Biodiversity in Production Landscapes and Sustainable Food Systems

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Abstract

Biodiversity in production landscapes and its linkages with sustainable food systems have been discussed here in context of i) potential of biodiverse food for better nutrition and health, ii) multiple benefits of sustainable farming systems; iii) the seed systems aimed at diversifying production in farming landscapes, and iv) need of enabling policies for mainstreaming biodiversity in production landscapes aimed at conservation of resources through use. Outcome of some recent case studies, in overall framework of indigenous food sovereignty, have proved that the traditional farming landscapes of Uttarakhand hills, with rich food culture and traditions, present a better model of sustainability of food and nutrition to showcase.

Introduction

The diversity that we have today in present day crops and animals is the results of constant interactions of countless generations of farmers, and the plants and animals they domesticated. This has resulted in wide-scale transition of several human cultures from a lifestyle of hunting and gathering to one of settled agriculture. The crop and livestock diversity, and the wild food resources have made appreciable contributions to human diets worldwide (Heywood, 2013).

When we think of good nutrition, and about the diverse food groups that should be in a healthy and balanced diet, we rarely think about where those foods come from. We are also often ignorant about the biological diversity that can be linked to our food systems which have been developed by farmers over millennia and which are adapted to local traditions, cultures and agro-ecologies. These links between production and consumption are important to sustainable food systems in order to have the richest possible food diversity on plates, sustainably sourced from the biological diversity that underpins agricultural systems.

The Sustainable Development Goals (SDGs) provide a renewed impetus for a focus on using biodiversity for food and nutrition and linking that to the sustainability of farming systems. Mainstreaming biodiversity in sustainable food systems is vital if we are to achieve those Goals, as envisaged. Using biodiversity for sustainable farming systems that produce diverse, nutritious foods will contribute to the conservation of these precious resources; conserving biodiversity resources will make them available for today's nutrient needs and future climate scenarios.

Agriculture plays a critical role in any given economy. Besides providing food and raw material, agriculture also provides employment opportunities to very large percentage of the global population. The primary importance of the food and agriculture sector in improving household food security and alleviating and preventing malnutrition is well recognized. When agricultural development fails in countries where there exist no other fast growing sectors, the chances of the poor rising above the poverty level and contributing to the economic development of any given country is diminished.

Awareness about the multiple links between biodiversity, healthy nutrition and sustainable food production is expected to go a long way promoting the multiple aspects of sustainable food systems. In this paper, contribution of agricultural biodiversity is discussed on the following four inter-connected dimensions, substantiated by outcomes of some recent case studies undertaken in Uttarakhand hills:

- Biodiversity for diverse, healthy and culturally acceptable diets
- Multiple benefits of sustainable farming systems
- Community seed systems delivering crop diversity for sustainable food systems
- Deploying more diversity in production landscapes for better conservation on-farm and use in sustainable food systems

Biodiversity for diverse, healthy and culturally acceptable diets

Despite the success of the agriculture, providing enough food to feed the world, today we are faced with issues of malnutrition, both over- and under-nutrition. More than a billion people today, in developing countries, are underfed and suffering from acute malnutrition, while much of the developed world is at the same time facing a crisis of obesity caused by over-nutrition, the so-called development-driven obesity (Heywood, 2013). Worldwide 30% more people are now obese than those who are underfed. Overnutrition has been the result of an unhealthy lifestyle, leading to diet-related non-communicable diseases, such as cardiovascular disease, hypertension, cancer, diabetes, etc. The causes of these nutritional challenges are many and complex as are possible solutions (Fanzo et al., 2013).

Since the time of colonization, there has been a drastic decline in health and integrity of indigenous cultures, social structures and knowledge systems which are integral to our ability to respond to our own needs for adequate amounts of healthy indigenous foods (*www.indigenousfoodsystems.org;* Bisht et al., 2018a,b). The changing food systems brought about by the forces of globalization have led to both challenges and opportunities (FAO, 2004). There is alarm that local culture and food traditions are disappearing, where multinational and transnational corporations are increasingly controlling national food in addition, for most countries, micronutrient deficiencies are of concern. It is, however, being argued that "indigenous food sovereignty provides a restorative framework for health and community development and reconciling past social and environmental injustices in an approach that people of all cultures can relate to" *(https://www.indigenousfoodsystems.org/)*.

An eco-nutrition model has been suggested for a healthy human nutrition that can be best achieved by an approach to agriculture that is biodiverse. However, such a model is sound in theory but very complex to achieve, as many complexities are involved, in reality (Blasbalg et al., 2011). Moreover, correlating agricultural biodiversity with human nutrition is generally difficult for a number of reasons including human diversity (DeClerck et al., 2011). Further, the agricultural biodiversity has provided enormous nutrition and health benefits but overexploitation of some resources and widespread habitat loss has negatively impacted the dietary diversity, nutrition, and health of some groups of society (Nakhauka 2009). The world is today faced with attempting to assess these impacts and seek a sustainable way forward (IAASTD, 2009). New approaches have been explored aimed at integrating environmental and human health, focusing especially on the many interactions between agriculture, ecology, and human nutrition (Blasbalg et al., 2011; Heywood, 2013).

Uttarakhand hills have a strong native food culture and traditions. Recently, we published the salient findings of some model case studies on the potential of local food systems in addressing community health and nutrition with regard to hilly areas of Uttarakhand state in north-western India (Bisht et al., 2018a,b) in overall framework of indigenous food sovereignty. Based on these, some policy considerations on food-based approaches for better health and well being in traditional farming agro-ecologies of Uttarakhand hills have been suggested (Bisht, 2018). The food-based approaches also include use of wild plant resources in agricultural systems, an important but undervalued supplement to household dietary diversity of native farming communities (Bisht et al., 2018b).

Household production and dietary diversity and its relationship with community health and nutrition with three representative farming agro-ecologies of Uttarakhand hills (Fig 1) are presented in Table 1. Table 1 reveals that better household production and dietary diversity is positively linked with community health and nutrition.

Using biodiversity in production landscapes provide multiple benefits in sustainable farming systems

The simplification of the world's farming and food systems leaves farmers with a decreasing range of resources to draw on to manage threats such as the risks of crop failure due to pests and diseases, declining soil fertility, or the impacts associated with increasing climatic variability. In order to address these and many other issues, sustainable practices are needed, and agricultural biodiversity is a key component of this. Areas in which agricultural biodiversity can contribute to the growing push for sustainable intensification include: increasing productivity, yield, stability, pollination, pest and disease control, various aspects of soil function, wild biodiversity conservation and climate resilience, etc. It can also substitute for many external inputs such as inorganic fertilizers and synthetic pesticides. Agricultural biodiversity's contribution to sustainable food systems can be analyzed at four scales: within species, between species, field and farm, and landscape.

Within-species diversity refers to the diversity of varieties within a species and can help deliver ecosystem services, such as reducing crop vulnerability to pests and diseases and increasing yield stability. At the species level, diversity can drive a wide range of ecosystem services, such as providing habitat and resources for pollinators and other wild biodiversity. At field scales, increased agricultural biodiversity (e.g. crop rotations) can lead to increased soil biological diversity, which in turn can increase nutrient status of soils. Finally, at the landscape scale, agricultural biodiversity can provide ecosystem services, from pollination to human nutrition to carbon sequestration. Agricultural biodiversity-based strategies are thus important for soil erosion control, climate resilience, pest and disease control, productivity, pollination and wild biodiversity conservation. Agricultural biodiversity in farming systems contributes in an integrated way to several global goals and targets at once, including SDGs.

Multiple benefits of sustainable farmer-led innovations have been documented from traditional farming landscapes of Uttarakahnd hills. Small-scale crop–livestock mixed farming systems representing about 70% of cropped area under rainfed farming could be characterized by high household food production and dietary diversity. In the mixed crop–livestock farming system of the hills, there still exists a dynamic relationship among CPRs, native crops, and livestock. The livestock substantially contributes to household cash income, whereas the surplus crop produce, if any, is sold locally and contributes very little to the household economy.

The important farmer-led innovations of the small-scale crop–livestock mixed farming systems, predominantly practiced in Uttarakhand hills, are as follows:

- Landrace agriculture with almost 100% seed requirement met locally through ISS.
- The forest resources and crop residues augment the nutritive value of the fields both directly through its foliage (forest litter) and indirectly through the dung of the cattle fed with crop residues and with forest grass and foliage.
- Mixed cropping of legumes, for example, wheat intercropped with lentil during rabi (winter) season and ragi (finger millet) intercropped with native black-seeded soybean, horse gram, black gram, cowpea, etc., during kharif (rainy) season that form symbioses with nitrogen-fixing rhizobia bacteria.

- A more realistic and often overlooked practice; the unique system of crop rotation and keeping the farm land fallow in traditional rainfed hill farming. The farmer households in each village divide the farm area into two equal halves. In a 2-year cycle, one half portion of the farm area remains fallow alternatively during rabi (winter months) after the harvest of ragi, mixcropped with several other crops, in the preceding kharif (rainy season). In the next cropping season (in March–April), rice, barnyard millet, potato, chili, etc., are planted in the farm area that remained fallow during the winter. In the other half portion of the farm area, wheat, intercropped with lentil and mustard, is planted in the rabi (winter) season after the harvest of rice, barnyard millet, potato, chili, etc., in the preceding kharif (rainy season). Farmers plant ragi, mixed-cropped with many other crops, in the following kharif season after the harvest of wheat (May–June). After the harvest of ragi and other crops, this farm area remains fallow for the following rabi. The kharif season crops like rice, barnyard millet, chili, potato, etc., are grown in the fields which remained fallow in the preceding rabi season as they require more soil moisture and nutrition. On the other hand, mixed-farming of ragi and several other crops in the kharif season grown in the farm area where wheat crop had been grown during the preceding rabi season can tolerate nutrient and water stress when sown in already exhausted fields. The legume crops intercropped with ragi are capable of fixing atmospheric nitrogen into the soil, and can grow under low moisture. Keeping the land fallow, alternatively, in a 2-year cycle is a traditional crop rotation practice primarily aimed at fertility and soil-moisture management.
- In predominant small-holder crop–livestock mixed farming systems of Uttarakhand hills, the fallow fields during rabi season also serve as grazing ground for cattle and goats during winter months. The excreta of these animals dropped during grazing add organic matter to the soil. This organic matter increases soil fertility. Further, in the nomadic pastoralist systems of the higher Himalayan mountainous ranges, the shepherds with migratory flocks of sheep and goats were traditionally allowed to graze the fallow fields at lower elevations during winters. The shepherds lived in temporary shelters on the fallow farm fields with their flocks of sheep and goats. They kept shifting to other farms/fields after about one week or so. This method helped in adding more organic matter in form of animal wastes to farmlands of hill farming.
- Several crops used in traditional hill agriculture are multipurpose, most commonly for the requirements of grain for human consumption and straw as livestock feed. In fact, the traditional mixed farming system fulfills the nutritional requirement of humans, livestock, and the soil. The crops grown together are highly compatible with each other. Most of these crops can withstand droughts, floods, and pests, thus ensuring some output even at times of major stress or natural calamity.
- The traditional polycultures reduce disease or pest problems and consequently there is no pesticide use. Further, certain crops act as natural biofumigants, releasing pest suppressing compounds. Mustard, intercropped with wheat in hill farming, is best known for this effect. There exist varieties of mustard shown to be almost as effective as synthetic pesticides.
- In traditional hill farming, the essentials of on-farm evolution "that is, the generation of variation and its subsequent natural and farmer selection" are always possible. Further, there is increasing recognition that the diverse needs of resource-poor farmers cannot be addressed by planting a restricted range of high-yielding, high-input varieties. The farm households, therefore, require a range of varieties to fulfill specific socioeconomic as well as agroecological needs in the small farm system.
- In the traditional small-holder farming systems, there are no well-developed markets for traditional crops. The crop production and consumption decisions of farmer households are often linked. The consumption preferences continue to influence these decisions. The surplus crop produce is sold locally in the community, sometime through bartering. Profit maximization has never been the production objectives of the farmer households and market prices are a small fraction of the private incentive that farmer attach to maintaining crop diversity in small-holder hill farming. Cultural and

consumption preferences, therefore, play a major role in decision making of farmer households. However, with enhanced awareness about the nutritional importance of local crops in the community, in well-functioning markets, the native crop landraces can be competitive and have enough potential to provide commercial opportunities fetching a premium price in local and distant markets. Maintaining crop landrace diversity in traditional farming landscapes also has public incentives to farmers and society. Genetic diversity in crop landrace populations has substantially contributed for adaptive response to changing climate and also has potential to generate novel variations needed to maintain the capacity of crops to adapt to change. The traditional farming systems thus provide an evolutionary service to the society.

- Livestock in traditional hill farming contribute substantially to rural livelihoods, employment, and poverty relief. They integrate with and complement crop production, embody savings, and provide a reserve against risks. The most common livestock species in mixed-crop farming are goats, cattle, buffaloes, and poultry. The raising of livestock is integrated with food crop production. While crops provide feed and fodder, livestock provide meat, milk, and milk products for subsistence and as a source of cash income. Livestock also supply draught power to till the land and provide power for other agricultural operations such as threshing and to a limited extent transport. In the mixed crop–livestock farming system, there exists a dynamic relationship between CPRs, crops, and livestock. Indeed, livestock are integral to the sustainability of the farming communities in Uttarakhand hills.

Strengthening community level informal seed systems (ISS) delivering crop diversity for sustainable food systems

Seed systems have several key functions including, facilitating access to seeds, seed production and distribution, seed-based innovation, regulation and conservation of seed diversity. These functions are common in any type of seed system, from informal seed systems (ISS) consisting of farmers who rely on their own seed with occasional seed exchanges with family or neighbours to formal seed systems (FSS), a fully developed commercial seed sector.

Different seed systems offer varying levels of provision of agricultural biodiversity, which in turn makes an important contribution to the capacity of food systems to produce food in a sustainable way and support healthy diets. However, current seed system and policies mainly focus on productivity and devote little attention to agricultural biodiversity. An expanded seed system monitoring systems is therefore needed that include metrics on agricultural biodiversity, sustainability and human nutrition.

State of community seed system at a traditional farming landscape target site of Uttarakhand hills was documented in a recent case study (Bisht et al., 2018a). Seeds of all the native crops/varieties have been selected and managed mainly by woman farmers. Much of this knowledge is gendered and passed down between generations from parents to their children. People embody their knowledge needed for each process, from sowing to harvest. Their knowledge and seed consistently have been localized along with their local climate, soil, and natural environment. It was shared among community members and passed on to next generations. Farmers shared good seeds and useful agriculture skills, which came from years of experience and contributions of the entire village community, so it had the character of public property. Indigenous villagers raised various crops calling for nutritional and cultural needs.

These largely small-holder, subsistence-oriented farmer households do rely on ISS for all the native/naturalized crops. Farmers of these target communities have limited access to formal institutions and the impact of formal crop improvement efforts in the target region leading to FSS has been negligible. Seeds used in ISS are produced, stored, and reused on-farms. Seed management, therefore, has a strong local decentralized character and is mostly done by women farmers.

The community level ISS in these target traditional hill communities is also characterized by wide diversity at crop and also at variety levels for certain major staples, a relatively high number of landraces in rice, ragi, and wheat that are better adapted and more resilient, simple seed production techniques, poor storage facilities, and informal transfer of knowledge. There has been large-scale exchange and distribution of seeds at the community level. These small-holder farmers in such remote areas are, however, most vulnerable with regard to seed supply in the event of seed shortage due to economic, social, and natural calamities. Nevertheless, ISS for most of these farmers is a source of economic independence and resilience in the face of threats, with one of the most important being climate change. The ISS provides about 95–100% of the seed used in households of these traditional farming niche sites.

Role of informal seed system in landrace diversification, *in situ* conservation on-farm and sustainability in production was investigated as a case study for rice diversity in Indian Himalayas. The diachronic pattern of landrace occurrence revealed substantial increase, both in landrace number and frequency, in time. The local level seed supply in Uttarakhand Hills revealed that about 96% seed supply originated from informal system and a mere 4% seed supply is met from formal seed supply networks (Table 2). In higher elevation ranges, beyond 1200 masl, largely landrace cultivation is practiced and a greater landrace diversification in traditional production was observed. Substantial variations due to environmental adaptations in niche habitats help provide important donor germplasm for crop improvement to users. Further, the population genetic structure also indicated enough diversity being maintained on-farm. Developing pathways for strengthening local level seed system for landrace diversification linked to sustainability in food production and conserving agro-biodiversity has been emphasized (Pandey et al., 2011).

Deploying more diversity in production landscapes for better conservation and use in sustainable food systems

Global food security now depends on a few widely cultivated species, the three crops, wheat, maize and rice providing over 50 per cent of the world's daily requirement of proteins and calories (Jaenicke & Höschle-Zeledon, 2006), and 12 species contributing about 80 per cent of total dietary intake. In contrast, wild foods provide a greater dietary diversity to those who rely on them. More than 7000 species have been reported to be used at some stage in human history, in past, based on ethnobotanical surveys of wild plants (Grivetti & Ogle, 2000; MEA, 2005). In India, 600 plant species are known to have food value (Rathore, 2009). Many agricultural communities have been reported to rely on wild plants and animals even today.

India has been the centre of origin and diversity of several important crops including large populations of related species in the wild, 'crop wild relatives' (CWR), which can be a valuable source of traits for breeding improved varieties. Many species have become foundational in local farming systems over generations. The greatest threat to agricultural biodiversity is the ongoing simplification of diets and farming systems. And yet, the genetic diversity conserved on and around farms continues to be remarkable.

Strategies to conserve agricultural biodiversity are based on consideration of the purposes for conserving it, the biology of the species and an assessment of benefits and challenges. The three options – on-farm, *in situ* and *ex situ* – are all considered necessary, but none is sufficient on its own, as each serves different purposes and each has merits and limitations.

To ensure that there can be sustainable agriculture it is imperative that priority be given to the sustainable conservation of the resources of agrobiodiversity on which agriculture depends. Deployment of greater genetic diversity in production systems is expected to take care of both their sustainable use and conservation. *In situ* conservation on-farm and crop improvement can complement one another in marginal production systems. Breeding programmes that evaluate farmers' landraces and use them in local improvement efforts are expected to produce material of direct value for marginal agroclimatic zones as well as achieve significant local conservation. New approaches to agricultural research and development are being tried in various places around the world, and virtually all of them emphasize a much better harnessing and management of biological resources than has prevailed in the past. Although many institutions are already actively involved, more coordination is needed at all levels to ensure effective reforms and agricultural biodiversity conservation policies that benefit the public, especially the poor and small farmers. Policy changes that attack the roots of problems and ensure peoples' rights are needed. We need to ensure public participation in the development of agricultural and resource use policies, develop markets and business opportunities for diverse organic agricultural products and change consumer demand to favour diverse varieties instead of uniform products. Various benefit enhancing options for farmers from local crop diversity were scrutinized based on farmer perceptions and priorities for efficient management of local crop diversity on-farm and its sustainable utilization for agricultural production as a case study from Indian Himalayas (Bisht et al., 2007). Further, many of the underutilized crops have been included in worldwide plans of action after having successfully raised the interest of decision-makers particularly for nutritional traits. These traits are being searched for in crops and plant species with greater emphasis than in the past in recognition of their role in combating diet imbalances.

The NBPGR has in recent past undertaken some case studies on on-farm conservation of agrobiodiversity at selected sites in Uttarakhand hills (Bisht et al., 2006, 2007, 2014, 2018a). The Himalayan highlands are the reservoir for a large number of crop genetic resources because of the richness of locally developed traditional crop varieties owing to high agro-climatic heterogeneity and high local socio-cultural diversity. Traditional agroecosystems in the Himalayan region are very diverse and crop husbandry, animal husbandry and forests constitute complex and interlinked production systems. However, there has been gradual reduction of traditional crop diversity in this region during the last two to three decades which requires adequate attention of researchers and policy makers for its safe conservation on-farm and sustainable utilization for agricultural production.

Agroecology, market structure and various household socio-economic characteristics like economic status of households, income sources, family structure, gender roles, land tenure system and local seed system are important factors dictating farmers' crop/variety choices (Bisht et al., 2007).

The detailed documentation of rice landraces in a study indicated that information collected at the level of household or farmers' plot may not be appropriate scale for analyzing diversity or for crop diversity conservation. Even one single village may not maintain a sufficiently large population for effective conservation over time. More likely it will be the network of villages or even a region that will be the approximate level for understanding the maintenance of crop genetic diversity on-farm in the Himalayan highlands. Documentation of rice landraces suggests that many of the rice landraces are adapted to marginal niche environments (common or rare localized landraces), the conservation strategy must therefore target these regions. Understanding farmers' system of classification for the different features of their agroecosystems may yield insights into the processes fostering conservation of diverse landraces (Martin, 1995).

Further**,** a study at NBPGR (Kumar et al., 2010) demonstrated farmer management of crop population structure and temporal evolution of rice genetic diversity in traditional production systems of Uttarakhand hills. The study compared genebank-conserved populations and on-farm managed landrace populations of same named landraces (Jaulia and Thapachini) and revealed greater diversity for on-farm managed populations as compared to the populations under static management.

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Table 1. Production and consumption pattern of major food groups in households (HH) of three different representative farming agro-ecologies and its impact on nutrition and community health

Indicators of household production and dietary diversity and community health	Agrobiodiversity rich niche sites where traditional small scale crop-livestock mix-farming is practiced *	Niche site with nomadic pastoralism and some arable land**	Niche site where improved agriculture is practiced** *
A. Household production and dietary diversity			
• Production diversity (no. of crop/livestock species produced/ reared)	32.06	28.70	14.20
• Food variety score (no. of food items consumed)	22.13	18.50	9.30
• Dietary diversity score (no. of food groups consumed)	6.43	5.60	4.30
• Dietary diversity score of healthy foods (no. of healthy food groups consumed)	5.49	4.50	3.40
• Dietary diversity of wild harvested food	31.24	25.50	7.50
B. Indicators of community health			
• Infant mortality rate	Nil	Nil	Nil
• Maternal mortality rate	Nil	Nil	Nil
• Level of malnutrition among children under five years*	Low (2%)	Low (2%)	Moderate (10%)
• Malnutrition among women of reproductive age**	Low (3%)	Low (4%)	Moderate (12%)
• Level of obesity among adults	Low (3%)	Low (5%)	Moderate (14%)
• Incidence of non-communicable diseases			
- Hypertension	Low (2%)	Low (2%)	Moderate (7%)
- Diabetes	Low (1%)	Low (2%)	Moderate (5%)

* Traditional farming areas in Tarikhet block of Almora district

** Johar valley in Pithoragarh district, nomadic pastoralists (the herded livestock include sheep and goats)

*** Someshwar valley in Almora and adjoining Garur valley in Bageshwar district

Source: Bisht et al., 2018a

Table 2: Comparative estimates of rice seed supply (%) at household level in Uttarakhand hills

Seed source	<1200 masl	1200-1800 masl	>1800 masl	Average seed supply
Own landraces	33.0	44.0	53.0	43.3
Neighbours' landraces from the village	11.0	12.0	18.0	13.7
Distant neighbours'/relatives' landraces in the region	12.0	16.0	20.0	16.0
Own improved variety	10.0	10.0	2.0	7.3
Neighbours' improved variety within the village	11.0	8.0	2.0	7.0
Distant neighbours'/ relatives' improved variety within the region	14.0	7.0	5.0	9.0
Other improved variety from formal seed supply network	9.0	3.0	-	4.0

Source: Pandey et al., 2011

A B C

Three representative farming situations in Uttarakhand hills

A: Rainfed small-scale crop-livestock mix-farming

B: Nomadic pastoralists of higher mountainous valleys adjoining Tibet

C: A few interspersed river valleys with improved agriculture

Fig. 1. Representative farming situations in Uttarakhand hills