total participants per FGD varies from study to study, according to the depth of information/data required and available resources. Based on the study objective (s), study participants need to be disaggregated by gender and age to incorporate the views and needs of community segments. In PPB, PVS and crop diversity study, FGD is the most frequently used method to collect information from local people to set the objectives of the studies. Considerations for conducting FGD:

1. Participants are selected purposively to ensure representation across the target area/villages/sub-villages/community.
2. Set the number of participants considering time availability, cost-effectiveness and information required. In PPB and PVS, there are usually 10 – 15 participants involved in FGD.

3. Consider the social, cultural, and economic heterogeneity of targeted area/villages/sub-villages or community.

4. Moderate the process to avoid over-dominance of certain participants and encourage participation of all participants. This is the role of the moderator.

1.2.3 *Snowball sampling*

Snowball sampling, also called chain-referral sampling, is defined as a non-random sampling technique in which the sample individuals have characteristics that are considered difficult to find or rare. It is a sampling technique in which the first-identified sample (participant) provides referrals to recruit other samples required for a research study. The researcher generates a sample purely based on referrals and continues to involve chain-referrals until sufficient data is collected to make informed decisions about the subject matter. Snowball sampling is used where potential participants are hard to locate. The method is well-suited to various research purposes and is particularly applicable when the study focuses on a sensitive issue. This may concern a confidential matter, and thus requires insiders' knowledge to locate study participants where it is impossible to determine the sampling error or make inference about the population on the samples obtained (Etikan et al., 2015).

This type of sampling is usually used where a population is unknown and rare. For example, if you want to study farmers maintaining endangered crop variety X in a given area, the snowball sampling technique could be the appropriate method to sample custodian farmers. This is because not all farmers in the area might keep this endangered crop variety, and thus random interview or random assembled FGD might not help. Another example where the snowballing method could be applied is for studies designed to understand traditional healers' local knowledge of using medicinal plants. These traditional healers are often unwilling to disclose their traditional knowledge and sometimes are not well-known to the wider community. However, the traditional healers know each other, and if you start with one healer, he/she can refer you to other healers on the same issue or other related issues. For this reason, snowball sampling could become a useful sampling method in these kinds of studies.

1.2.3.1 *Types of snowball sampling methods*

a) Linear Snowball Sampling

The formation of a sample group starts with one subject and the subject provides only one referral. The referral is recruited into the sample group, and he/she also provides only one new referral. This pattern is continued until enough subjects are available for the sample.

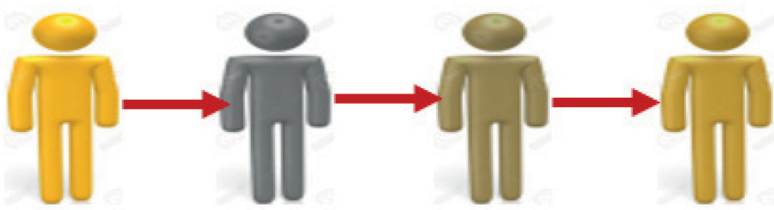
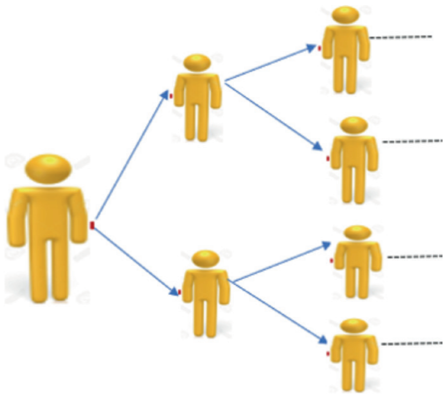


Figure 1: Schematic representation of linear snowball sampling technique

b) Exponential Non-Discriminative Snowball Sampling

In this type of snowball sampling, the first recruited study participant provides multiple referrals, each new referral provides another new referral, and so on, until a statistically representative number of participants is sampled. Each referral provides required information to the researcher before referring another participant for elaboration of the discussed matter and/or to acquire new data/information from the new referral. The final number of referrals is determined in two ways: i) when the intended sample size is reached, the researcher decides to stop any further referral admission, or ii) when the number of potential referrals on the subject matter is limited, it forces the researcher to terminate the study as further recruitment for referral is no longer possible.



For example, if the study is aimed at documenting the traditional knowledge and experience of traditional healers in a given area, then the sample size is limited to the actual number of existing and known traditional healers in that particular area. The researcher cannot determine the sample size based on his/her own perspectives. Furthermore, the standard requirements for statistical sampling are also violated, and hence the interpretation of the obtained results should be done carefully. Inferences regarding the population from the studied samples may not be encouraged in this case.

Figure 2: Schematic representation of exponential non-discriminative snowball sampling technique

c) Exponential Discriminative Snowball Sampling

In exponential discriminative snowball sampling, each recruited participant can provide multiple referrals, but the researcher can recruit only one participant from each referral. That means not every recruited participant is going to recruit another participant, implying that the chain is discriminative (Dudovskiy 2018). The choice of the new participant depends on the convenience of the researcher/data collector.

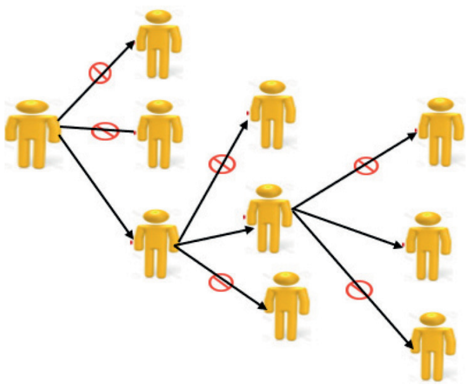


Figure 3: Schematic representation of exponential discriminative snowball sampling technique

This method gives flexibility to the researcher to include participants in the survey who are not required to provide another referral.

1.2.3.2 *Steps in the application of Snowball Sampling*

Application of snowball sampling involves the following stages[1]:

1. Establish a contact with one or two initial participants from the sampling frame. This stage is usually the most difficult one.
2. Request the initial cases to identify more cases.
3. Ask new cases to identify further cases (and so on).
4. Stop when:

a) Your pre-specified sample size has been filled.

b) There are no further cases left.

c) Pursuing further cases will make the project unmanageable due to the large size.

1.2.3.3 *Advantages and disadvantages of the snowball method*

The advantages of Snowball Sampling studies (as summarized here[2]):

1. Can recruit hidden populations.
2. Can collect primary data in a cost-effective manner.
3. Can be completed in a short time period.
4. Require very little planning to start primary data collection process.

Disadvantages of Snowball Sampling (as summarized in the link given in footnote 3):

1. Oversampling a particular network of peers can lead to bias.
2. Respondents may be hesitant to provide names of peers and asking them to do so may raise ethical concerns.
3. There is no guarantee of sample representativeness. It is not possible to determine the actual pattern of distribution of population.
4. It is not possible to determine the sampling error and make statistical inferences from the sample to the population due to the absence of random sampling.

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1 as summarized on https://research-methodology.net/sampling-in-primary-data-collection/snowball-sampling/

2 https://research-methodology.net/sampling-in-primary-data-collection/snowball-sampling/

1.2.4 *Secondary data review*

In quantitative research, researchers use large secondary quantitative datasets in their research studies. Because international research organizations and national authorities are making various data types open public resources, using available survey data is now perhaps more common than creating one's own quantitative data from a survey. These datasets are comprehensive and easily available as downloads (Goodwin, 2012). The access to local-level secondary data is lower than at the global level, as most data are archived by international organizations and libraries. On the other hand, the access to resources in international libraries and institutions for local researchers is extremely limited, hence local-international collaboration is very important. Access to existing data sources has become easier due to the development and expansion of computing and internet resources. A range of very large datasets derived from massive national and international surveys are available from national and international statistical offices, for example Eurostat, FAOSTAT, and national statistical agencies. The national central statistical agency in many countries provides valuable data on agriculture, health, demography, economy and so forth, and can be an important source of data for researchers. The national and international meteorological agencies (NAMA) such as NAMA of Ethiopia, WMA (world meteorological agency) and other institutional meteorological stations are vital sources of climate data.

Most non-experimental quantitative social research is now done using these secondary data sets (SAGE 2017). Although use of secondary qualitative data is less common, it is becoming a more widely used resource.

1.2.4.1 *Precautions in using secondary data*

There are certain things that a researcher must consider before deciding to use / analyse secondary data. It is imperative to be familiar with the dataset, as the researcher has not collected the data him/herself. The familiarization process entails:

– Learning which methods were used to collect the data.
– Knowing the population represented by the sample data.
– Understanding the objective/s of the original study.

– Knowing the respondents and their response categories.

– Ensuring that the data collected and the collection methods are still applicable to the current situation.

1.2.4.2 *Advantages and disadvantages of using Secondary Data*

One of the most noticeable advantages of using secondary data is its cost effectiveness. Resources and time should not be invested to collect data similar to already-existing data. Not all secondary data are always accessible freely. Even if you purchase secondary data to use, costs are almost always lower than the cost of creating the same dataset from scratch[3].

The other advantage is that datasets from secondary data are typically cleaned and stored in an electronic format, which saves time otherwise spent on data cleaning and transposing. Instead, the research focuses on analysis and interpretation of the already-accessed dataset. Time-series data, on crop productivity and climate, for example, can be obtained from governments and analyzed by researchers to derive required information. It would be impossible for researchers to amass such enormous volumes and breadths of data themselves. The use of such publicly available data to perform secondary data analysis helps researchers avoid years of intensive labor investment and unnecessary costs.

The disadvantage of using secondary data is that it might not answer the researcher's specific research question to the extent that the researcher would have hoped. If a researcher sets out to perform a study with a very particular question in mind, a secondary dataset might not contain sufficiently precise information that would allow the researcher to answer his or her research question(s). Secondary data identification that addresses specific questions might also be difficult, as the data validity depends on the collection timeframe, collection method, and representation of geographic settings. The extent of the primary data collector's knowledge and skills will never be known exactly by the secondary data user, and this can lead to data misinterpretation. It can also lead to a lack of important information that may compromise the reliability of the interpretations derived from secondary data analysis. Sometimes, working on secondary data forces researchers to alter their original question or work with a dataset that doesn't adequately align with the research objectives.

3 https://www.alchemer.com/resources/blog/secondary-data-analysis/

2.
PART II
CROP DIVERSITY ANALYSIS KITS

2.1 *Reconnaissance and the Transect walk*

The spatial distribution of plant genetic resources is systematically studied using various tools. After consulting baseline data, it is important to conduct an initial reconnaissance visit in the study area with selected community members along with the research team to ascertain issues raised during the community discussion.

The reconnaissance visit will help to

i) generate a general understanding of the state of natural resources, of their use and misuse, and of factors causing any erosion of genetic resources

ii) select locations for transect walks and detailed sampling sites for diversity assessments

iii) gauge variations in land use, farm types, state of focused genetic resources, level of genetic resource erosion, and management measures

iv) identify/ select locations and plan numbers of required transects

v) identify along each transect locations of possible key sites for detailed assessments to provide useful comparisons of species/varietal genetic diversity practices

A transect walk is a systematic walk along a defined path (transect) across the community/project area together with the local people to explore the distribution conditions of genetic resources diversity by making observations, asking questions, and then collecting representative samples to produce a diversity list and transect diagram. The transect walk is normally conducted during the initial phase of the fieldwork. It is best to walk a route, which will cover the greatest diversity in terms of the targeted plant/crop diversity. The transect walk is conducted by the research team and community members. The information collected during the walk is used to draw a diagram or map based on which discussions are held amongst the participants.

2.1.1 *Objectives of a transect walk*

1. To collect and identify specimens of the main plant species within the target locality.

2. To obtain a general understanding on the target species' genetic resources' status, including their erosion and those processes associated with such erosion in the study area.

3. To know the distribution of plant species and genetic diversity in various land use types that are associated with the crop diversity focus of the study.

4. To know the indigenous knowledge of local people involved in transect walk on identification of the focus group of plant species, their use and conservation.

5. To help locate sites for further quantitative sample collection and detailed genetic resources study.

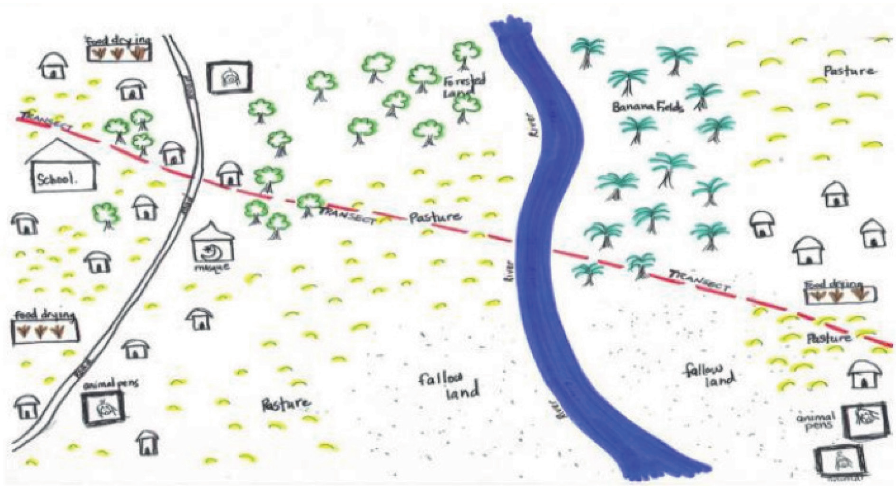

Figure 5: Example of transect walk route: Source-Coady International Institute 2012

Transect walks are not necessarily done on a straight line. They are used to verify features discussed in the community discussion during FGD. Comparison is at the heart of the sampling strategy. The detailed diversity assessment is conducted considering different landforms and land-use types, such as protected areas, farmlands, various slope aspects, and socio-economic conditions such as population density.

2.1.2 *Transect walk Participants*

During FGD or key informant interviews, individuals knowledgeable on the subject matter are usually noted. From the local community, 2-3 local people should be included in the transect team to help guide the walk and provide useful information on land use changes, plant species and uses (local name), their crop, livestock, and resource management practices. Individual participants are selected from those involved in the community FGDs and study area mapping, and with the land users, and should involve an equitable gender balance. It is also important that the local community is supportive of the choice of informants for subsequent works.

2.1.3 *Materials and preparations required for a transect walk*

Collecting necessary information later used for description of the study sites and specimen collected is needed during the transect walk. The following materials and preparations are required before starting the walk:

1. note-taking materials (paper and clipboard)
2. maps, aerial photos and/or satellite image to locate transects, features, and boundaries
3. GPS device to record locations and altitude (of major changes in land use, landform, vegetation, soil) and detailed assessment sites
4. digital camera
5. measuring tape or any new technologies to measure distances
6. machete to cut sample plants
7. labelling sticker
8. container to take any collected samples (plant specimen, insects, soil)
9. carrying baggage, where the samples need transporting to laboratory for further analysis

2.2 *The diversity kit*

The long-term sustainability of agricultural systems relies on existing crops and ecosystem diversity including macro – and micro flora and fauna. Agrobiodiversity is the diversity of crops and their wild relatives, trees, microbes, and other species that contribute to agricultural production (Bioversity International, 2018). Until climate change forced the world to utilize crop diversities for adaptation, the diversity within and among crops has been largely ignored. More than 70% of agricultural production has been generated from three major crops: maize, wheat, and rice, and relatively few varieties of these crops have been promoted. Genetic resources are an aspect of agrobiodiversity providing an invaluable pool of traits to withstand harsh new climate conditions, to respond to consumer preferences, and to increase nutritional content, while at the same time maintaining or boosting crop performance.

The diversity kit is a method in which existing intra – and intercrop diversity is listed and documented for easy access by those in need to use them. It uses text, illustrations and practical methods to help involving stakeholders (agricultural students, extension agents, educators, and genetic resources conservationists etc) to understand the multiple dimensions and complex processes related to biodiversity through innovative learning pathways and hands-on activities (UNESCO, 2017). The kit also explains the status of biodiversity and how it is affected by prevailing natural and anthropogenic factors.

Diversity kits document the existing diversity of species, at genetic and ecosystem levels, and identify the most usable diverse crops, making them available for use by community. For instance, in Ethiopia, the diversity in 400 durum wheat (*Triticum turgidum var. durum*) genotypes was assessed both phenotypically and genotypically. Various diversity kits were developed for further use, based on the knowledge gained from the diversity study. The first diversity kit consisted of genotypes with good tolerance capacity to terminal drought – *drought that occurs during later crop developmental stages* – while the second diversity kit consisted of genotypes that were preferred by farmers for direct use in shorter periods to increase their wheat varietal portfolio.

From 'farmer-preferred' kits consisting of the top 50 performing durum wheat genotypes, seed packets with promising local varieties (landraces) were distributed to more than 1,300 smallholder households over two seasons so that farmers could test them under their own growing and management conditions.

The diversity kit method involves:

– Seed packets of three varieties (amount of seed depends on the availability, usually 10 g to 1 kg) are prepared and distributed to farmers as described below using the Triadic Comparisons of Technologies (TRICOT)[1] method. This can work for cereals, pulses, oil crop, and fruits and vegetables, among others.

– Informing farmers on the purpose of the diversity kit and helping them to critically evaluate the varieties compared to their local varieties and safeguard seeds.

– Collecting farmer feedback on the variety/ies and their reasons for acceptance or rejection via sample survey. Use of mobile phones is a common way to obtain feedback.

– The total sets of kits distributed depend on the number of varieties distributed and farmers involved. For instance, if 20 genotypes are to be distributed to 200 farmers, the number of diversity kits is 600 (200*3, where each farmer is given three varieties).

Diversity kits deploy a portfolio of varieties (farmer varieties, improved varieties, inbred lines), from within and outside the target village, and encourage farmers to select, exchange, and disseminate the best varieties for a certain location based on their adaptation to local growing conditions, the overall performance, and cultural preferences. Participatory plant breeding has played a vital role in developing diversity kits and ensuring wider access to farmer varieties. These selected farmer varieties can be identified through participatory varietal selection (PVS), diversity fairs, and diversity blocks. The diversity block is a farmer-led, on-farm seed conservation approach, whereby its manage-

1 Triadic Comparisons of Technologies (tricot) is an approach to test crop varieties and other technologies on-farm under realistic conditions. Tricot is a ready-made methodology serving both research and the dissemination of varieties and other technologies and practices in highly variable areas. It provides a means to link technology development of research institutes to real-life experiences of farmers. It is supported by a digital platform that can be found at www.climmob.net. (see also https://www.fao.org/plant-treaty/tools/toolbox-for-sustainable-use/details/en/c/1071302/)

ment is carried out by the community members[2]. By providing wider access to selected farmer varieties, diversity kits promote the use and conservation of agricultural biodiversity (Sthapit et al., 2017).

2.2.1 *Advantages and disadvantages of the diversity kit approach*

The Diversity kit approach is perceived as the rescue method of variety and seed provision in variety and seed deficient areas.

Advantages of applying the diversity kit approach include:

– *Ensures fast access to a diverse portfolio of farmer varieties and landraces:* pre-evaluated farmer varieties or any other varieties are distributed to farmers within a short period of time.

– *Bulk seed multiplication is not needed:* farmers are the primary seed multipliers and distributors. Researchers need only starter seeds.

– *Applicable where formal seed supply is poor and seed availability is limited:* in developing countries the extent of any formal seed system is usually less than 10%, and this approach covers most of the seed supply. In marginal areas where the scope of formal breeding fails to address local needs, participatory breeding systems play a pivotal role.

– *Promotes local-level seed selection and exchange:* individual participant farmers are seed selectors and distributors. This approach ensures selection of specifically adapted varieties and helps farmers to better adapt to their local climate.

– *Ensures resilient seed systems:* variety distribution from farmer to farmer is more trusted than when distributed through the formal extension system, as fellow farmers trust the participant farmers more than anyone. The distribution of selected varieties within target areas is also faster.

– *Local institutions are its primary managers:* farmers and farmers' organizations such as farmers training centers (FTCs), community seedbanks (CSBs), and local administrations are involved in managing varietal evaluation and selection. The knowledge of these local institutions about the selected varieties is already developed and its adoption and distribution will be more comprehensive.

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2 BK Joshi, D Gauchan and DK Ayer (Eds). 2020. Participatory agrobiodiversity tools and methodologies (PATaM) in Nepal. NAGRC, LI-BIRD and Alliance of Bioversity International and CIAT; Kathmandu, Nepal.

– *Creates niche markets for new identified varieties*: diversity kits supply local crop varieties to segments or target groups outside the mainstream market. For instance, there is no formal market for purple-seeded durum wheat in Ethiopia, but it has a local niche market in different parts of Ethiopia and is being sold at higher prices for malting and local brewing.

– *Creates platform for citizen science:* – farmers are trials managers, varietal evaluators and selectors, and data collectors. Farmer-generated data are shared with breeders/researchers via mobile phone communication. Gradually this facility can improve national agro-advisory services.

The weaknesses of a diversity kit approach include:

– No single defined method is used to conduct a diversity kit approach because it is perceived as the simplest variety-deployment approach.

– Seed quality control is not easy, and sometimes poor-quality seeds enter local production systems.

– This approach might be used as a cheap way to win farmers' support for short-term projects that impact magnification with inappropriate consequences in the long run.

– Monitoring of village-level adoption and dissemination of selected varieties cannot be easily done.

– Strong advocacy work is needed to convince the formal breeding and seed systems, which have largely guided the extension system.

2.3 *Four-cell analysis (FCA) for understanding local crop diversity*

"*Four-cell analysis is a participatory method that i) identifies the most important biological assets playing a role in local livelihoods; ii) facilitates systematic analysis of farmers' logic of extent and distribution of local crop diversity; and iii) identifies common, unique and rare plant genetic resources, so that any community or professional can develop diversified livelihood options and conservation plans*" (Sthapit et al., 2006).

Four-cell analysis is a participatory technique to appraise the type and distribution of local crop diversity within farming communities. It considers richness and evenness of inter – or intra-specific diversity. This participatory tool can be used to map out arable crop diversity, or fruit trees in home gardens and community orchards. It can disaggregate for gender and age during data collection. FCA is a useful participatory methodology that helps researchers and farmers understand the distribution patterns of local crop diversity. FCA is performed to assess crop varietal diversity status within one species (intra-specific) or the species diversity status between different species (inter-specific). When repeated over time, FCA can give valuable insights into the rate of loss of diversity in any target area and reveal factors associated with decreases or increases in genetic diversity of any considered crop, tree, or animal type.

2.3.1 *Why FCA?*

FCA is used to assess the genetic status of agrobiodiversity in any target area. Genetically diverse crops that offer a valuable gene pool and useful characteristics for crop improvement need to be studied well. Documenting the indigenous knowledge of farmers as custodians of genetic resources on conservation, nomenclature, and use is very important for participatory planning for use and conservation genetic resources. Smallholder farmers across the world have continued to maintain and manage substantial crop diversity within their agricultural production systems. FCA is a useful tool for understanding the extent and distribution of community-level local crop diversity alongside local communities' indigenous knowledge for managing and conserving on-farm agricultural biodiversity.

The specific objectives of conducting FCA include:

– Measuring the abundance (richness) and distribution (evenness) of local crop diversity in the target area.

– Identifying common, unique and rare/endangered varieties or species in the target area.

– Understanding and documenting reasons why each crop/ variety is in a dynamic state within a community, and enhancing community knowledge for potential interventions.

– Identifying the level and type of interventions needed for conservation of crop/varieties in the target areas.

– Helping researchers and farmers understand distribution patterns of local crop diversity

2.3.2 *Functions of FCA*

FCA helps to:

– Assess the abundance and distribution of crop varieties in terms of richness, evenness, and divergence at community level.

– Categorize the distribution of species/crop/variety in the target community as common, unique, or rare, and document the key reasons why crops/varieties are in a certain dynamic state.

– Document the key characteristics and reasons why any crop species or varieties are in a certain dynamic state regarding their abundance and distribution within the community.

– Trigger decision-making for conservation of plant genetic resources by farmers, researchers, and other stakeholders, and develop action plans for conservation.

– Acquaint farming communities with the concept and threat of genetic erosion.

– Gauge the rate of genetic erosion in any target area, when repeated over time, and develop strategies to cope with such erosion over time.

2.3.3 *Procedures of FCA*

– FGD: FGD are normally held with key informants having sufficient knowledge of growing crops and conserving diversities within their community. The participants should be disaggregated by sex and age, with the number of participants depending on the objectives of the study.

– Representative samples collection: ask participant farmers to bring samples of each variety that they are growing (e.g. seeds, leaves, or other parts). This works best for crops. For other forms of agrobiodiversity, a transect walk helps to collect samples for characterization.

– List preparation: prepare a list of crop varieties under consideration, through discussion with participant farmers.

– Assign samples into the four quadrants of FCA: mark a large cross sign on the ground, paper, or board, and assign the varieties into the four squares (Fig. 5).

2.3.4 *Information assessed during FCA*

After live samples, or names of plants/crops/varieties or animals/breeds (or both) are collected during the transect walk, FGD is conducted to get information on the status of the plants/crops being considered. Participant farmers are asked and guided to sort and assign:

a) varieties/crops cultivated in large areas by many households (LxM)
b) varieties/crops cultivated in large areas by few households (LxF)
c) varieties/crops cultivated in small areas by many households (SxL)
d) varieties/crops cultivated in small areas by few households (SxF)

The facilitator draws the four cells (quadrants) as shown in figure 6 below and asks every participant farmer to assign his/her sampled varieties into the appropriate cell and explain why that specific cell was preferred.

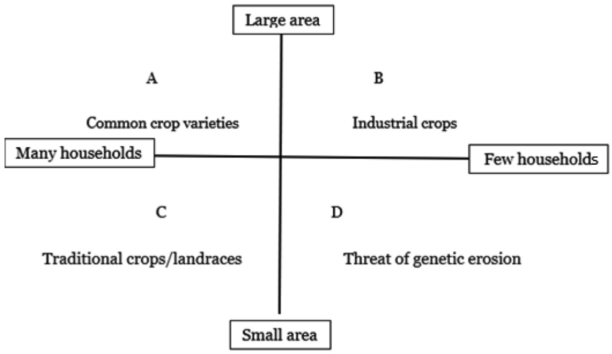

Figure 6: Model for FCA of extent and distribution of crop diversity

2.3.5 *Defining the four scenarios*

“Large or small” and “many and few” are relative measures, which can be interpreted differently in different areas. Consultation with the local community to define a piece of land in the village allocated to a particular crop as a “large” or “small area”, and what they understand as “grown by many households” or “grown by few households” is a very important qualification. The interpretation of ‘large or small’ and ‘many or few’ requires caution following the nature of the resource in consideration. The following tables 1 and 2 summarize the interpretation of results from FCA studies (adapted from Sthapit et al., 2017).

Table 1. Interpretation of results of crops diversity found on privately-managed farms

Category	Many households (M)	Few households (F)
Large area or many trees	Mostly food security crops (common cereals, pulses). Examples: Wheat, barley, maize, sorghum crops. Some varieties of these crops may not qualify for this classification. Abundant and no risk of extinction.	Commercial crops, locally-adapted farmer varieties (landraces), crops with specifically important traits, or newly-introduced crops. Examples: Commercial crops: cotton, sugarcane, haricot bean Locally adapted varieties 'sasa' barley in Tigray region. Crops with specifically important traits: Rye and emmer wheat could be such types. Under threat
Small area or few trees	Varieties grown for own consumption; varieties preserved for special traits or values. Example: Ethiopian mustard (*Brassica carinata*), gesho (*Rhamnus prinoides*). Potentially under threat	Varieties with low demands, varieties maintained by custodian farmers, varieties with specific use values to limited families. Example: pumpkin, Under threat of extinction

Note that crops mentioned as examples under each case are from an Ethiopian case-study and may not hold true for other countries.

The rationale for assigning crops into different cells is as follows:

a) Varieties/crops grown for food security, for the market, or with multiple use values tend to be cultivated in large areas by many households. These include common crops like wheat, maize, rice, barley etc.

b) Landraces cultivated for socio-cultural (traditions, religious rituals, food culture) purposes are grown in small areas by many households. Examples of plants/crops include mustard and hops (*gesho*).

c) Varieties with specific adaptative traits (such as cultivars adapted to swampy lands, poor soil fertility, drought, shade, etc.) are grown in large areas by few households.

d) Varieties with specific uses or limited use value to families are grown in small areas by a few households. For example, soap berry (*endod*) is now found in very limited areas of Ethiopia and some individuals still use it as soap to clean clothes.

Table 2. Interpretation of FCA results of crop diversity found in communally managed areas

Category	Many households (M)	Few households (F)
Many trees/ plants	Varieties or species collected for home use or for the market. Examples: wild coffee, cactus pear – Potentially under threat	Varieties or species with low use value or with specific use values to particular group. Examples: wild fruits, forest trees – Abundant and not under threat
Few trees/plants	Varieties or species collected for home consumption or for the market. Examples: timber woods like *Zigiba* (*Podocarpus falcatus*) and local detergent *endod* (Phytolacca dodecandra) in Ethiopia – Under threat of extinction	Varieties or species with low use value or specific use value for a particular group. Examples: *Kosso* (*Hagenia abyssinica)* – Rare and potentially under threat

Note: examples are based on experience with Ethiopian crops/plants

Assessment of the state of communally managed/used plant genetic resources and interpretation of the obtained results is different from that of privately managed crop diversity. Communal resources are openly exploited and are simply exposed to the threat of extinction as exploitation without replacement continues.

2.3.6 *Use of FCA in agrobiodiversity functional service assessment*

FCA can also be used to designate existing agrobiodiversity into functional services such as production, consumption, income generation, and landscape restoration. Figure 7 shows the frequency of plant species (including cultivated crops, trees, bushes etc.) identified in the Tigray region during an agrobiodiversity assessment within the CGIAR research project (CRP) Water Land and Ecosystems (WLE). The graph was constructed from an FCA table which categorized the list of agrobiodiversity into functional groups by men and women participants.

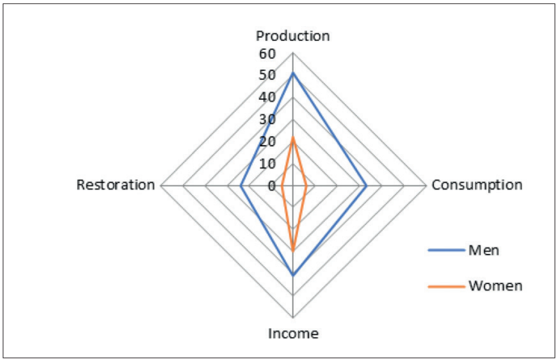

Figure 7: Functional classification of agrobiodiversity by men and women participants in Tigray, Ethiopia

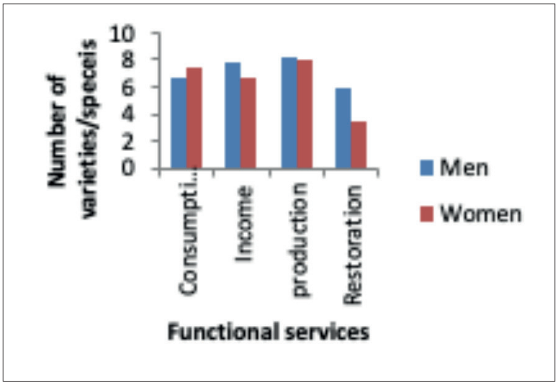

Figure 8. Number of species identified for the various functional services at Melfa village

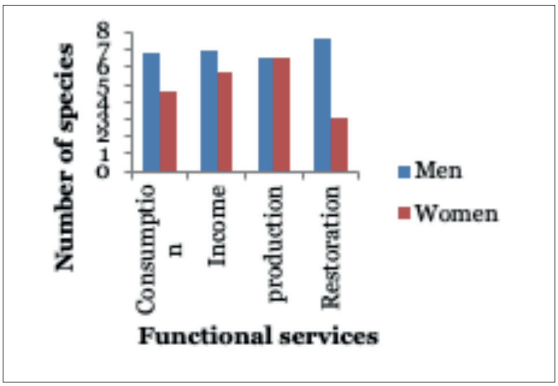

Figure 9. Number of species identified for the various functional services at Ayba village

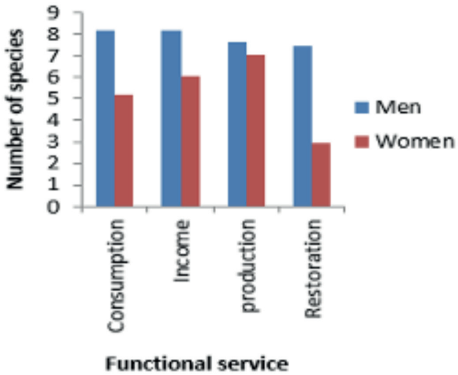

Figure 10. Number of species identified for various services at Atsela village.

Figure 7 shows that:

– the number of cultivated and wild species mentioned by men for all the four functions exceeds the numbers mentioned by their women counterparts.

– the peak of the graphs (blue for men and red for women) is proportional to the number of species mentioned under each functional use. For instance, both men and women participants listed many varieties for production over the other services.

The results of FCA can be presented in tabular form or in figure.

Figure 9 presents the number of varieties categorized into functional services during an agrobiodiversity assessment study in three districts of Tigray.

At Melfa village (figure 8):

– Many plant species were identified for the production function, followed by income generation and consumption functions.

– Species identified by both men and women participants for landscape restoration were small in number compared to the other functions at Melfa village.

At Ayba village (figure 9):

– Men identified many plant species used for landscape restoration, probably because it is mountainous, and many plant species have been planted for environmental protection.

– About seven plant species were identified for consumption and income generation services by men participants.

– Women participants listed less species than men participants in most cases, except for production.

At Atsela village (figure 10):

– Men identified more species than women for all functions.

– A relatively higher number of species were identified for consumption and income-generation by men participants.

– Women identified fewer species for landscape restoration but more species for production function.

Four cell analysis is also useful to assess:

– indigenous knowledge in the community associated with plant diversity use

– knowledge and skills concerning managing plant genetic resources

– knowledge and perception differences attributed to gender regarding the functional services of agrobiodiversity

– cultural, economic, social, and environmental factors associated with the use of diversity.

3.
PARTICIPATORY CROP IMPROVEMENT (PCI) METHODS

Participatory crop improvement (PCI) uses various methods that rely on local farmers' indigenous knowledge. In contrast to the conventional crop improvement approaches, participatory crop improvement aims to combine scientific and indigenous knowledge from researchers and farmers to identify crop varieties that are productive and acceptable by end-user farmers and consumers.

3.1 *Participatory varietal selection (PVS)*

PVS is an approach used to improve local landraces through selection and to evaluate the near-final breeding materials in farmers' fields that were obtained from research institutions. The evaluation and selection of varieties is done through the collaborative participation of breeders and farmers.

PVS involves the following steps and activities:

3.1.1. *Assessing needs*

Identifying key community problems in relation to the lack of adaptable crop or livestock varieties in the target area is the first necessary step. This can be done in consultation with the farming community through FGD or key informant interviews. Improving the performance of existing varieties or introducing new promising varieties might be an alternative approach.

3.1.2. *Preparing list of varieties for test*

Collecting local landraces/finished materials from research institutions with known traits for adaptation to the target area is a second critical step. Include as many varieties as possible (usually

25 – 100 varieties) to offer farmers a wide range of options for thorough selection.

3.1.3. *Selecting participant farmers*

The PVS process then requires selecting groups of farmers with good knowledge and skills in variety selection and management, in consultation with the community. Disaggregating the participants by sex and age is needed to harness indigenous knowledge from elderly and female, participants and transfer knowledge to the younger generations in the community.

3.1.4. *Formulating PVS activities*

Specific trial site selection; land preparation; and designing the experiments and planting trials, are some of the activities. Participation of farmers in crop husbandry decisions and practices is also important to further familiarize the farmers with the different varieties.

3.1.5. *Participatory evaluation and selection of varieties*

Firstly, help farmers to establish variety evaluation and selection criteria. Farmers usually evaluate crop varieties based upon adaptation, productivity, use value (suitability), and market perspectives. Varieties are also preferred for their socio-cultural values. Resource use efficiency of varieties is usually considered as a major criterion for variety selection by smallholder farmers. Steps include:

– During evaluation, varieties are rated using scales of 1 - 5 or 1 – 3, where 1 is very poor, 2 = poor, 3 = good, 4= very good and 5 = excellent; on a scale of 1 – 3, 1 = poor, 2 = good, and 3 = excellent. Where the evaluation is based on observation for quantitative traits, a scale of 1 – 5 is preferred over the 1 – 3 scale. It is important to stress that 1 = the poorest ranking, as it is quite common for evaluators to use the inverse where 1 = the top or most preferred, and any inversion will completely skew the overall results.

– Give 5 beads to each participant and instruct them to show 1 bead, 2 beads, 3 beads, 4 beads, or 5 beads for their rating of the variety under evaluation as very poor, poor, good, very good, or excellent, respectively (Mancini et al 2017). Avoid peer influence during evaluation. Each evaluator should do his/her own evaluation rating. In one of our PVS trials, we used finger display instead of beads and found it effective in controlling peer influence.

– The rating should be done separately for each agreed trait of evaluation.

– Calculate the arithmetic mean of farmers' ratings as the sum of each farmer rating divided by the number of participant farmers, for each farmer group (male and female, usually).

– Rank the genotypes based on the magnitude of farmers' ratings mean (from largest to smallest) for each farmer group.

Photo 1: Women and men farmers evaluating durum wheat participatory breeding program in Tigray, Ethiopia during 2014 cropping season. Photo: Dejene K. Mengistu
For each defined trait, the participant farmers were asked to show their fingers simultaneously (to reduce peer influence) to score the wheat varieties in the field on a scale of one to five (1=poor, 2=fair, 3=average, 4=good, 5=excellent).

It is advisable to collect necessary crop, climate, and soil data via the researchers from each PVS trial to base the decision of selected varieties on concrete evidence.

The final selection of varieties for production should include:

– *Variety registration for formal production:* if the PVS trial is systematically conducted according to the protocol required, selected varieties (usually two to three) can be submitted for registration. After document submission for registration, planting the selected varieties in standard plots subject to standard monitoring is required.

– *Seed multiplication and dissemination:* seeds registered or selected by farmers from local varieties can then be multiplied by interested seed-producer farmers or by the research group. Seed multiplication can be outsourced to local seed-producing farmer groups for bulk seed multiplication for use by other farmers in the community, after approval for production.

– *Seed inspection and approval:* during seed production, seed quality regulation and inspection should be done by the relevant inspection and regulatory bodies for approval and certification. For commercial production, only certified seeds are distributed.

– *Field days:* organizing field days, during PVS and/or seed multiplication, with the participation of participant and non-participant farmers, extension agents, local agricultural offices, seed producers, seed traders, and local administration is important for adopting and disseminating new varieties.

– The participants can be drawn from farmers, academics, media, national genebanks, and research organizations.

Photo 2: Field day participants of durum wheat participatory breeding program in Tigray, 2017.

3.2. *Crowdsourcing crop improvement (CCI)*[1]

Ex-Bioversity international[2]'s Seeds for Needs[3] (S4N) project developed a new participatory approach to variety evaluation and selection by farmers individually or jointly. The S4N concept was developed to further empower farmers to evaluate and select varieties independent of any peer influence by growing varieties on farms of individual participant farmers. In PVS, there is usually unavoidable peer influence where some farmers dominate, and the others remain silent unless appropriate facilitation and evaluation methods are used.

Crowdsourcing can be defined as the outsourcing of variety evaluation and selection and seed dissemination activities to 'crowds' of large numbers of volunteer farmers. Crowds: a group of people, united by a common interest, who do not influence each other (e.g. a crowd of 60 farmers etc.) Crowd farmers are recruited voluntarily and work with project staff for the overall success of the project. These crowd farmers:

a) Contribute their indigenous skills and time for common efforts without influencing each other. Individual members of the crowd grow a set of varieties, usually three, on his/her own land, manage the trial, evaluate the varieties in comparison with his/her own variety (ies), and rate/rank the varieties on their own defined traits.

b) Are technically supported by project-recruited enumerators and woreda focal persons. The enumerators support farmers in recording their feedback on the varieties and relay this to the researchers, especially where the farmers have reduced literacy.

c) Allocate their time, land, and knowledge free of any compensation payment.

d) Are the major drivers of project success.

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1 see also diversity kits

2 In 2021, Bioversity International forged a research alliance with CIAT, known as the Alliance of Bioversity International and CIAT, and at the time of writing (Feb 2022) there are further CGIAR reforms ongoing.

3 see https://www.bioversityinternational.org/e-library/publications/detail/bioversity-international-seeds-for-needs/

3.2.1. *Why crowdsourcing?*

The major reasons for using a crowdsourcing approach include:

a) Varieties are tested in many farmers' fields and evaluated by these many crowd farmers.

b) It minimizes or even avoids peer-to-peer influence during variety evaluation and selection.

c) It empowers each participant farmer to make his/her own evaluation and choice of varieties.

d) It helps farmers and experts to acquaint themselves with crop varieties at a grassroots level and helps engage them in selection processes.

e) It allows citizen scientists or farmers to perform some activities usually performed by designated scientists/breeders.

f) It encourages variety selection for specific localities and accelerates the dissemination of selected crop varieties.

g) It is a quick way of testing, evaluating, and selecting crop varieties, breeding lines, or advanced inbred lines for variety recommendation. In doing so, it could potentially improve national crop-breeding and extension systems, which are normally top-down.

3.2.2. *Objectives of crowdsourcing crop improvement*

CCI aims to achieve many interlinked short-term and long-term objectives, including:

a) Introduce many new crop varieties (including local varieties) to farming communities, thereby increasing farmers' seed portfolios in a shorter period, and ensuring their conservation.

b) Create space in which farmers can contribute to variety evaluation and selection, which provides new opportunities to accelerate innovation.

c) Contribute to developing demand-driven (instead of supply-driven) seed-marketing systems.

d) Empower farming communities to select varieties that satisfy their needs and accelerate the adoption rate of selected varieties.

3.2.3. *Difference between CCI and PVS*

There are major differences between CCI and PVS approaches. The major difference lies in the number of impacted farmers per cropping season, the level of participation, and the degree of participant farmer empowerment to make decision on the adoption and use of distributed varieties. Target farmers engage from research designing to final decision making in CCI, while this is less likely in PVS. Participant farmers own the distributed varieties under CCI approach. Table 3 below provides the basic differences between crowdsourcing crop improvement and participatory varietal selection.

Table 3. Basic differences between CCI and PVS

CCI	PVS
– Targets many farmers with small quantity of seeds. – Each participant farmer receives at least three varieties and compares with local varieties under their own management. – The influence of farmers' peer-to-peer perspectives during evaluation and selection is very minimal, as evaluation is carried out on individual farmers' fields. – Farmers' preferences are taken for granted when identifying candidate varieties. – Highly empowers farmers [full participation] – Incurs less cost to run trials. – Participants own the harvested seed and can use for next growing season.	– The trials are not placed on individual farmers' fields and farmers are invited as evaluators. The number of participant farmers is usually small. – PVS trials are placed at representative sites, usually farmer training centers or research stations, and only nearby farmers are invited as evaluators. – The influence of researchers is very high. – Peer-to-peer influence is very high during variety evaluation. – Inclusion of farmer preferences depends on the researchers' will for final variety selection. – Incurs relatively higher running costs – Evaluating farmers do not own the harvested seeds. Access to the seeds depends on the will of the researcher.

3.2.4. *Phases of CCI research*

Crowdsourcing research has four important and interlinked phases of execution: i) the planning phase, ii) the implementation phase, iii) the data analysis and information mining phase, and iv) the feedback provision phase. Each are briefly discussed below.

3.2.4.1. *Phase I. Planning and preparation*

This phase is the responsibility of the research team, where the number of varieties to be tested and number of testing farmers is determined and sampled. Acquisition of identified varieties and preparation of seed packages is the major activity of this phase. Major activities include:

a) *Define the number of crop varieties to be tested*

– The number of varieties to be tested ranges from 10 – 50 according to the number(s) of participating farmers.

– Each participant farmer should receive and grow three randomly assigned varieties as the data generated will be analyzed using special software[4] developed for this purpose.

– The amount of seed given to each farmer depends on the minimum amount of seed available for each variety (flexible). It can be around 10 – 30g depending on availability. For instance, a recent durum wheat crowdsourcing trial distributed only 5g of seed of 21 varieties for 400 farmers in two zones and 24 villages in 2013. We were forced to give only 5 g due to large demand for selected varieties with less than a kg of available seed per variety.

b) *Number of participant farmers*

The purpose of CCI determines the final number of participant farmers: research purpose or seed evaluation and dissemination purpose. If its purpose is to evaluate and select new varieties, the number of participant farmers per village could be small, with many villages sampled in the target area. However, if its purpose is to expand farmers' seed portfolios of

4 www.climmob.net

known varieties as an upscaling mission, many farmers per target area are usually targeted. For instance, a bilateral Dutch and Ethiopian project on Integrated Seed System Development (ISSD) used a crowdsourcing approach to ensure access to more than 50,000 seeds of diversified varieties of wheat, barley, faba bean, finger millet, and chickpea over two years. Considerations in sampling farmers for crowdsourcing trials include:

– Volunteer participation: make sure that the farmers agree to participate on a voluntary basis, as there will be no compensation paid for his/her time and allocated land. The number of participant farmers per site/village can vary as per the objective of the project. For instance, 200 farmers per district, split into four villages of 50 participant farmers each, participated in the various crowdsourcing projects conducted in Ethiopia.

– Informing participant farmers prior to the trial: participant farmers should be trained on project objectives and implementation methods and understand their role in the project. Also, they must know how they could benefit from project involvement.

– Ensuring representativeness of sampled farmers to target area: the distribution of participant farmers should represent the target population. For instance, if 200 farmers are participating from 20 villages, the number of farmers sampled per village should be proportional (i.e. 200/20 = 10) unless special systematic sampling is justified.

– Defining trial plot size per variety per farmer: like any other trial, the size of experimental plots should be defined for scientific reasons. The amount of seed distributed determines the size of experimental plot. For example, if 30g of wheat seed is distributed per variety, the plot size will be 3 m^2 based on a 100 kg/ha seeding rate. So, trial plot size is defined based on the available seed amount and seeding rate of the crop under consideration.

Important considerations:

1. *Ensuring even distribution of the varieties:* in CCI, participant farmers are considered as plots and the villages as incomplete blocks. For instance, if participant farmers are distributed in four villages in each district and the total number of participant farmers per district is 200, then even distribution of farmers per village and distribution and replication of varieties per village is important. The following formula helps to calculate the replication of each variety per district.

Where R_v = replication of each variety, k = the number of varieties accessed by each farmer (usually k= 3), N = total number of participant farmers per district, and n= the total number of varieties to be distributed (e.g. 20, 30, etc.).

The replication per village should also be considered to have equal representation of varieties in the target villages. If the R_v for variety X is 30 per district and the trials are conducted in four villages per district, then variety X should be equally represented in the four villages. As dividing 30 by four is 7.5, variety X replicated 8x at two villages and 7x at the other two villages.

Such testing of varieties involving many incomplete villages improves trait heritability (h^2) and the responses to selection by reducing the variance from genotype-by-environment (location) interactions. This is practically what breeders have been looking for but struggled to achieve in conventional breeding programs.

2. *Quantifying the amount of seed needed for each variety:* before starting to weigh and pack the seeds for distribution, quantifying the amount of seed needed for each variety is very important. This amount is computed as seed rate per plot*R_v. For instance, if the seed rate per plot is 37.5 g on the basis of a 125 kg/ha seeding rate and the variety X replicated 30 times in the district, then the total amount of seed of X variety required is 37.5 x 30 = 1125 grams. This means we need to have a minimum of 1125 grams of seed for each candidate variety.

3. *Preparing, packaging and distributing seed*

Seed preparation is completed in a seed store supervised by research team members. The preparation requires basic information such as seed rate per plot and number of recipient farmers of each variety, i.e., replication of each variety per project site. Seed preparation, packing and distribution involves:

– Weighing seed parcels of each variety to the designated rate and labelling it as 1, 2, 3 …. n, where n is the total number of varieties. It is agreed that CCI researchers should not disclose the actual name of varieties to growing farmers for two reasons: i) to avoid bias during evaluation of varieties, as farmers usually tend to bias in favor of a variety that they are familiar with over varieties they do not know; and ii) it creates eagerness in participant farmers to attend the feedback workshop as the name of the varieties is disclosed during this session.

Figure 2: Seed preparation & packing for distribution

Photo 3. Seed preparation & packing for distribution. Source: Crowdsourcing training manual

– Pack each variety with appropriate label in small seed package.
– Randomly assign varieties to farmers.
– Pack three varieties assigned to a farmer as a single package.
– Pack samples allocated to a village containing pack of varieties to farmers in that village.
– Pack all the samples for the district in larger packs and label with the name of the district, crop, and trial name and number.
– Ensure the big seed pack contains necessary information:
 i) Site and village code.
 ii) Numbers of smaller seed bags inside it.
 iii) Ranges of farmers' codes.
– Ensure the small seed bag contains:
 i) Variety code.
 ii) Field tags with labels of variety code.

c) *Seed distribution*

The prepared and packed seeds should be delivered to farmers on time through an appropriate channel. Seed distribution must be monitored to ensure timely provision and correct allocation of samples, as misallocations and delays often occur when not distributed by the research team.

Photo 4:Seed packages prepared for 10 sites

As stated above, all small seed bags that go to one village should be packed into one large pack as shown below. Each big pack should contain the following information:

– Trial number (trial 1….)
– Crop type (e.g. FB = faba bean)
– Site name (e.g. Hagreselam)
– Number of small packs in it (e.g. 50 farmers)

The distribution: A pack for a village is given to a village enumerator or village coordinator for distribution and monitoring the sowing/ planting processes.

d) *Record maintenance*

The research team should have a full record of trial information, trial site, villages with code, farmers with code, and varieties provided to each farmer in the various villages as an excel spreadsheet for monitoring as well as data collection purposes. A simple example of a data record sheets looks as presented in Table 4.

Table 4. Data record sheet for varietal distribution and subsequent data collection in crowdsourcing trials

	Site NAME	village ID	village name	HH ID	HH name	Genotypes			
1	Hagreselam	05	Hadnet	01		1	16	12	21
2	Hagreselam	05	Hadnet	02		32	11	2	21
3	Hagreselam	05	Hadnet	03		29	10	3	21
4	Hagreselam	05	Hadnet	04		4	15	9	21
5	Hagreselam	05	Hadnet	05		31	5	8	21
6	Hagreselam	05	Hadnet	06		14	7	6	21
7	Hagreselam	06	Adi Kuenti	01		32	11	2	21
8	Hagreselam	06	Adi Kuenti	02		29	10	3	21

In this trial 21 durum wheat varieties have been distributed to 200 participant farmers in Degua Tembien Hagreselam district. The 21 durum wheat varieties were distributed and the types of varieties to each household in each village. In this case, we gave four varieties to all farmers with the inclusion of standard check, variety 21, on every farmer's trial. For instance, farmer 1 (HH01) in Hadnet village (coded as 05) was given varieties 1, 12, 16 and 21 while the second farmer (HH02) was given varieties 2, 11, 32 and 2, and so on. The data collection sheet is prepared from this spread sheet by simply including the traits to be collected.

e) *Farmers' training workshop*

Provision of training is one of the most important agricultural extension services. Informing participant farmers why they are selected to implement the project and what benefits they could obtain from the project is an important starting point. In CCI, farmer training is one of the important activities implementing researchers must perform for the success of the project. Invited farmers, development agents, local agricultural extension services, local administrators, and enumerators (if needed) are among participants on the training. The training provides:

– an overview of the concept and principles of crowdsourcing crop improvement

– a broad understanding of project implementation

– an outline of the philosophy behind crowdsourcing projects, particularly on participant farmers' and researchers' roles and responsibilities

– clarity regarding assistance provided to participant farmers by researchers, local extension experts, development agents, and enumerators.

Photo 5:Experts explaining method of crowdsourcing to participant farmers. Photo: Dejene K. Mengistu

The training explains:

– Crowdsourcing and its objectives

– Why the target crop was selected

– The main methodology for implementing the project

– How the trial is laid out and managed

– Plot or row-making techniques using practical demonstrations

– The need for each variety evaluation and ranking for farmers' defined traits

– Agreeing on the method of communication of results and feedback

– How to best discuss monitoring and evaluation of trials by local staff and project members

– How to register the contact details of participant farmers

3.1.4.2. *Phase II. Implementation of the trials*

a) *Planting the trials:*

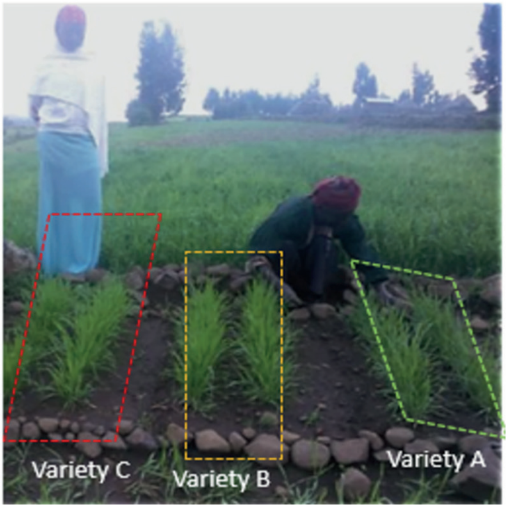


Photo 6: Orientation of crowdsourcing plots. Photo: by Yosef Gebrehawaryat

Planting or sowing is a practice of placing the seeds in contact with soil at a specified depth, so they can access soil resources to germinate and develop into viable seedlings. This is the first important step in selecting good varieties in a crop improvement process. If varieties are not properly planted, important breeding activities such as evaluation and selection are difficult.

Each farmer should plant the three varieties in separate plots or in well-separated rows, as shown in photo 6. The three varieties A, B, and C were planted in two rows separated by enough spacing to avoid any mixing.

Important considerations during planting crowdsourcing trials:

1. Planting should be done by the farmers: the farmer is the ultimate manager of the trial, so he/she should plant the trial him/herself. During the training session, how to plant the trials is comprehensively discussed.

2. Each variety should be allocated equal plot size with similar shape, or equal rows of the same length. The spacing between plots or rows should be sufficient to avoid mechanical mixture and to reduce inter-varietal competition.

3. Each plot should be labelled to easily identify the varieties during data collection and harvesting. Some different ways of plot labelling are articulated in photos 7-9 below.

Photo 7: Modern labels: Variety codes written on label and pegged in front of each plot.

Photo 8: Traditional field label: Variety code tied on stake using tape meter

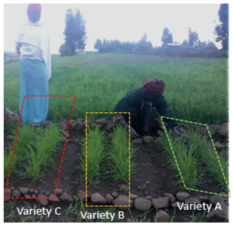


Photo 9: Traditional field label: Variety code placed in plastic bags & buried in front of the variety. Farmers' innovative labelling

Photos 7-9. Types of plot labelling

b) *Data collection*

Any research is conducted to answer a specific question and systematically deliver its outcomes. It sets a hypothesis on the expected differences between dependent variables due to effects from independent variables. Data collection is the process of gathering and measuring information on variables of interest, in an established systematic fashion that enables the researcher to answer stated research questions, test hypotheses, and evaluate outcomes (Syed, 2016; NIU, 2005[5]). Data collection is mandatory in all fields of studies regardless of methodology, which should be truly representative and accurate to ensure reliability.

Use of appropriate data collection methods, collecting the right type of data and analyzing it using appropriate statistical packages is crucial to reduce experimental errors and generate useful information to (dis) prove the hypothesis. North Illinois University (NIU, 2005) summarized the consequences from improperly collected data as i) inability to answer research questions accurately; ii) inability to repeat and validate the study; iii) distorted findings resulting in wasted resources; iv) misleading other researchers to pursue fruitless avenues of investigation; v) compromising decisions for public policy, and vi) causing harm to human participants and animal subjects. The level of harm due to faulty data collection varies between and across research fields, and in crop

5 https://ori.hhs.gov

improvement research, the damage can be significant enough to damage trust and compromise adoption of developed varieties.

Even though crowdsourcing, crop improvement relies more on farmers' scoring and ranking data, other types of data also need to be collected to help decision on the promotion of crowdsourced varieties in target areas. These are presented below:

1. *Farmers' data:* all participant farmers evaluate all the three varieties they are growing and rank them 1 to 3 based on their own defined traits. Encouraging all farmers to do the evaluation (scoring for traits and overall ranking) is important to the overall ranking of the varieties in the target area. In case farmers are illiterate, as is the case in most developing countries, supporting them with enumerators to collect this data type is critical for generating usable data.

Photo 10: Farmers evaluating crowdsourcing varieties with the help of enumerators. Photo: Dejene K. Mengistu

– Farmers' data is nearly always quantitative and analyzed with simple descriptive statistics such as percentage and correlation.

– Farmers' data is based on simple ranking and reasons provided for assigning each rank.

– In durum wheat crowdsourcing research conducted in northern Ethiopia, we have observed that farmers usually use the following traits to evaluate varieties:

– Tillering capacity

– Spike forms (density and length)

– Earliness

– Overall performance (yield assumed)
– Disease resistance
– Drought tolerance

Farmers' evaluation recording has been changed from printed spread sheet to mobile based data collection developed by the team from Bioversity International. The Tricot CLIMMOB software, which was designed to compare three varieties at a time, has been used to compare varieties for different traits at different developmental stages. Figure 12 shows how the platform works.

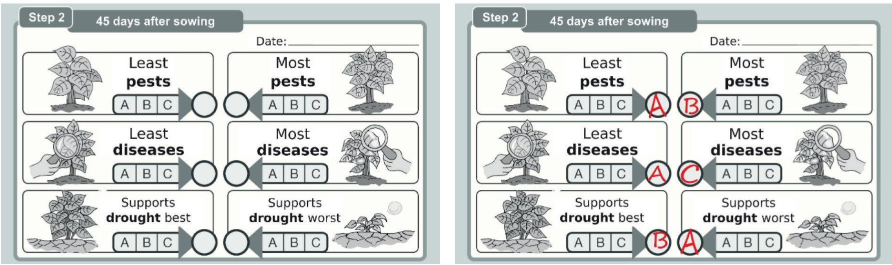


Figure 12: Tricot data recording using CLIMMOB platform. (Source: Tricot CLIMMOB training Manual)

To use a Tricot CLIMMOB data record sheet, each trait is represented by a picture so that farmers easily recognize it. Varieties are rated as 'best' or 'worst' for the trait under consideration. The third variety is automatically considered as the medium performer. For instance, the spread above shows that variety A is resistant to early leaf disease infestation while variety C is susceptible. Variety B is considered as medium resistant or medium susceptible. The performance of the varieties changed when considering early season drought tolerance. Variety B is tolerant for early-season drought, but disease-tolerant variety A found to be susceptible to early-season drought stress. The evaluation continues for other traits in a similar way.

Variety evaluation is done by all participant farmers and the overall rating of varieties is compiled to identify the winning varieties for the target area, and also to know the most discriminating traits used by farmers to differentiate the varieties. For example, the analysis of ranking data and the associated reasons for ranking varieties in the Tigray region of Ethiopia was combined and is presented in figure 13 below. It was observed that high grain and straw yield, uniformity and spike quality (length and density) are the leading traits to rank varieties as number 1 or not. No single variety can qualify for all the traits or rarely happen in a single variety. Even though farmer participation is very important, their data is highly influenced by their perceptions and their previous knowledge of the variety. It is thus more of an assumption than a precise measurement.

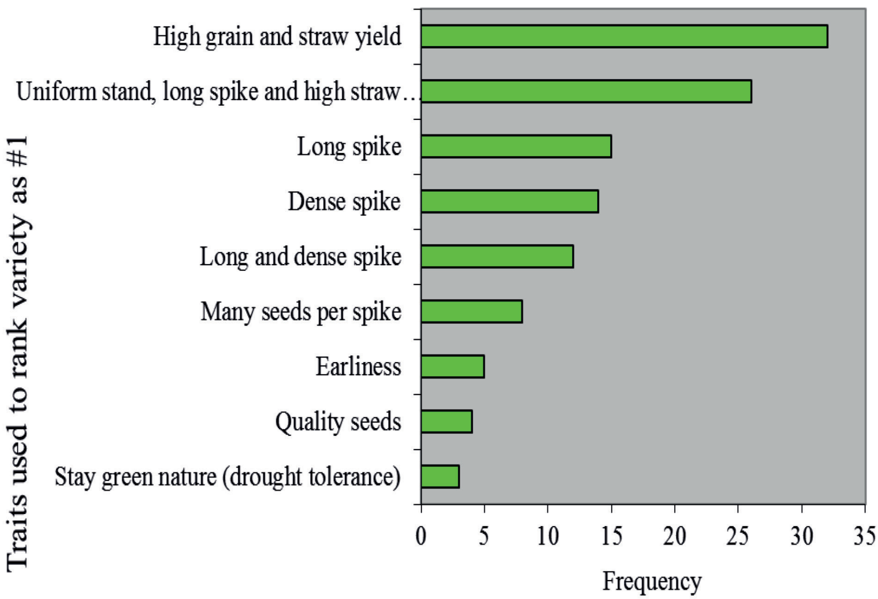


Figure 9: Traits most influenced farmers' durum wheat varieties ranking in Tigray, Ethiopia

For this reason, collecting some additional agronomic data helps to normalize farmers' qualitative data and helps to make sound decisions on variety selection. Hence supporting farmer data with metric data enables us to identify the right variety to satisfy farmers' needs and national variety-release requirements.

2. *Researcher data:* – as described above, supporting farmers' ranking data with researchers' metric data strengthens the confidence in varietal identification processes and linked recommendations. Collecting phenological and common agronomic data and their subsequent analysis is needed. The following provides an example of a dataset collected from durum wheat crowdsourcing trials.

Photo 11: Monitoring metric data collected by enumerator

Phenological traits data on:
– Days to sowing (DS)
– Days to heading (DH)
– Days to flowering (DF)
– Days to maturity (DM)
Agronomic traits data on:
– Number of productive tillers (NET),
– Spike length (SPL),
– Number of seeds per spike (SPS)
– Grain yield (g/plot) (GY)
– Biomass yield (BY) (if possible)

To compare farmers' ranking data and researcher data, the following activities should be performed:

a. Make sure that the ranking is done for specific traits like earliness, grain yield (prediction from overall rating), disease tolerance, drought tolerance, plant height, etc.

b. Analyze the collected metric data using appropriate statistical analysis methods, usually spatial analysis, and generate best linear unbiased predictor (BLUP) means for all collected traits.

c. Rank the mean of your preferred trait in descending order (from large to small mean value).

d. Compare the position of your varieties from BLUP mean ranking and farmers' score ranking.

e. Select varieties with overlapping ranking or close ranking in the top for further dissemination or registration.

3. *Geographic and climate data:*

Collecting geographic data such as altitude, latitude and longitude, and soil data from each participant farmer is important for two reasons: i) description of the research site is needed for scientific purposes, and ii) mapping the participant farmers' locations is needed to show their geographical distribution and later for impact assessment.

Materials required for geographic data collection:

GPS

Smart mobile phone

Both machines measure the altitude (N), longitude (E) and altitude (masl)

If possible, record both N and E data for each participant farmer

Photo 12: Materials required for geographic reference data

Soil data: – Soil samples can be taken using an auger from each trial village instead of from each participant farmer as the soil per village is nearly the same. This reduces unnecessary research costs.

Climate data: – Climate data is not an optional data type as it is crucial for linking varietal performance with the nature of local growing conditions and helping to identify candidate varieties that could potentially adapt to the temporal variation of local climate. Access to quality local climate data from local stations is difficult in most developing countries as representative meteorological stations are scarce. Even where meteorology stations are installed for the research, lack of regular maintenance can compromise data quality. Hence, alternative ways of collecting major climate data such as daily rainfall, temperature, and other weather elements are required.

a. *Satellite climate data:* – Retrieving climate data from satellite datasets is one approach. There are many platforms, such as *worldclim*[6],

6 https://www.worldclim.org/data/worldclim21.html

which allows retrieving climate data from satellite by just using the latitude and longitude coordinates of your specific locations.

One of the problems of using such data is that the data can deviate from the actual data in terms of magnitude and distribution. Considering rainfall, for instance, it reads some amount of rainfall for all the 12 months despite the fact that the amount of rainfall for most months in the tropics is zero. This is because the prediction of the climate elements is indirect considering the greenness of the area, estimation from nearby areas, and predicting rain from cloud occurrence, among other reasons. Figure 14 presents the rainfall amounts retrieved by satellite for a very dry area in northern Ethiopia during the 2016 and 2017 cropping seasons.

It is inferred from the figure that:

– Rain has fallen during all 12 months even though the sampled area receives rainfall only during June, July, August, and September and very little rain in October.

– The area is less likely to receive any rainfall during January and May, although some rain is possible during February, April, November, and December.

– In this area, the amount of rainfall during July, August and September is highly exaggerated.

– The amount of rainfall received in February, March, and October is practically unattainable.

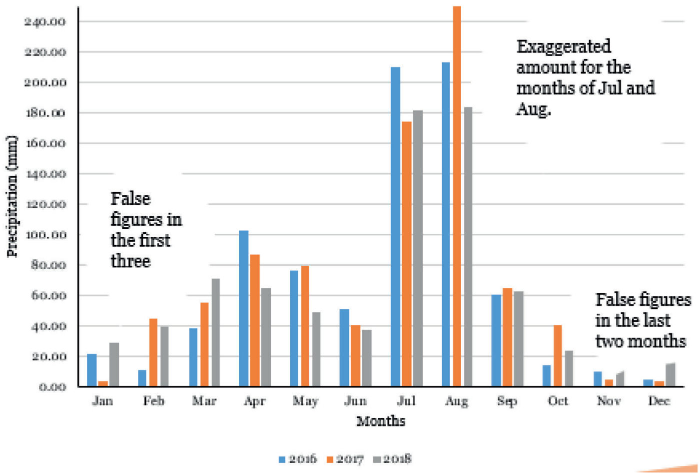
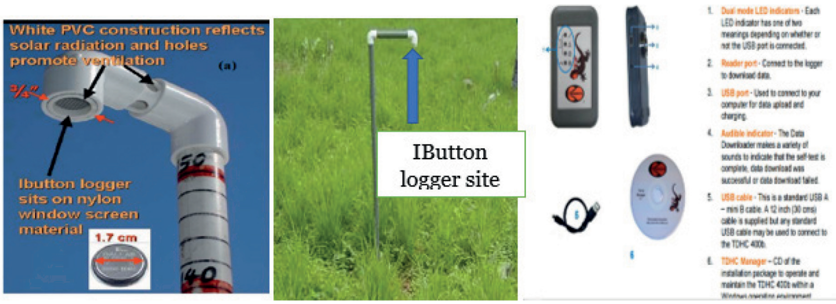


Figure 10: Mean monthly rainfall amount of Endamehoni district, Ethiopia, retrieved from satellite for 2016-2018 cropping seasons

b. *iButton and local rain gauge*

iButton®[7] devices are small, durably-packaged modules with globally-unique digital addresses. They are simple devices which can be installed to record data where meteorological stations are not available. They record minimum and maximum temperature and relative humidity at any calibrated time interval. The most widely available iButtons cannot record rainfall, which is their main disadvantage. When enhanced with a 1-Wire communication protocol, it provides the capacity to access temperature and relative humidity data on an hourly basis.



Modern modular — Local modular — Accessories of iButton

Photo 13: Features of an iButton device and its installation in the field.

The device can be installed in each farmer's field and helps collect temperature and relative humidity data at the microclimate level. Complementing temperature and relative humidity data with iButton rainfall data from nearby Met-stations could give a full picture of the climatic pattern of your target area and help you to associate variety performance with the climate variation during the cropping season and over seasons. This can help to identify the best variety for local growing conditions. What is particularly useful about iButton is that it records daily weather data at any time interval. The data presented in Table 3 below was recorded every three hours, resulting in eight recordings of

7 https://www.maximintegrated.com/en/design/technical-documents/app-notes/3/3808.html

temperature and relative humidity per day. Furthermore, iButton is a powerful tool for studying the micro-climates of target areas.

Table 5. Example of data for temperature (^{0}C) and relative humidity (%) recorded at three-hour intervals on July 7, 2013, using iButton sensor in Hadnet, Tigray.

Log data: date/time	Temperature (°C)	Relative humidity (%)
7/26/2013 0:56	12.086	102.38
7/26/2013 3:56	12.086	101.9
7/26/2013 6:56	14.088	102.38
7/26/2013 9:56	19.092	86.23
7/26/2013 12:56	25.094	48.97
7/26/2013 15:56	16.09	95.99
7/26/2013 18:56	15.59	84.11
7/26/2013 21:56	14.088	92.97

Advantages of using an iButton device:

– easy to use

– inexpensive

– simple to download data from data logger

– gives real-time data for local temperature and relative humidity (RH)

– easily installed in the field

– logger has sufficient capacity to store seasonal data

– data is recorded in a user-friendly format

Disadvantages:

– the installed iButton holder can be easily removed (stolen) if not protected

– it can give the wrong reading for RH, sometimes more than 100%, if the sensor is exposed to water splashes or moisture retention.

c. *Simple rain gauges*

In the absence of representative scientific meteorological stations in your target area, simple rain gauges, which are easily installed, can be used to measure daily rainfall.

Photo 14:simple rain gauge[8]

These simple gauges are labelled and calibrated when manufactured. The advantages include:

– the daily rainfall can be registered by anyone with brief training.

– available at an affordable price.

– can be installed around the homestead for protection.

– gives more accurate rainfall amounts and monthly distribution than relying on satellite retrieved data.

Disadvantages:

– it cannot give accurate readings in abnormal cases, such as when daily rainfall surpasses the gauge label. For instance, this gauge may not be used where daily rainfall exceeds 40mm.

3.2.4.3. *Phase III: Data analysis and feedback workshop*

The (dis)proving or disproof of any hypothesis and generation of linked information greatly depends on the accurate analysis of collected data. Data analysis using scientifically proven, statistical software is a prerequisite for the validation and acceptance of presented results, inferred conclusions, and drawn rec-

Figure 11: ClimMob interface used for crowdsourcing data analysis

8 https://kalamazoogardencouncil.org/product/rain-gauge-bracket/

ommendations. Data collected from farmers from crowdsourcing trials can be analyzed by CLIMMOB software which ranks varieties grown by each farmer for the various traits and produces an overall ranking of varieties tested in the target area for the varieties' traits. This ranking data is used to make decisions on which varieties to promote and which to drop.

To analyze collected data using ClimMob, the project should be designed using the same software. Project creation and other procedures of ClimMob is not the concern of this Manual. Refer to ClimMob training Manuals[9] for further information.

The analysis of results is done for individual farmers and the performance ranking of the tested varieties is presented at the end of each farmer's report. Consider the following example for clarification:

– Farmer: Tsigab Yebyo
– Village: Hadnet
– District: Degua Tembien

This farmer grew three barley (*Hordeum vulgare*) varieties under his own management conditions and evaluated the varieties for their performance. The enumerators collected his evaluation data, which was analyzed to discriminate between the varieties. The CLIMMOB software was used to analyze the performance of the varieties for the considered traits and make the ranking.

Table 6 details the barley varieties given to this farmer with the respective code of A, B, or C.

Table 6. Code and name of three varieties given to a farmer for crowdsourcing trial

Variety code	Name
Variety A	Adona
Variety B	Felamit
Variety C	HB

9 http://genecampaign.org/wp-content/uploads/2015/03/Annexure-7.-ClimMobUser-Manual.pdf

The farmer has evaluated these varieties as best, better (second position) and worst for the various traits (Table 7):

Table 7. Performance of three varieties grown by a farmer for agronomic traits

Characteristic	Best	Second	Worst
Plant architecture(height)	Felamit	HB	Adona
Yield	HB	Felamit	Adona
Straw_Yield	Felamit	HB	Adona
Seed Size	Felamit	HB	Adona
Overall performance	Felamit	HB	Adona

According to this farmer, variety Felamit is the most preferred for four of the five traits and second for grain yield after HB. On the other hand, variety Adona was perceived as the worst performer for all the traits. Because the performance of varieties is affected by farmer management as well as micro-climate conditions, the ranking of a variety by various farmers in the same locality may vary.

Based on the ranking of 125 crowdsourcing farmers in the same district variety, Felamit ranked as the second best, next to HB, and Adona was ranked as the least preferred. This implies that farmers evaluate varieties very closely even if they do the evaluation and ranking independently. For grain yield, the ranking position of the eight barley varieties based on the evaluation of 125 farmers in Degua Tembien district is articulated in table 8.

Table 8. Overall ranking of varieties tested through crowdsourcing at a given place

Positions (Rank)	Varieties
Position 1	HB

Positions (Rank)	Varieties
Position 2	Felamit
Position 3	Fetina
Position 4	Welelay
Position 5	Hirity
Position 6	Elala 2
Position 7	Elala 1
Position 8	Adona

The farmers confirm that HB, Felamit and Fetina are the top three performing varieties while Elala 1 and Adona are the poorest performing varieties.

After data analysis is completed, a final workshop is held to inform participant farmers about the overall performance of varieties and discuss any possible future dissemination of identified varieties.

During the feedback workshop, the research group:

1. Presents the final results of the varieties‘ performance

2. Distributes personal information sheets and encourages discussion among farmers

3. Discusses practical lessons derived from the study (incentive for participating in the project)

At the same time, participants evaluate the project’s success based on the following 5 recommended indicators.

1. *Rate of completed trials*: – from the total participants, how many of them completed the trial successfully. For instance, in our previous durum wheat crowdsourcing trials, the completion or success rate was about 83%.

2. *Gender ratio of participants*: – ensuring gender disaggregated participation is a key concern of participatory crop improvement approaches. In crowdsourcing, the participation of female-headed households is not an option. In our various crowdsourcing trials, 30 – 50 % of female-headed household participation was ensured.

3. *Rate participants’ willingness to continue growing the varieties*: – if farmers grow the distributed varieties only during the project period, the impact will not be sustainable. It is therefore im-

portant to secure sustained commitment among the participants to continue growing the preferred varieties and to disseminate them among other farmers.

4. *Changes in seed choice*: – observe the perceptions of participant farmers considering whether the selected varieties are their seed choice or not. Experience shows that farmers tend to grow varieties they choose themselves over varieties introduced through any formal extension system. This was proved in Ethiopia.

5. Willingness for scaling-up the top selected varieties through farmer-to-farmer seed exchange and use: – try to observe farmers' willingness to scale-up the production of top selected varieties by disseminating to other farmers and continuing to use them themselves. We have observed that the rate of sharing seed with other farmers during the first few years is slow, as the primary participant farmers want to maintain selected varieties for their own use.

3.2.4.4. *The Potential Impact of CCI*

The benefit of conducting crowdsourcing projects is beyond getting varieties evaluated and ranked by farmers. There are many direct and indirect benefits that can be obtained if the research team is keen enough to harness these. The distributed new varieties show different levels of reaction to local growing conditions, and critical observation of such differences is very important. Below are some of the undesigned achievements from conducting crowdsourcing trials:

1. *Identify varieties resistant to drought*: – terminal drought (i.e., drought occurring due to early cessation of rainfall) is the major crop production threat in tropical agriculture. Several million people are affected every year in Africa due to drought, but the national breeding programs were not as successful in breeding for drought tolerance. During the past eight years of implementing crowdsourcing trials, we have observed that identification of drought-tolerant varieties in drought prone areas is highly likely.

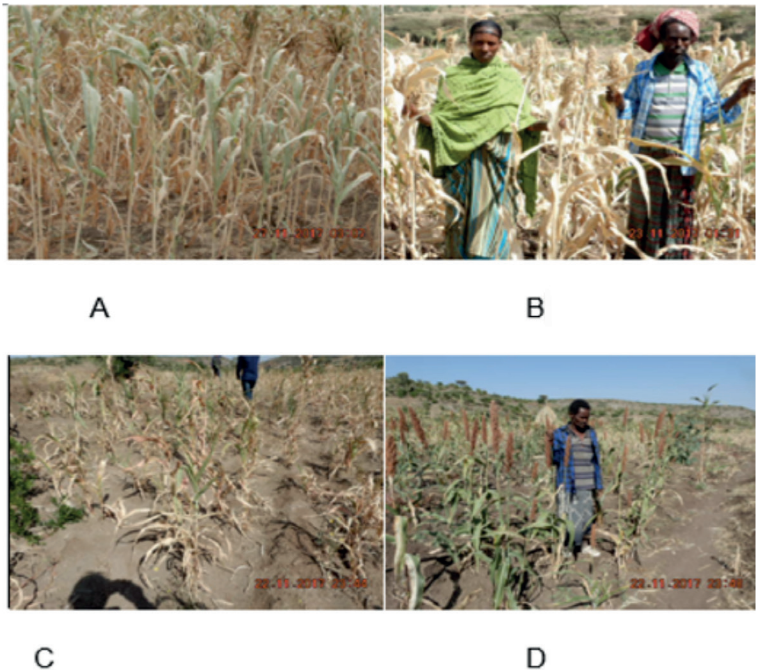


Photo 15: A-D Comparison of local and crowdsourced sorghum varieties for performance in drought prone area of western Haraghe. Photo @ Dejene K. Mengistu

Here are some examples:

– This trial was conducted in *Saro kebele* of western Haraghe. During the trial, only two rain showers were received, according to the local farmers.

– Varieties A and C are local sorghum varieties grown in the area for a long time.

– Varieties B (Meko) and D (Selam) were new varieties introduced through crowdsourcing.

– Despite an extended drought in area, the two varieties performed well compared to the local varieties.

– The farmers were surprised by the performance and extremely happy to be able to access these varieties and promised to maintain them for future use.

Photo 16: Extraordinary drought-resistant durum wheat farmer varieties (landraces) identified in eastern Tigray through crowdsourcing. Photo @ Dejene K. Mengistu

Similarly, drought-tolerant varieties of wheat (both bread [*Triticum aestivium*] and durum [*Triticum turgidum var. durum*] wheat), barley (*Hordeum vulgare)*, haricot bean (*Phaseolus vulgaris*) and tef (*Eragrostis tef*) were identified in different parts of Ethiopia through crowdsourcing trials.

When a field visit was made on November 10 of 2017, we found that some of the durum wheat varieties had survived the extreme drought conditions of eastern Tigray. Common varieties of bread wheat distributed through the extension system had totally failed, and the lady growing these varieties of durum wheat was extremely happy to have the varieties. She said during the visit, "I never lose these varieties" and promised to expand their cultivation over the next seasons. The objective of the trial was not directly to identify drought-resistant varieties, but due to the trial period coinciding with the drought, drought-resistant varieties were identified. This is the power of crowdsourcing crop improvement!

2. *Identify disease-tolerant varieties:* – plant diseases such as rusts, Septoria leaf blotch (*Zymoseptoria tritici*), and fusarium are some of the common diseases affecting the production of crops such as wheat and barley. Developing disease-resistant or tolerant varieties is accepted as a sustainable approach to disease control and yield loss reduction, thereby improving crop production and productivity. Experience shows that crowdsourcing research helps identify varieties with various degrees of resistance to common diseases. Some evidence is presented below:

Photo: @Dejene K. Mengistu

Photo 17: Differential responses of bread wheat varieties to rust diseases in Tigray, Ethiopia

Such disease-resistant varieties can be utilized in various forms to naturally control the impact of plant diseases reducing pesticide dependance, which is costly and environmentally unfriendly.

Durum Wheat

Photo 18: Figure 28. Varieties in adjacent plots react differently to Septoria wilt. Photo @ Dejene K. Mengistu

In Photo 18, the variety to the left was heavily infected by Septoria wilt while that on the right was completely free of infection. The difference in their reaction is extremely marked. It is useful for growers and breeders to have such innately resistant material.

3. *Identify weed-tolerant varieties:* – Striga weed (*Striga hermontica*) is a major weed that severely affects sorghum production in Ethiopia. Identifying striga-resistant lines and using them in pedigree breeding

has proved an effective way of improving striga-resistance in sorghum. From sorghum varieties tested in Tigray and the western Hararghe lowland areas through crowdsourcing during 2017 and 2018, some were found to be resistant to the parasitic weed.

4. *Helps to develop national variety catalogue:* – In most developing countries like Ethiopia, Nepal, Bhutan, and Uganda, the agricultural sector is complex and geographically diverse, where growers farm from lowlands to mountain peaks. To address such complexity, profiling crop diversities with agro-morphological and agronomic traits is more important. Developing a crop-diversity catalogue for high productivity, earliness, disease and pest tolerance/resistance, drought resistance, and agronomic and quality traits helps to choose the right varieties as the need arises. Conversely, if a variety catalogue for various agro-ecologies, uses, and adaptations is not available, countries and farmers will have little or no access to varietal information to make informed decisions on which variety to plant for any predicted growing environment. For example, there were several occasions where the government of Ethiopia advised planting early maturing and drought-tolerant varieties for predicted drought conditions, but huge crop failures were recorded because these crops were unsuited to the actual prevailing weather conditions.

We believe that a crowdsourcing approach could be a useful way to develop catalogues of notified varieties and promise farmer varieties (landraces) of various crops for highland, midland, and lowland agricultural zones. Suggested approaches include:

1. Forming consortia of institutions, professions, and expertise containing the ministry of agriculture (MoA), the local bureau of agriculture (B0A), plant breeders, extension agents, farmers, development agents, and farmer associations such as seed production cooperatives.

2. Developing a set of varietal diversity of crops to be tested in various target test areas.

3. Preparing the test seeds/promising varieties and distribute to target areas for planting. Because many varieties will be planted for evaluation, preparing a large plot of land is needed for the trials. Farmer training centers (FTCs) and technology demonstration centers can be used.

4. Identifying important traits for varieties evaluation and selection, together with local participant farmers. The traits should include, (but are not limited to), agro-morphological variation, phenological traits, yield traits, and adaptation traits for existing and predicted abiotic and biotic stresses.

5. Organizing farmers' variety evaluations for the defined traits during different developmental stages and ranking them using appropriate scales (scale of 1-5 when many varieties are being tested and evaluated).

6. Mobilizing local agricultural expertise to collect metric data for every planted variety to scientifically prove the superiority of farmer-selected varieties. This is important to build trust between stakeholders at various levels, including decision makers, for recommending the identified varieties for production.

7. Identifying winning varieties for different purposes over several seasons, and then developing the catalogue for future use by farmers. This helps the farming community adapt to local climate change, sustain their productivity, and improve their livelihoods.

A number of additional works available in the published literature, variety release registry books, and genebank records can help to compile relevant, variety-specific information for the catalogue. Such a catalogue would provide information on crop variety specific traits to farmers and all other stakeholders such as researchers, development professionals, planners, and field staff. It would also serve as an important repository for varietal information regarding any targeted agricultural environment.

3.3. *Participatory plant breeding (PPB)*

3.3.1. *Rationale for PPB*

Formal or conventional plant breeding (CPB) has failed to address the varietal needs of subsistence farming systems worldwide. Subsistence farming systems are characterized by a heterogeneous production environment, a large diversity of farmers' needs, a lack of adaptable varieties, and disinterest in the formal seed sector (Desclaux, 2005). Having to address such diversity and heterogeneity led breeders to think outside of the box more than a century ago. Despite a long-abiding recognition of the value of farmers' participation, actual participatory work started in the 1980s, when scientists became more aware that user participation in technology development may substantially increase the probability of adopting any generated technology (Ceccarelli, 2012). It was increasingly noticed that accommodating the multitude of farmers' preferences had proved challenging to CPB. Serving their preferences for taste and cooking quality, earliness, quality and quantity of straw yield as animal feed, local adaptability, and resistance to local pests and diseases, needed a different approach.

The need to increase the impact of agricultural research and to further the adoption of improved varieties are some of the reasons for the use of participatory plant breeding (PPB) and participatory variety selection (PVS). This was especially the case for developing countries and for poor farmers operating in marginal environments.

PPB is defined as the type of plant breeding in which farmers, as well as other stakeholders, such as extension agents, seed producers, traders, and interested NGOs, participate in the development of new varieties (Ceccarelli, 2012; Bhargava and Srivastava, 2019). Participatory crop improvement programs use PVS and/or PPB, and now also evolutionary plant breeding (EPB) approaches depending on the production context, and the farmers' varietal needs, breeding knowledge, and technical skills (Desclaux, 2005). As already stated, PVS is used to characterize local landraces and evaluate 'nearly-finished', improved breeding materials to select varieties that attract the attention of farmers and fulfill varietal requirements.

PPB is initiated when varietal options available to farmers through PVS are limited or exhausted. It is a decentralized approach, where varietal testing and selection take place in the target environment, unlike the conventional approach where testing and selection occur on research stations under breeders' management. Since the 1990s, on-farm conservation, crop improvement, and genetic resources management through the direct participation of farmers, plant breeders, and stakeholders in the breeding process has increasingly captured the attention of many. This concept of PPB is considered an effective method for on-farm conservation and for promoting the use of local crop diversity. It has been developed to overcome the apparent limitations of current formal and centralized breeding systems. PPB attempts to develop crops and varieties that are better adapted to farmers' local environmental conditions and give more attention to the diverse traits that farmers and consumers value in their specific localities. As a default, one of the locally adapted parents is used for hybridization as this allows for retaining some useful alleles in the gene pool.

PPB is a response to various agricultural developments that have occurred over the last fifty years, mainly the following:

– Strong genetic erosion caused by changes in farming systems, land use, and commercialization, which limits farmers' options to produce crops and narrows the genetic base needed for rural farming communities to cope with future demands in crop improvement.

– Erosion of farmers' knowledge and culture on how to deal with new biotic (pest and diseases) and abiotic stresses (drought, cold, heat)

– In general, a low adoption rate of varieties disseminated from conventional breeding programs by farmers in specific and difficult areas, due to emphasis on cultural and other use values. PPB involves a range of different approaches, including researcher-led and researcher and farmer-led initiatives.

3.3.2. *Objectives of PPB approach*

PPB aims to:

– Improve locally-adapted cultivars by integrating different farmer-preferred traits (e.g. higher yield, better quality traits, biotic and abiotic stress resistance etc.).

– Engage farmers in the breeding process so that they would be able to advance the existing desirable variation observed in PPB programs.

– Raise farmers' awareness of the importance of locally available genetic resources and their conservation needs.

– Empower farmers to select their preferred varieties for further dissemination. This increases the adoption rate of identified varieties.

– Institutionalize crop improvement efforts at the local level through collaboration with seed actors and other stakeholders.

3.3.3. *Advantages of PPB initiatives*

The availability of genetic materials is critical to the success of PPB. Such materials include products of locally adapted landraces and breeding lines. By adding value, PPB aims to conserve local genetic resources that are endangered or on the verge of extinction. Within traditional crop production systems, the direct use value of local crop diversity is well recognized by farmers; however, farming communities often do not fully recognize the breeding value of genetic traits inherent in farmers' varieties or landraces. Sthapit et al (1996) have shown that the value of local diversity has been increased by participatory plant breeding by utilizing farmers' knowledge.

Past experiences show that the value of farmer-identified landraces could be increased by PPB, including those that are threatened with extinction. PPB offers skills and opportunities to farmers in searching for new diversity and selecting and exchanging variable populations that match their local preferences and needs. Under PPB, both farmer and breeder take part in selecting segregating populations from the earliest stages. Involving farmers in the breeding process not only adds value to the conservation of local crop diversity, but also helps to maintain and enhance farmers' knowledge in selecting and managing local crop populations and enhancing seed-supply systems. PPB farmers' group formation during the PPB process has also increased the quality of farmer participation, increased local capacity, improved work efficiency, and increased both social learning and the sense of ownership. There has also been greater recognition and respect between farmers and plant breeders, who together can make a difference regarding crop improvement of their specific interest.

3.3.4. *Success examples of PPB in varietal provision*

3.3.4.1. *Durum wheat PPB programs in Ethiopia*

PPB programs using farmer varieties of durum wheat managed adaptable varieties for production conditions in northern Ethiopia. Two varieties, *Rigeat* and *Wehabit*, were developed through a PPB approach and were widely adopted within the northern Ethiopian wheat production system. Furthermore, their production has been extended to other parts of Ethiopia, including high potential areas like the Aris and Bale zones due to their high yielding potential and stable performance. They have good drought and wheat disease tolerance capacity. Other varieties are currently in the PPB pipeline for release.

3.3.4.2. *Barley PPB program in Ethiopia*

Using a PPB approach, more than five varieties of feed barley were released by Mekelle University to the dryland part of northern Ethiopia. The varieties included *Fetina*, *Felamit, Welela, Hiriti* and *Himblil* and were nationally registered and released from PPB programs. Due to their better adaptation to the prevailing local growing conditions, these varieties are now very popular in the barley production areas of northern Ethiopia. They display good drought tolerance.

3.3.4.3. *Rice PPB program in Nepal*

PPB programs using local landraces have integrated desirable traits such as cold tolerance, rice-blast resistance, and adaptive traits, and have eliminated undesirable grain color and improved rice quality. Similarly, the PPB program PATaM in Bara, Nepal has resulted in 5 promising Kachorwa rice lines for their better yield performance under rainfed and drought conditions, improved resistance to lodging, better taste, and more acceptable grain types similar to the popular local parent (Sthapit et al, 2006).

3.3.5. *Methods and Process of PPB*

Participatory plant breeding is a collaborative effort by farmers, plant breeders, seed actors, and other stakeholders for improving desirable traits in a participatory way. The varieties developed through PPB involve the direct engagement of farmers, plant breeders, and stakeholders, and such varieties have better adoption by the farming community and market because of the known value addition through participatory plant breeding. The PPB process can be completed using the following key steps:

3.3.5.1. *Goal Setting*

Setting breeding goals is vital and requires an understanding of the existing problems to which the breeding program seeks solutions. Consultation with farmer communities in the target areas helps to establish more realistic breeding goals.

3.3.5.2. *Generating diversity*

Any breeding requires variation, based on which selection happens. Try to include diverse materials in the PPB program to allow participant farmers to select among the diverse varieties. If crossing is involved, choose the right parental lines for contrasting performance for important traits. For PPB, inclusion of traditional varieties/landraces is encouraged. Choose parental lines from diversity blocks and previous PVS trials.

3.3.5.3. *Selection in segregating generations*

Selection is performed using PVS to advance preferred materials from segregating generations of advanced lines. The selection could be done on individual plants, on head selection, or bulk selection among and within families. Target farmers are empowered to participate in the selection process and breeders are expected to provide training to participant farmers on the simple concept of segregation, selection, heritability, and genetics. Field visits facilitate interaction with farmers and breeders from different PPB projects and encourage joint selection by breeders and farmers to enhance selection skills.

3.3.5.4. *Testing varieties*

Selected varieties, together with standard checks, are further tested in multilocation trials both on-station and on-farm. The purpose of such trials is to generate scientific data on varietal performance for yield, quality, and resistance to biotic and abiotic stresses. The trials are replicated to allow rigorous statistical analysis so that the result can be submitted to the national variety release committee if variety registration is required. Such trials conducted over seasons and locations help to select stable and adaptable varieties from the tested mass of varieties.

3.3.5.5. *Seed multiplication and dissemination of selected varieties*

Seed is the ultimate output of breeding programs. Breeders are required to provide breeder seeds and maintain these foundation seeds for future use. In PPB, breeders should work together with farmers, seed producer associations/cooperatives, and other concerned stakeholders to multiply, certify, and disseminate their varieties. Sometimes, the formal seed system may not support the extension of PPB varieties to due economies of scale. Hence, facilitating the diffusion of PPB varieties formally/informally, promotion, and marketing are all done at the local level by local seed businesses.

3.3.5.6. *Impact assessment*

After variety release and seed dissemination, the knowledge on the variety adopters should be recorded, and the suitability of the varieties in the adopted areas should be assessed. Collecting feedback from the users/adopters through surveys, interviews and group discussions is another important step in identifying the strengths and weaknesses of the disseminated varieties and helping to establish the next crop-improvement objectives. For example, if a variety is accepted for most of its agronomic traits but susceptible to a given disease, the variety can be improved for its disease tolerance in the next breeding program.

3.3.6. *PPB enhances on-farm conservation of agrobiodiversity and farmers technical knowledge of using them*

In PPB, farmers are allowed to select, maintain, and exchange local crop diversity even before official release, and this has been recognized as an important aspect of on-farm agrobiodiversity conservation. Additionally, PPB offers plant breeding concepts and skills to encourage farmers to improve their locally adapted varieties through i) cross breeding with the help of plant breeders, ii) effective selection, and iii) managing local crop populations and seed supply systems through informal and formal seed networks. Hence, PPB can be considered as a strategy for on-farm management of local crop diversity.

3.4. *Evolutionary plant breeding (EPB)*

Evolutionary plant breeding is an approach that combines diversity usage and evolutionary processes in order to increase on-farm buffering capacity against changing environmental conditions. It harnesses existing crop diversity and exposes crop varieties together to these changing farm conditions to enhance the genotypic adaptation of component plants of the local populations.

Farmers living in marginal environments have been instinctively growing interspecific and/or intraspecific varietal and crop mixtures to manage these environmental risks. For instance, growing mixtures of wheat and barley, technically called *Hanfets*, in the northern Ethiopian and Eritrean drylands is an age-old practice. Agricultural modernization has promoted growing single improved varieties that respond well to chemical inputs and require mechanization. This leads to high risk of crop failure, mainly due to abiotic and biotic stresses and severe genetic erosion. In recognizing monocropping limitations, evolutionary breeding has emerged to better understand and plant varietal and crop mixtures.

The practice of harnessing evolutionary populations is at least a century old (Harland and Martini, 1929) and has subsequently been better defined by Suneson (1956). For a more detailed understanding of evolutionary breeding, refer to the Manual developed by Ceccarelli and Grando (2020).

Evolutionary plant breeding utilizes all forms of genetic resources: cultivars, landraces, advanced lines, and modern improved varieties or evolutionary populations. As a result, evolutionary plant breeding could be regarded as a sustainable way of managing genetic resources to boost productivity and adaptation to abiotic and biotic stresses as well as stabilizing crop production in marginal environments. Changing climate, the instability of monocrops, and increasing demand for diversified nutrition has forced farmers and consumers to look for crop varieties that can better adapt to these changing conditions, and satisfy required nutritional diversity. EPB creates and maintains a high degree of genetic diversity (polymorphic populations) and is a preferred approach for breeders and farmers for accelerating the development of climate-resilient and sustainably high-performing crop varieties (Joshi et al., 2020). An evolutionary population can be compared to a living gene bank, not only because it brings greater yield stability and better agronomic traits, but also because it provides greater diversity in aroma, nutritional value, and quality. Evolutionary populations have the potential to produce higher yields and perform better than their local or improved counterparts in adverse conditions. Under stress conditions, evolutionary populations have also been shown to be more resistant to weeds, diseases, and pest damage than homogenous crop populations. Based on the source of diversity used in EPB, two different types of populations – Composite Cross populations, and Composite Mixtures populations – are developed (see figure 16).

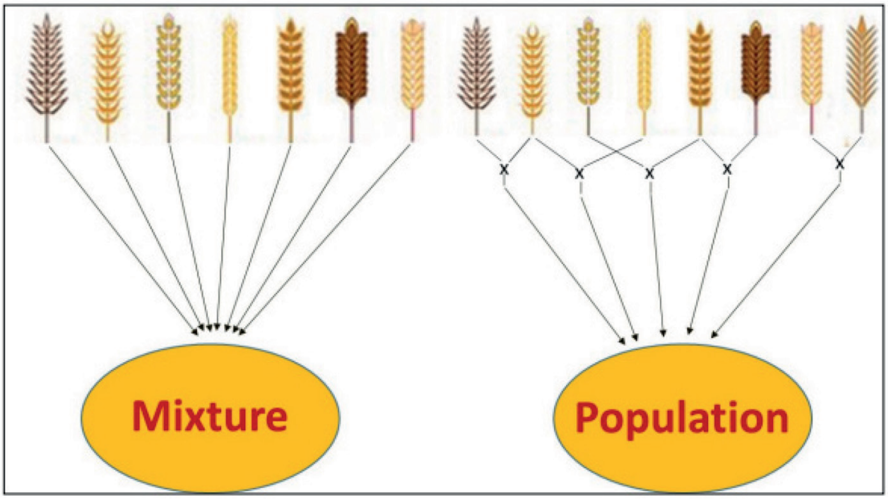


Figure 16: Types of evolutionary populations. A mixture is obtained by mixing seed of different varieties while a population is obtained by mixing the seed obtained by crossing different varieties (Adopted from Ceccarelli and Grando, 2020).

3.4.1. *The state of evolutionary populations*

There are two main states of evolutionary populations, which can be described as follows:

1. *Static mixtures:* – The state of populations that are established by physically mixing the seed of each of the components at the beginning of each cropping season. They are static because they do not capture the effects of natural selection occurring in the field. This is despite such physical seed mixtures being genetically more complex than monocultures that can therefore be subject to natural selection (Ceccarelli and Grando, 2020).

2. *Dynamic mixtures:* – Populations that are subject to natural selection from a cyclical production of static populations or populations generated from genetically mixed segregants. Over generations, out-crossing decreases and the genetic structure of such dynamic mixtures becomes a cross-composite population (CCP) (Wolfe and Ceccarelli, 2020).

EPB programs are initiated with the following objectives:

– Developing dynamic evolutionary populations or static varietal mixtures on which natural and artificial selections take place. Natural selection increases the frequency of fit components and eliminates the weak, non-adaptive varietal components of the populations.

– Harnessing the buffering capacities of the populations, thus minimizing the risks of crop failure due to biotic and abiotic stresses and ensuring high yield even under low-input farming regimes.

– Ensuring farmers' access to diversified crop varieties, based on which they make continuous selections to sustain their crop production and improve their livelihoods.

– Enhancing on-farm conservation of crop diversity and creating new varieties through evolutionary recombination.

– Providing both locally adaptable varieties and ecological services due to its reduced reliance on intensive inputs.

3.4.2. *Functions of EPB*

Research has shown that reincorporating diversity into agro-systems to promote ecosystem services is a viable approach for reducing environmental impact while maintaining and even increasing yields (Kremen and Miles, 2012). EPB is supposed to play these roles. As summarized by Ceccarelli and Grando (2020), this wealth of research has shown that:

1. Evolutionary populations and mixtures can adapt their phenology to the location in which they are multiplied.
2. Evolutionary populations evolve to become more and more productive.
3. Evolutionary populations, and to a lesser extent, mixtures, have a more stable yield over time than uniform varieties but not over space, i.e. they become specifically adapted.
4. Evolutionary populations and mixtures evolve to become more and more disease resistant.
5. Evolutionary populations and mixtures can provide a source of new genetic material for formal breeding programs.

3.4.3. *Principles for constituting an evolutionary population*

The principle of constituting dynamic evolutionary populations and varietal mixtures differs. We have to consider:

3.4.3.1. *The mating system of target crops*

Mixing the seeds of pure-line varieties of self-pollinating crops makes a mixture which relies on a low level of natural cross-pollination. Such mixtures take a longer time to become a population because of few or limited opportunities for recombination. On the other hand, if segregant populations from crosses of self-pollinated species are composed, many more opportunities for recombination can be realized in shorter periods, and consequently, evolutionary populations are created much more rapidly. For cross-pollinated crops, evolutionary populations are created at every generation.

3.4.3.2. *Breeding objectives*

The choice of how many or which varieties to mix or cross depends on the breeding/farmers' objectives and the characteristics of the crop (Ceccarelli and Grando, 2020). For instance, if disease susceptibility is one of the problems affecting productivity in the target environments, one or more parents of the EP or one or more varieties in the mixture should carry the desirable genes for disease resistance.

3.4.3.3. *Compatibility of component varieties*

Compatibility for agronomic and end-use quality traits is required from the component varieties making populations. For instance, when varieties that are very diverse for their phenology (days to maturity) are mixed, it becomes difficult to decide when to harvest. Similarly, cooking time may differ considerably between varieties for crops such as beans, chickpeas, lentils, and rice. Hence, it is necessary to mix varieties with similar maturity times or cooking times. When grain color is the major determinant of market attraction and market price, it is important to consider this factor. For example, the grain color of tef, an Ethiopian staple cereal, is an important factor for producer farmers as well as buyers; a mixed white with red-seeded varieties may not be desirable.

3.4.3.4. *End use value*

For specialty crops such as coffee and spices, the flavor or aroma of a particular variety may be different when mixed with other varieties. In such cases, a strict selection of component varieties is important, or indeed, making EPs or mixtures does not have to be extended to such crops.

Mixing diverse genotypes, for example 10 to 1000 or even more, and growing them together in a single plot is the main method of EPB. Component varieties are proportionally mixed.

The components can be landraces, improved varieties, hybrids, segregating lines, breeding lines, or wild relatives. EPB can be applicable to self-pollinated, cross-pollinated, and vegetatively-propagated crops. The different varieties, advanced lines, inbred lines, or segregants can be bulked without selection, and can be mixed to form a heterozygous and heterogeneous population. These populations are grown at a location over several seasons to allow evolutionary processes to occur. Population seeds harvested from a location are preferably grown over years at that given location, so as not to interrupt with the evolutionary process and help them thrive through adaptation. The detailed steps of EPB programs are described in figure 17.

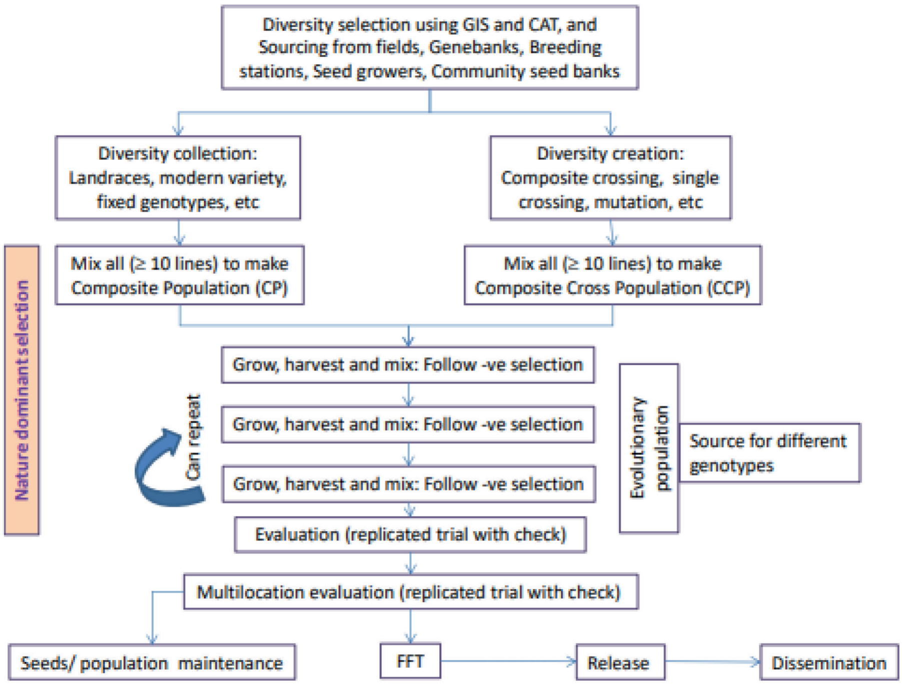


Figure 17: General steps of EPB
(either on-station, or on-farm participatory evolutionary plant breeding).

3.4.4. *Some evidence of advantages of mixtures or evolutionary populations*

Scientists have been documenting the advantages of growing mixtures or evolutionary populations, compared to their pure stand components, to improve yield and enhance resistance to diseases and climate anomalies. EPB aspects linked to phenology and yield improvement, and to disease resistance, are covered below:

3.4.4.1. *Phenology and yield improvement*

– The use of composite hybrid mixtures to enhance yield started more than 90 years ago (Harlan and Martini, 1929).

– The term "evolutionary population" was first used by Suneson in 1956 and popularized then after.

– Phenology of populations is affected as populations advance- i.e., populations grown in different localities evolve differently for heading time (Allard and Hansche, 1964).

– Populations with contrasting phenologies were observed being able to stabilize the combined risks of frost, heat, and drought stresses in dryland environments of Australia (Fletcher et al., 2019).

– Composite cross populations of barley gave 21% higher yield at the 25th generation and 16% higher yield at 11th generation composite populations in Davis, California (Soliman and Allard, 1991).

3.4.4.2. *Disease resistance*

More durable resistance to various diseases has been reported as one of the advantages of mixtures or evolutionary populations over their component varieties by various scholars. The increased disease resistance could be due to the dilution of inoculum because of physical distance between plants of the same genotype. Below are just some examples of the many benefits seen with mixture or evolutionary populations:

– Disease severity in wheat and barley mixtures decreased by more than 30% compared to the pure stand component varieties (Smithson and Lennè, 1996).

– The average damage level in banana and plantain crops because of black Sigatoka wilt disease has remarkedly decreased in diversified populations (Mulumba et al., 2012).

– Mixtures of resistant and susceptible varieties of beans has resulted in the highest overall reductions in root damage due to stem maggot infestations (Ssekandi et al., 2016).

– Disease severity in winter wheat mixtures was reduced between 13 and 97% compared to the mean of the component varieties, resulting in yield increments of 8 – 13% (Finckh and Mundt, 1992).

3.4.5. *EPB projects in progress*

In 2018, IFAD approved a four-year project, "*Use of genetic diversity and evolutionary plant breeding for enhanced farmer resilience to climate change, sustainable crop productivity, and nutrition under rainfed conditions*" involving Uganda and Ethiopia in Africa, Jordan and Iran in the Middle East, and Nepal and Bhutan in South Asia. The project has been implemented by Bioversity International[10] in collaboration with national partners. Four major staple crops – common beans, barley, rice, and wheat (both bread and durum) – are the focus crops of the project, and several populations were formed for each crop. The populations are both varietal mixtures (VM) and cross composites (CCs). The goal of the project is to sustainably increase crop productivity and enhance climate-resilience of farming communities under low-input, rainfed, and less-favorable production conditions and organic production systems. The objective is to enhance the resilience of target low-input poor farmers in the project area through developing evolutionary crop populations (EP) with higher and more stable yields under the local farm agronomic and stress conditions, including drought, higher salinity, and pest and disease pressures.

To achieve the above-stated objective, about 90 populations have been tested together with 60 pure stand varieties across 41 locations in the six countries (Table 9). The targeted communities in all countries are characterized by subsistence farming and frequent exposure to climate-change events, and are consequently affected by temporal food insecurity. Over the last three years, we have been evaluating the populations for their agronomic performance, adaptation to local climatic conditions, and preference by targeted farming communities.

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Table 9. Summary on the number of EPs together with their pure stand varieties for the four crops in the six EPB partner countries

Sn	Country	Crop	# EPs	# Pure stand varieties	# Test locations
1	Bhutan	Beans	3	11	2
2	Bhutan	Rice	3	15	3
3	Ethiopia	Durum wheat	27	3	4
4	Ethiopia	Barley	4	3	3
5	Iran	Wheat	12	4	4
6	Iran	Barley	4	3	4
7	Jordan	Wheat	3	9	3
8	Jordan	Barley	8	6	3
9	Nepal	Rice	13	2	2
10	Nepal	Beans	7	2	1
11	Uganda	Beans	6	2	12
	Total		90	60	41

It was observed that:

a) Some populations have consistently out-performed the pure-stand, ‘improved’ varieties for grain yield and associated traits in all countries.

b) Products or foods made from some populations are more preferred by farmers for their taste, flavor, smell, and nutritional content, compared to the popular improved varieties.

c) The populations have displayed better tolerance to climate change-related stresses such as drought, pests, diseases, and weeds.

4. FINAL NOTE TO THE READERS

Just as farmers are considered the primary producers, so should they be considered as the primary breeders. Agriculture began with hunter-gatherers who started domesticating plants and animals. Selection of plants and animal variants from domesticated species was also performed by farmers in the absence of breeders or modern scientists. Indigenous traditional knowledge – the heritage of generations – is still the basis for modern science, particularly plant breeding. However, for decades, the wealth of accumulated indigenous knowledge in the farming community as well as farmers' active participation has been undermined by centralized crop breeding systems. Consequently, developed technologies have faced low adoption rates or even complete rejection by farmers as end users. Furthermore, developed technologies usually perform badly in most marginal growing areas and have consequently increased the probability of seasonal crop failures and livelihood impoverishment among farming communities. Managing these problems requires a paradigm shift in crop breeding. To succeed, participating farmers and other relevant stakeholders should be centrally involved in decision making, in breeding programs, and in other development-oriented research programs. The need for this change has created a fertile ground for the emergence of many participatory approaches. This manual has selectively compiled the most frequently used approaches in participatory agrobiodiversity utilization and conservation.

Participatory approaches enhance two-way learning, whereby farmers gain modern knowledge from the scientists/breeders and scientists/breeders learn the accumulated traditional knowledge from farmers. This synergy positively influences outcomes of jointly managed breeding projects and programmes. Furthermore, farmers' active participation helps them to more fully realize their potential to manage their farms in general and in varietal selection in particular. On the other hand, closely working with farmers help researchers/breeders/scientists understand actual on-farm environments, which are more complex than on-station research environments.

To harness the positive impact of participatory research in any future project, we recommend using one or more of the participatory toolkits presented in this manual.

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After some decades of research and demonstrations, participatory research has become the science of action in plant breeding. There are different degrees of participation of farmers in crop improvement research ranging from passive to self-mobilization. The former participation is guided by the scientists/researchers to let know the farmers what they are doing for themeselves, but the later participation is achieved after many years' experience of farmers to participate from problem identification to solution proposition stages of the research phases. Participatory plant breeding and varietal selections – PPB & PVS – have made it possible to cascade research activities to farm level and consequently varieties adaptable to local growing conditions and preferred by end users were developed and disseminated to other areas of similar growing environmental conditions. Crop varieties developed through PPB and extended through PVS were proven to be acceptable by end user farmers and adaptable to local growing conditions and were stable in performance over seasons. The fruit of participatory approach!

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Carlo Fadda, currently Director of the research area in Biodiversity for Food and Agriculture, joined Bioversity International in 2004 in Vietnam, where he spent almost three years as part of a project to manage agrobiodiversity in situ. Fadda has managed projects in China, Ecuador, Morocco, Kenya, Ethiopia, Papua New Guinea, Uganda, and Tanzania, among others. In 2015, he moved to Ethiopia to establish Bioversity's office in the country. From 2016, he represented all Bioversity's country offices on the Senior Management Team. For the last six years, he led the "Seeds for Needs" research team, which matches genetic diversity to farmers' needs and brings material from genebanks back into production systems. His work centres on the understanding that conservation and use of genetic resources cannot be decoupled from rural development, livelihoods, and economics. He has a PhD in evolutionary biology and zoology from the Sapienza University of Rome. Fadda is also an Adjunct Researcher at Scuola Superiore Sant'Anna in Pisa, Italy. He is based in Nairobi, Kenya.

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