Mainstreaming *Barahnaja* cultivation for food and nutritional security in the Himalayan region

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Abstract

Selective production of input intensive crops in the present scenario have resulted in productivity stagnation or even decline due to excessive usage of chemicals, affecting the farmers economically. Sustainable agriculture is the way to increase agricultural productivity and economic prosperity by protecting all natural resources. It maintains a balance of soil fertility with crop productivity and nutritional quality. The mixed cropping systems followed earlier in different regions according to their tradition, climatic zone, soil and water conditions were climate-smart approaches to sustainable food production based on practical experiences over the years of old generations. The life style changes, imbalance in farming system in last 70 years and demand for more food as well as declining land resources resulted in intensive agriculture. Besides, least returns and less demand of ethnic crops gave more preference to major staple food crops. *Barahnaja* is a traditional orphan crops based mixed cropping system practiced in Himalayan region due to its sustainability and assured crop harvest during erratic weather conditions. This traditional farming method is an exemplary scientific approach to derive innovations with respect to productivity, quality, plant soil interactions and organic agriculture. The main focus of the review is to substantiate the characteristics of the traditional mixed cropping system by describing the advantages of the system and opportunities for scientific innovation towards new knowledge and sustainability.

Keywords *Barahnaja* · Sustainable agriculture · Mixed cropping · Food security · Organic agriculture · Rhizosphere biology

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Introduction

Sustainable agriculture is vital in today's world as it offers the potential to meet our agricultural needs without harming the environmental and degrading the natural resources base. Agriculture has changed dramatically since the middle of twentieth century. Green revolution changed the course of Indian agriculture with the advent of high yielding fertilizer responsive cultivars of wheat and rice making India a food-grain surplus country from food-grain importer (Ahmad and Haseen 2012). The high yielding varieties seeds along with full package of practices propelled the food-grain production from 50.0 MT in 1970 to 220 MT in 2015. Food productivity soared due to new technologies, mechanization, increased chemical use, specialization, and government policies. Fewer farmers produced more food at the cost of soil degradation, air pollution, water contamination, new threats to human health and many more. These changes were more prominent in Indian plains in comparison to the hills. Himalayan agriculture is altogether different from plains with many traditional crops and farming practices occupy the major place. The concept of this type of farming in the Himalayan region was to achieve self-sustainability all-through the year without any commercial interest (Pandey et al. 2016). It benefitted us through conservation of agro-biodiversity due to least disturbance to the ecosystem. Now, there is a renewed interest in such eco-friendly and sustainable agricultural practices for health food production and maintenance of soil and environment health (Singh and Singh 2017; Kavino et al. 2007; Saravanakumar and Samiyappan 2007; Harish et al. 2009a, b). Traditional agriculture practices are helpful for human health safety, natural resource management, energy conservation and socio-ecological integrity in the climate change scenario (Singh and Singh 2017). Agricultural sustainability rests on the principle that we must meet the needs of the present without compromising the ability of future generations to meet their own needs. Therefore, equal importance need to be given to environment, society and economy. Different cultivation systems are followed in different region worldwide which not only provide chemical free nutrient rich produce for human and animal but also makes the soil healthy and nutrient rich and facilitates the sustainability to the environment for long term. The traditional mixed cropping system (*Barahnaja*) is one of the examples of these systems which has sustained since ages in the central Himalayan region. Here, we describe the *Barahnaja* system, its components, spatio-temporal distribution of crops in the system, benefits accrued from the system and future opportunities for scientific leads on various aspects of the system.

Components of orphan crops based mixed cropping system

Himalayan region is identified as the agro-biodiversity hotspot and agricultural practices are the main stay of the people of Himalayan region. Out of the total population, more than 75% people are engaged either with the main occupation of agriculture or its allied practices, dominated by traditional subsistence cereal farming. The traditional mixed cropping system (*Barahnaja*) is known to people who are deeply involved in this traditional farming system of Himalayan region particularly Uttarakhand hills. The literal meaning of *Barahnaja* is twelve grains and it does not involve only cereal grains but also pulses, oilseeds, vegetables, spices and fibre crops (Fig. 1). Growing these diverse crops in mixed culture is known as *Barahnaja* system of crop cultivation. It is not essential that only

Fig. 1 *Barahnaja* system of cultivation in hills **a** Mixed cultivation of diverse crops **b** Turmeric (spice), **c** Cowpea **d** Ricebean **e** Ginger (spice), **f** *Bhat* (Black Soybean) and **g** Cannabis plant supporting the *Bhat* and Cowpea

twelve different crops will be grown in the traditional mixed cropping system (*Barahnaja*) system. In different places < 12–20 different crops are known to grown depending upon the geographical conditions, eating habits and culture of the area but will be always a mixture of different group of crops (Table 1). In essence, *Barahnaja* is a mixed farming, companion planting system, a veritable community/society of crops. All crops planted together on the same terraced fields in the *Kharif* /*chau masa* (Rainy season) and includes the combination of cereals, pulses and other creeper legumes, vegetables, and root crops (Maikhuri et al. 1997; Partap 2011), which can grow in harmony with each other. For example, the legumes creepers use the stems of cereals/ pseudo-cereals as a natural support and due to their nitrogen-fixing abilities, return nutrients into the soil which are used by other crops (Goulding et al. 2008). The grain roots on the other hand firmly grip the soil to prevent

Table 1 Most commonly cultivated crops of traditional mixed cropping system (*Barahnaja*)

Local name	Common name	Scientific name
<i>Mandua</i>	Finger Millet	<i>Eleusine coracana</i>
<i>Ramdana/Chaulai</i>	Amaranth	<i>Amaranthus</i> spp.
<i>Kuttu/Ugal</i>	Buckwheat	<i>Fagopyrum esculentum</i> and <i>F. tataricum</i>
<i>Jowar/Jonyala</i>	Sorghum	<i>Sorghum bicolor</i>
<i>Makka</i>	Maize	<i>Zea mays</i>
<i>Rajma</i>	Kidney Bean	<i>Phaseolus vulgaris</i>
<i>Gehat/Kulathi</i>	Horsegram	<i>Macrotyloma uniflorum</i>
<i>Urad/Maas</i>	Blackgram	<i>Vigna mungo</i>
<i>Bhat</i>	Local Soybean	<i>Glycine max</i>
<i>Rayaans/Naurangi</i>	Ricebean	<i>Vigna umbellata</i>
<i>Tor/Arhar</i>	Pigeonpea	<i>Cajanus cajan</i>
<i>Lobia/Sut</i>	Cowpea	<i>Vigna unguiculata</i>
<i>Bhangeer</i>	Perilla	<i>Perilla frutescens</i>
<i>Til</i>	Sesame	<i>Sesamum indicum</i>
<i>Jakhiya</i>	Cleome	<i>Cleome viscosa</i>
<i>Bhaang</i>	Hemp	<i>Cannabis sativa</i>
<i>Kakdi</i>	Cucumber	<i>Cucumis sativus</i>

erosion. Pest control is achieved with the use of walnut and neem leaves, and the application of ash and cow's urine without external chemical inputs. Such bio-farming system is useful to maintain ecological balance and enable the farmers to get benefit from certain crops even in case of damage to other crops. In hilly areas, most peasant families have very limited land holdings which do not facilitate the separate cultivation of different staple food crops (Francis et al. 2016). In this context also, the concept of the twelve grain system is scientific and sustainable as different crops harvested at different time of the year provide security against food shortage, as well as against drought and crop failure in a small piece of land. It also provides nutritional security as diverse crops grown in the system are rich source of minerals and nutrients, e.g. millets are rich source of calcium, iron, phosphorus and vitamins, while legumes are rich in proteins. Along with providing food and nutritional security to mankind traditional mixed cropping system (*Barahnaja*) also maintains the strong traditional relationship of agriculture and animal husbandry by utilizing the crop residues as nutritious palatable fodder for the animals (Misra et al. 2011).

Agriculture sustainability through traditional farming approach

Agriculture is sustainable when it is based on a holistic scientific approach, ecologically sound, economically viable, socially justifiable and culturally appropriate. For sustainable agriculture one should integrate three main goals i.e. environmental health, economic profitability and social as well as economic equality (Bjornberg et al. 2015). Green revolution has somehow advertently institutionalized the process of discouragement of traditional farming system in the name of feeding growing population and to develop their livelihood (Brown 2013). Although, it was the need of the hour that time but long time vision for sustainability of agriculture was missing (Kesavan and Swaminathan 2008). High yielding varieties was not the forced choice but their field performance made the farmers pick up these high yielding varieties. However, cultivation of majority crops with the use of high yielding hybrid crop varieties in monoculture, incessant use of chemical pesticides and synthetic fertilizers is resulting in soil degradation and decrease in biodiversity due to the air and water pollution (Aktar et al. 2009). Food is critically important for survival but as per the requirement we need to think about the related aspects also so that one can evolve new approaches and policies which really have positive impact on the environment considering the other consequences of evolving agri-food systems. As of today, one should think about and consider the “quality” food production from natural resources rather than simply more production (McLaughlin and Kinzelbach 2015). Food along with nutritional security, sustainability and profitability is always remaining as a target for agriculture development. “Agricultural development along with conservation of biodiversity shows opposite interests sometimes. But, such conflicts in many cases are certain and still are not reported. In fact, evidence shows that integrating biodiversity and agriculture is beneficial for food production, ecosystem health, and for economically and ecologically sustainable growth (Altieri et al. 1998). Unlike mono-cropping or cash crop farming, no additional efforts are required in *Barahnaja* cultivation and single time ploughing is generally required to be done. Growing multiple crops at a time on same field as in case of the traditional mixed cropping system (*Barahnaja*) is an example of sustainable agriculture which enables us to produce healthy food without compromising the ability of further generations’ to do the same (Fig. 2) (Chaudhuri 2005; Altieri et al. 2017).

Fig. 2 *Barahnaja* mixed cropping system—An approach to sustainable agriculture

Himalayan region shows differences in geographical distribution, topography, habitat-flora and fauna, ethnic diversity, different patterns of land use for farming and socio-economic conditions in comparison to plain regions. The farmers in Himalayan region have vast scope for cultivation of diverse crops including cereals, millets, pulses, oilseeds, vegetables etc. The major limitation however is low yields of cereals, oilseeds, pulses grown in this region. Diverse or mixed cropping system was started by the farmers of this region to cope up with climatic vagaries and related risks during the crop season. The traditional mixed cropping system (*Barahnaja*) is conserved in hills, specifically in the Garhwal Himalaya region, through crop rotation practices (Sati 2009). This cropping pattern divides the total agricultural land into two parts, downward fields near to water source and the upside fields mostly dry (Sati 1993). The crops are grown in particular season with specific combination of supportive crops. The main *Kharif* (Rainy season) crops grown in the downward fields during April–May to September–October include paddy, foxtail millet, and barnyard millet while the upward fields mainly include other millets like finger millet grown in the same period/season. After harvesting the *Kharif* (Rainy season) crops during October–November, the *Rabi* (winter season) crops which includes wheat, barley and oilseeds are sown in the downward fields. The spatio-temporal distributions of major crops grown in Himalayas in different seasons are presented in Table 2. After harvesting of finger millet, the land remains fallow in the upper dry fields during October–November to March–April. The cropping pattern is interchanged in the following year in these fields (Fig. 3). The vegetables and spices comprising cucumber, pumpkin, potato, eggplant, lady finger and garlic are also grown during the rainy season along with field crops (Sati 1993). This system of crops and field rotation is the basis of sustainable agriculture along with the facilitation of rich nutrient diversity in our daily food. It is a way to maintain the field fertility, increasing the productivity and controlling the weeds without the use of any chemicals. The basic concept behind the cultivation of diverse crops simultaneously is based on symbiotic relationship between soil micro-biota and different crops as plants and microbes

Table 2 Spatio-temporal distributions of major crops in Himalayan region (particularly Uttarakhand hills, India)

Agro-ecological regions	Cropping season	Major cereal crops grown	Major cash crops grown
Valley Regions (< 1000 m amsl)	<i>Rabi</i> (Oct/Nov–March/May) <i>Kharif</i> (April/May–Sep/Oct)	Wheat, Barley, Gram, Lentil, Wild Mustard and Mustard Rice and Maize	Lemon (<i>Citrus</i> spp.), Ginger, Garlic and Green vegetables Onion, Tomato, Cucumber, Pumpkin, Beans and all Green vegetables
Mid Altitudes (1000–1600 m amsl)	<i>Rabi</i> (Nov/Dec–April/May) <i>Kharif</i> (May/June–Oct/Nov)	Wheat, Barley, Gram, Lentil and Mustard Rice, Finger Millet, Barnyard Millet, Horse Gram, Black Soybean, Blackgram, Cowpea, Black-eyed Peas, Kidney Bean, Pigeonpea, Hemp, Perilla and Sesame	Lemon, Orange, Green vegetables, Ginger and Garlic, Potato, Cucumber, Pumpkin, Beans, All Green vegetables, Pear, Peach and Nut fruits
Highlands (> 1600 m amsl)	<i>Rabi</i> (Nov/Dec–April/May) <i>Kharif</i> (May/June–Oct/Nov)	Wheat, Barley, Brown mustard (<i>Sarson</i>) and Rapeseed (<i>Toria</i>) Rice, Barnyard Millet, Amaranth, Buckwheat, Cowpea, Black-eyed Peas, Kidney Bean, Pigeonpea, Hemp and Sesame	Lemon, <i>Citrus</i> sp., Orange, Green vegetables, Colocasia, Ginger and Garlic Potato, Cucumber, Pumpkin, Beans, Eggplant, Chilli, Pear, Peach, Apple, Almond and Nut fruits

Fig. 3 Biennial cropping system in Uttarakhand hills, India

have co-existed for millions of years. Plant roots are involved in complex interactions with soil micro-biotic environment through various signaling mechanisms which are necessary for proper nutrient assimilation, development and activation of defense mechanism (Castro et al. 2009).

The system is beneficial for farmers as well as for the environment because there is no need to invest on external inputs. Moreover, this system provides nutritional security along with food security and healthy environment (Ghosh and Dhyani 2004). Better utilization of locally grown crop varieties in diversified cropping systems can be an important first step towards food security for uncertain conditions. It is also likely to contribute to the resilience of rural communities and ‘sustainability’, the capability for dynamic and intelligent responses to future unpredictable events (Van Noordwijk 2010; Jackson et al. 2010). Such local crops are directly consumed as staple foods, can provide valuable nutrients as part of a healthy diet. Traditionally, the hill farmers maintain close linkages and balance between agriculture, animal husbandry and forestry using the traditional farming system, which is known as integrated farming system. These crops also provide quality fodder which in turn results into higher meat, milk or eggs production to increase farm income thereby provide greater flexibility to producers and consumers (Yenagi et al. 2010; Padulosi et al. 2011).

Benefits accrued through the traditional mixed cropping system (*Barahnaja*)

Self-sufficiency with sustainable development

The land holding of farmers in hill states are fragmented and small. The traditional mixed cropping system (*Barahnaja*) of crop cultivation was practiced by farmers for crop diversification. Moreover, poor road networking and connectivity, and poor facilities made the farmers to grow diverse crops in their limited landholdings to produce sufficient food for

their families. The traditional mixed cropping (*Barahnaja*) cultivation facilitates the sowing of cereals, pulses, oil seeds and vegetables on same fields. These crops are sown in single or double rows which occupy small space in the field with maximum variation in crops (Negi 2014). It helps to maximize the land use, resulting in optimized utilization of soil, water, nutrient and sunlight and increased productivity and profit. Due to erratic rainfall, if one crop fails, other one serves as the insurance for assured harvest. The system facilitates the fulfillment of present requirement without compromising the future generation's needs (Altieri 1995).

Ecosystem and eco-fragile regions

The crops selected in *Barahnaja* system are based on nutritional requirements, ecological gradients and the socioeconomic conditions existing in the area (Singh et al. 1997; Ghosh and Dhyani 2004). The different food crops are grown in synergetic combination, supporting each other (Singh and Tulachan 2002; Zardhari 2000). In *Barahnaja*, it is essential to maintain a balance among the various crops, but certainly this can come only from the farmers, having the knowledge and experience through close observation for many years (Himanen et al. 2016; Dach et al. 2013). Closer to the mounds in the field, cowpea, maize or amaranth is planted aplenty. Close to the amaranth, Rajma (*Phaseolus* sp.), ricebean or other pulses take their place. The balance of crops in the field is so maintained that they grow in a spirit of cooperation to cover the entire field promoting enhanced nutrient use, pest and disease control, and weed suppression (Ghosh and Dhyani 2004). Diversification in crop cultivation with the introduction of medicinal plants can even be more important for profitability along with balanced environmental and climatic conditions (Pandey et al. 2019). It also provides more emphasis on conservation of all these diversified local crop plants (Ramakrishan et al. 1996) by the use of their natural genetic resources and their development for food and agriculture and the ecosystem services they provide, which is compulsorily required (Shennan 2008).

Organic by default

As the productivity of crops gets affected by continuous use of pesticides it also has negative impact on the entire ecosystem and soil fertility. By agricultural practices and several other means the biomass produced in the traditional mixed cropping system (*Barahnaja*) or other farming system gets converted into organic manure. Instead of chemical control measures, effective pest control is accomplished using leaves of walnut, neem, ash and cow urine. Generally for most crops, compost is mixed with the soil in the field before sowing, but in case of the traditional mixed cropping system (*Barahnaja*) it is spread over the seeds after sowing. The produce is therefore organic by default but not certified organic.

Prevention of soil erosion

The particular combination of crops grown in a region can be seen as the cause as well as solution to the land degradation problem (Clay and Lewis 1990). Soil erosion is responsible for the damages like loss of productive soil, silting, drifting and land fragmentation, which ultimately affects the soil quality. In the traditional mixed cropping system (*Barahnaja*) of cultivation, mixed cropping prevents soil loss because of diverse root system of different crops

grown at a particular time in same field and total covering of the field soils with the crops. The root system of *mandua* (finger millet), amaranth, *ugal* (buckwheat), *bhangeera* (*Perilla* sp.) and sesame hold and conserve the soil tightly and much efficiently, prevent the water and nutrient loss. As farmers pick the mature spikes, stems or leaves of the crop plants and roots remain intact inside the soil, thus preventing soil erosion even in the absence of crop also.

Food and nutritional security

The traditional mixed cropping system (*Barahnaja*) crops possess all the necessary ingredients for the community's food and nutrition security. Cultivation of different crops in the same field provides multiple food options and least chances of crop failure in adverse conditions or natural calamities like flood or pest disease outbreak (Sauerborn et al. 2000). Most of the crops grown in the *Barahnaja* system are hardy, drought tolerant, resistant/tolerant to pests, diseases and are nutritionally superior to major cereals (Muthamilarasan and Prasad 2020). Owing to their nutritional value, millets, pseudo-cereals and under-utilized pulses, which are part of *Barahnaja* system have been termed as nutri-grains. Many review articles have been previously recently on the nutritional aspects of these crops (for details, kindly refer Kumar et al. 2016; Sood et al. 2015, 2016; Joshi et al. 2018).

Health benefits

Due to non-inclusion of any chemical in the *Barahnaja* cropping system, the products are free from pesticide residues and safe for the consumers as well as environmental health. Each crop included in the *Barahnaja* system has its own medicinal value or health promoting benefits. As the different crops are co-cultivated in this system, they compensate the nutritional deficiency of each other and facilitate the high nutritional value as a combinatorial food. Finger millet (*Eleusine coracana*) along with other traditional crops grown in the traditional mixed cropping system (*Barahnaja*) system are known for several health benefits as they are nutritionally very rich source of calcium which helps in strengthening bones and iron which helps in condition of Anemia and also improves hemoglobin status of children (Chandra et al. 2016). The grains of *Setaria italica*, *Panicum miliaceum* and *Echinochloa frumentacea* are used in cures for jaundice, pneumonia and abdominal ailments. *Gahat* (Horsegram, *Macrotyloma uniflorum*) the pulse grown in *Barahnaja* system is a rich source of protein and is highly recommended for the treatment as well as the cure of stone (Sen et al., 1997). Bhat (Black soybean, *Glycine max*), highly rich in protein is recommended to jaundice patients and also effective for stomach infection. With all these nutritional values *Barahnaja* crops plays significant role to overcome the malnutrition conditions and provide not only energy through carbohydrates but also contains minerals, biologically important proteins, vitamins, antioxidants and anti-cancerous compounds which help in disease resistance and to provide good health (Sarita and Singh 2016). Moreover, small millets, a group of *Barahnaja* crops have the potential to combat malnutrition and hunger in the COVID-19 pandemic hotspots (Muthamilarasan and Prasad 2020).

Carbon sequestration

The mixed system of crop cultivation in Himalayan region maintain and conserve crop diversity and the farming communities of this region practice low-input agriculture with a significant concern for agricultural sustainability. A wide range of variation in

edaphic, topographic and climatic conditions and selection procedures over centuries of cultivation has resulted in the preservation of an immense crop genetic diversity. Trees planted on the bunds of terraced crop fields as part and parcel of this mixed cropping provide additional income. The cultivation of trees along with the crops provide higher plant diversity and facilitate more efficient conversion of CO₂ to organic form during photosynthesis by acting as carbon sinks, thus reducing the atmospheric carbon dioxide in Earth's atmosphere. The leaf fall of trees also acts as a stable and steady production zone for a fair amount of organic matter. Hence, high vegetational diversity in the *Barahnaja* mixed cropping system escalates the conversion of CO₂ to organic form and consequently reduce global warming (Misra et al. 2008).

Deriving innovations in the traditional mixed cropping system

Building architecture and soil health

Fertilizer application increases the crop yields but simultaneously decreases the soil health in terms of soil structure, availability of nutrients and microenvironment of soil due to excessive accumulation of chemicals. Crop rotation has been advocated globally to solve the increasing agroecological problems such as declining soil quality and climate change resulting from short rotation and monocropping (Liu et al. 2016). Crop rotation is also an ancient practice followed for thousands of years but received scientific attention recently. The synergistic combination of many crops belonging to different families having different root systems in *Barahnaja* mixed cropping system also maintain the soil health by maintaining the nutrients status of soil, promoting plant growth, development and avoiding indiscriminate use of chemical fertilizers. The selection of different crops, crop diversification and placement of crops in different terraces is the key to success in the *Barahnaja* mixed cropping system. The crops grown under this system have already gained momentum as climate-smart nutri-grains but much need to be studied as a whole system than individual crops.

Co-existence of different plants-microbes and resource partitioning

Coexistence of competing species are limited by most of the resources and the consumption of most limited resource is at higher rate than the other species which can be explained by prevailing models (Tilman 1982). Strong support for the mechanism of coexistence among aquatic organisms has been proved by the studies but limited evidences are found in support of terrestrial plants (Dybzinski and Tilman 2007; Miller et al. 2005; Schamp et al. 2008). A large portion of terrestrial N fixation is contributed by symbiotic N-fixing microbes and the uptake of phosphorus by most plant species is facilitated by mycorrhizal fungi (Vance 2001). Since these symbionts modify nutrient uptake, they will also modify the conditions for competitive coexistence, either positively or negatively. Different microbial symbionts associated with plant species provides resource partitioning and differential access to alternate forms of particular resources, which could contribute to plant species coexistence as in the case of mixed cropping systems (Reynolds et al. 2003).

Metagenomics for studying rhizosphere biology

The soils in which plants grow are inhabited by microbial communities, with one gram of soil approximately containing around 10^9 – 10^{10} microbial cells which comprise about one gigabase of sequence information (Janet 2011; Vogel et al. 2009). Within rhizosphere, microorganisms along with their products affect the roots in positive, negative and neutral ways (Morgan et al. 2005; Broeckling et al. 2008). The plant growth promoting rhizo-bacteria (PGPR) increase growth and productivity of plants through root system architecture modulation and increased shoot growth by production of phytohormones such as auxins and cytokinins. To study the interaction between microbes and plant root system it is imperative to explore the information of these microbes. But as about 99% of all the microbes cannot grow under laboratory conditions and can be studied in their natural habitat only. These microbes play significant roles in various processes such as bio-control agents, symbionts and in nitrification and composting etc. All these processes should be studied for understanding the rhizosphere and its interaction with plants. By studying the plant–microbe interaction in traditional mixed cropping system (*Barahnaja*), the hidden facts about this system can be revealed and explored for enhancing the crop productivity, maintaining the soil health for sustainable agriculture with least inputs of water, chemical fertilizers and other agrochemicals. Functional metagenomics strategies are being used to explore the interactions between plants and microbes through cultivation-independent study of these microbial communities (Charles 2010; Francoise and Ivan 2015). By allowing insights into the role of previously uncultured or rare community members in nutrient cycling and the promotion of plant growth, metagenomic approaches can contribute to improved disease management in crops and livestock, and to improve crop health by harnessing the relationship between microbes and plants. Comparative analyses between metagenomes can provide additional insight into the function of complex microbial communities and their role in host health (Ken et al. 2007).

Crosstalk of soil flora and fauna

Some of the most complex chemical, physical, and biological interactions experienced by plants are those that occur between roots and their surrounding environment of soil. Interactions involving plant roots in the rhizosphere include root–root, root–insect, and root–microbe interactions (Bais et al. 2006). Among all, the beneficial interactions play a significant role for proper development of plants as well as for maintaining soil fertility. In traditional mixed cropping system (*Barahnaja*), diverse microbiotic environment exists in soil which fulfills the nutritional requirements of the plants growing there. In the long term, if the microbiotic environment is not disturbed with the use of harmful chemicals or deep ploughing, the beneficial interactions between soil flora and fauna will help attain higher productivity in terms of biomass production, crop yields and quality. To decipher all possible factors involved in plant growth and development, interactions between soil microbiotic environment and roots need to be studied. All the possible microbial organisms in symbiotic relationship with plants and fungi need to be identified and characterized for their successful application in the fields. Recently, a bacteria, M6 have been identified to be associated with finger millet roots which provides anti-fungal activity against *Fusarium graminearum* (Mousa et al. 2016). This antifungal activity of bacteria from finger millet

roots is transferrable to major cereals where the fungus, *F. graminearum* cause serious damage.

In addition, the root exudates play significant role in facilitating different biological interactions for proper growth and development of plants. Root exudates contain various low and high molecular weight compounds which function as a signal molecule or chemotactic compound for the biological interactions of plant and plant roots with microbiotic environment of soil. Some of the compounds increase the conversion and absorption of microelements from rhizosphere to plant, influence the growth and development of plants. Such mechanisms can improve the quality and quantity of crop products. Unearthing these interactions in the traditional mixed cropping system (*Barahnaja*) will have wider applications. Moreover, identification of signaling molecules involved in plant defense, cell growth and nitrogen fixation can provide better understanding of regulatory genes and metabolic enzymes.

Gene regulation and metabolic networks to increase survival and productivity of plants

Like other organisms, plants too need the signaling process for communicating the information from cell to cell within the plant or from plant to environment. Some microbial infection such as *Agrobacterium tumefaciens* or *Ustilago maydis* can affect cell proliferation of shoot by the production of auxin and cytokinin which causes tumor growth or lateral roots and root hairs over-production which leads to modification of root system architecture and increases nutrient and water uptake. Advantageous or deleterious effects of microbial interaction may be decided by auxin-cytokinin ratio along with the site of accumulation in the plant (Lopez et al. 2007). Some additional bacterial signal molecules including N-acyl-L-homoserine lactones (AHLs) and volatile organic compounds (VOCs) have been found to play a role in plant morphogenetic processes. AHLs produced by gram (-ve) bacteria belong to a class of bacterial quorum sensing signals which enable bacterial cells to regulate gene expression as per their population density. It has been found very recently that AHLs identified by plants can alter gene expression in roots and shoots and modulate defense and cell growth responses. Similarly, certain PGPRs produce some volatiles such as acetoin and 2, 3-butanediol which can be used for plant-bacteria communication and as plant growth promoters (Fig. 4) (Castro et al. 2009). Modification in the signaling molecules or in the receptor molecules by gene alteration completely change the particular pathways involved in the metabolism of plant. As the chemotactic stimuli involved in nodule formation change the expression of regulatory genes and ultimately affect the process of N₂ fixation. Signaling molecules involved in the expression of such genes can provide better understanding of regulatory genes and enzymes involved in the metabolic pathway. It is a vast area of research and provides opportunity to dig in the *Barahnaja* mixed crop rhizospheric interactions for discovering new horizons in this field.

Rainfed crops and stress adaptation

Recent reviews have considered an impending global water crisis in the context of continued population growth and predicted climate change. These will curtail the ability of irrigated agriculture to respond to the expanding food requirements of a global population particularly those in the developing world (Cooper et al. 2006). Agriculture is a dominant area in sense of land usage. It faces new challenges which include the scarcity of water,

Fig. 4 Plant-bacteria communication to modulate root system architecture and interfere with bacterial quorum-sensing. Bacteria produces AHLs (N-Acetyl Homoserine Lactones) i.e. *a* N-octanoyl-HL *b* N-decanoyl-HL *c* N-3-oxodecanoyl-HL *d* N-dodecanoyl-HL, and Plant produces signal molecules i.e. *e* N-isobutyl decanamide *f* N-isobutyl-2E,6Z,8E-decatrienamide (Affinin) *g* N-ethanol decanamide. Plants alter their morphogenesis or activate defense and stress-related pathways to modulate growth in response to VOCs produced by microorganisms

land and other natural resources. Much emphasis is required to increase the productivity of global rain-fed agriculture, which currently provides 60% of the world's food. Improving agricultural water productivity, under rainfed or irrigated conditions, holds significant scope for addressing climate change vulnerability (Alemaw and Simalenga 2015). The adaptation capacity gets developed in the rainfed crops because of their evolution. They do so by producing osmo-protectants like proline which prevent plant from dehydration without affecting the metabolic processes. The crops grown in the traditional mixed cropping system (*Barahnaja*) have inherent drought tolerance and growing all of them together in system further improves the water and nutrient use efficiency. Importantly, some of the crops grown in the *Barahnaja* system, like minor millets and pseudo-cereals are suitable for low-input agriculture and exhibit high resistance to a variety of environmental stresses (Zhang et al. 2018). By studying the genes responsible for such adaptations, new crops or new varieties can be developed which can resist for adverse conditions and maintain the productivity (Sood et al. 2016, 2019).

Improved water and nutrient use efficiency

An increased crop water productivity (an increase in marketable crop yield per unit of water used by plant) and reduction in water losses from the crop root zone is required for improving WUE (water use efficiency) which is mainly associated with different

carboxylation pathways among crop species (Ludlow and Muchow 1990). Among the three groups of plants, CAM shows the highest WUE followed by C4 plants (having twice the WUE of C3 species) and C3 plants, respectively. Water use efficiency of crops can be improved by selection of crops according to cropping systems based on available water supplies and increasing seasonal evapo-transpiration (Prihar et al. 2000). In the traditional mixed cropping system (*Barahnaja*) crops are selected based on their stress tolerance and placed as per the availability of water in different fields. The deployment of crops in the system is designed to utilize nearly all the precipitation during the growing season (Ghosh and Dhyani 2004). The nutrient use efficiency is also given due importance while placement in different soils as per the fertility status. All the nutrients required for the growth and development of plants are taken from the soil only but as the nutrients are available in different forms in the soil therefore cannot be absorbed directly by plant. Instead, the nutritional elements are converted into easily available or in required forms so that the roots can uptake them easily and transport them to different parts of plants. Similarly, in the case of traditional mixed cropping system (*Barahnaja*) the nutrient requirement of one crop is fulfilled by others. The N-rich residues and exudates from the legumes add the nitrogen to the soil for use by other non-leguminous crops, such as cereals however, dead and decomposed remains of legumes supply nitrogen to the soil for a neighboring plant (Lindemann and Glover 1996). The amount of N₂ fixed by legumes is strongly linked to productivity as some grain legumes (peanuts, cowpeas, soybeans and faba-bean) are good nitrogen fixers (can fix up to 250 lbs of N/ acre) which facilitates most of the fixed N directly into the plant and prevent the nutrient loss through leaching followed by improved soil fertility and increased nutrient as well as water use efficiency. These nutrients play significant role in different metabolic processes and are also being stored in different forms within plant cells for further use, e.g. iron is stored in the form of 'Ferritin' protein. Some minerals are stored in the inorganic form such as borate, sulfate which can be consumed by human or animal for their diet. The nutritional quality of crops can also be increased if the bioavailability of these nutrients is more in plants. New metabolic pathways can be discovered by studying the various functions of these elements, transportation within different parts of plants, accumulation and their involvement in different processes which can be utilized for the betterment of crop variety in terms of quality and quantity of yield. Study of the interaction among mineral complexes and their absorption along with the metabolism of these elements make vast area of interest.

Natural fortification and functional foods

Both the cereals and pulses are co-cultivated together in this system and compensate the nutritional deficiency of essential amino acid of each other. Moreover, the crops grown in this system are nutritionally superior to major staple cereals grown today. Nowadays public awareness has increased tremendously and people are more concerned for their health. In such case scientific know-how and delineation of health promoting and nutritious compounds of the crops grown in the system will be profitable to the farmers. Recently, the term functional foods have been used for foods that promote health through prevention of specific degenerative diseases. Small millets, pseudo-cereals and traditional pulses are rich in fibre, vitamins, minerals, essential fatty acids, condensed tannins, polyphenols etc., which have protective effect against malnutrition and degenerative diseases. Being non-glutinous, millets are safe for people suffering from gluten allergy and celiac disease. They are also non-acid forming, and hence easy to digest. Epidemiologically lower incidence of

diabetes is reported in millet consuming populations (Saleh et al. 2013). Diets high in fibre and antioxidants have been shown to have beneficial effect on serum lipid profile and prevent some forms of cancer also (NAAS 2013).

Agro-biodiversity conservation

Genetic erosion is now so rapid that within 50 years, natural habitats will have little to offer plant breeders searching for genetic variability. The major driving forces behind genetic erosion in crops are variety replacement, land clearing, overexploitation of species, population pressure, environmental degradation, overgrazing, government policy, and changing agricultural and cropping systems. The main factor, however, is the change in farming trends as farmers replace their less productive but genetically diverse local traditional practices and crops with ‘improved’ and genetically uniform modern crop varieties and mono-culture practices. Many researchers believe that the main problem related to agro-ecosystem management is the general tendency towards genetic and ecological uniformity imposed by the development of modern agriculture. The widespread use of genetically uniform modern crop varieties has caused agricultural crops to lose about 75% of their genetic diversity in the last century. Industrialized agriculture favours genetic uniformity. Continuous monoculture, or mono-cropping, where the same species is grown year after year using expensive inputs such as irrigation, fertilizer and pesticides to maximize production, can lead to the quicker buildup of pests and diseases, and then rapid spread where a uniform crop becomes highly susceptible to the pathogen. The practice has been criticized for its environmental effects and for putting the food supply chain at risk. The quest for increasing food production and the ensuing success achieved in several crops has begun to replace not only landraces and traditional crop varieties, true-breeding cultivars but also affect long-established farming ecosystems. For thousands of years, farmers have used the genetic variation in wild and cultivated plants to develop their crops. Genetic diversity is the basic factor of evolution in species. It is the foundation of sustainability because it provides raw material for adaptation, evolution, and survival of species and individuals, especially under changed environmental, disease and social conditions (Hammer 2004), and it will allow them to respond to the challenges of the next century (Hammer et al. 1999). The value of genetic diversity to modern plant breeding is enormous which include not only cultivated species but also the genes from wild relatives. The erosion of crop genetic diversity poses a serious threat to food supplies. Without exploring the traditional cultivation system including local varieties and practices, modern agriculture would be seriously endangered. Diversity can be added both in time, as with a crop rotation or sequence, or in space, or with a mixed cropping system. The considerable genetic diversity of crops and varieties grown in traditional systems like *Barahnaja* is the most useful and economically valuable part of global biodiversity.

Source of important genomic resources

Crop genetic diversity is conserved in the regions known as “centers of diversity”, which mainly belong to the developing world. Himlayan region is also one of the biodiversity hot-spot in India and the farming communities still follow their traditional cultivation practices like *Barahnaja* by saving their own seeds. The local varieties and their wild relatives are the richest repositories of crop genetic diversity and source of important adaptation and stress related genes. The plant genetic resources grown in traditional system comprise an

inimitable universal heritage, and their conservation and utilization are of instantaneous concern. These crop plants are not only important from conservation point of view but also to get insights into their genetic backgrounds and important genes or alleles present in them favouring their sustenance in harsh conditions (Goron and Raizada 2015; Sood et al. 2016). Mining these genes could help understand these crops better and can be potentially utilized in other crops also (Table 3). Until recently, model plants such as *Arabidopsis* and rice were the focal point of research pertaining to studies on plant stress responses, while orphan crops like millets lagged far behind. However among millets foxtail millet, pearl millet, and to lesser extent finger millet have lately started gaining some importance among the research community wherein ‘omics’ have played an important role apart from conventional plant breeding. Large genome size and polyploidy in some cases hindered the basic goal to unravel the nutritional traits and abiotic stress tolerance mechanisms in these naturally stress tolerant crops, recent progress in this area has been significantly enhanced by the development of foxtail millet as a model system to investigate evolution, physiology and the genetics of stress tolerance as well as nutritional importance in millets. Foxtail millet has become the obvious choice for model millet crop owing to its small genome size, diploid nature ($2n=2x=18$), self pollination, short generation time and availability of efficient transformation platform (Lata et al. 2013). Powerful genetic and genomic tools such as isolation of expressed sequence tags (ESTs), genome sequencing, genetic and physical mapping, comparative mapping etc. have been thus established for the molecular genetic studies in millet crops (Dwivedi et al. 2012; Lata et al. 2013; Muthamilarasan and Prasad 2014; Sood et al. 2016; Babu et al. 2018). The foxtail millet genome sequence and the high degree of synteny between foxtail millet and switch grass (*Panicum virgatum*), a bio-energy crop have a potential to facilitate genetic and genomic studies in related Panicoid crops (Lata et al. 2013; Lata and Prasad 2013). Genetic maps and molecular markers also help in comparative mapping and synteny studies in crop plants, for example one of the recent studies have shown the synteny between pearl millet and foxtail millet chromosomes along with those of other grasses. However discovery of DNA markers and construction of genetic linkage maps in millets have lagged behind other cereal crops such as rice, wheat and maize (Dwivedi et al. 2012). Among millets, mainly foxtail millet, pearl millet, finger millet, job’s tear (*Coix lacrymajobi*) and tef (*Eragrotis tef*) have been investigated for development of genetic and genomic resources (Dwivedi et al. 2012; Sood et al. 2016; Babu et al. 2018). Similarly, pseudo-cereals like Buckwheat Amaranth and Chenopods, and under-utilized pulses have also witnessed good progress in identification of genomic resources for important traits in recent years (Joshi et al. 2018, 2019; Pattanayak et al. 2019; Yabe and Iwata 2020).

Conclusion

Barahnaja is one of the traditional systems in India promoting the idea of diversity to prosperity in Agriculture. Although advanced agriculture currently dominate the Indian food system, public awareness on the problems caused by this model has grown rapidly, building extensive support for sustainable agriculture, creating a robust market for agricultural produce, and inspiring formidable demand for agricultural policy and regulatory reforms. Sustainability works to support the transition to a traditional farming future by educating people about the benefits of traditional agriculture, and by adding present era scientific knowledge to help farmers use best practices for crop production. Growing variety

Table 3 Some of the quality and adaptation traits genes of *Barahraja* cropping system and other under-utilized crops

Sl no	Source	Target Gene/QTLs	Function	Target trait	References
1	Finger Millet	<i>Opaque 2 modifiers</i> <i>bZIP transcription factor RUSBZ1</i> Two-pore channel (<i>TPC1</i>), <i>Ca2+ATPase</i> , <i>Ca2+/H+</i> antiporter (<i>CAX1</i>), <i>CaM</i> , <i>CBL</i> , <i>CIPK</i> , and <i>CDPK</i> Prolamin-binding factor DNA binding with one finger only (<i>PBF Dof</i>) <i>EcNRAMP2</i> , <i>EcNRAMP6</i> , <i>EcPDR9</i> , and <i>EcZTP29</i> , <i>NAM</i> , mitochondrial 3-hydroxyisobutyrate dehydrogenase-like	Transcriptional regulation of lysine and tryptophan in endosperm Activator of seed storage proteins genes Uptake, translocation, and accumulation of calcium Nitrogen transport and mobilization in the plant Fe and Zn assimilation in finger millet under stress	Limiting amino acids lysine and tryptophan enhancement Protein content enhancement Calcium biofortification Nitrogen use efficiency Fe and Zn biofortification	Babu et al. (2014); Mbithi-Mwikya et al. (2000); Kemper et al. (1999); Goron and Raizada (2015) Babu et al. (2014); Tiwari et al. (2020) Sharma et al. (2017); Sood et al., 2016; Mirza et al. (2014); Singh et al. (2014) Gupta et al. (2013); Gupta et al., 2018 Chandra et al. (2020); Puranik et al. (2020)
2	Foxtail millet	<i>Granule-bound starch synthase 1</i> Phosphate1 transporter family genes (<i>PHT1</i>) Absciscic acid stress ripening gene (<i>ASR</i>), Late embryogenesis abundant protein (<i>LEA</i>), Dehydration-responsive element-binding protein 2 (<i>DREB2</i>), 12-oxophytodienoic acid reductase (<i>OPR1</i>), Nuclear factor- χ (<i>SIN1-YA1</i> , <i>SINFYB8</i>) genes, <i>SiOPRI</i>	Physicochemical properties of starch Phosphate transport and mobilization for nutrient use efficiency Tolerance to drought and oxidative stresses	Amylose content Phosphate mobilization Drought tolerance	Fukunaga et al. (2002); Bai et al. (2013) Ceaser (2019) Nadeem et al., (2020); Zhang et al. (2007)

Table 3 (continued)

Sl no	Source	Target Gene/QTLs	Function	Target trait	References
3	Quinoa	<i>Diaminopimelate aminotransferase, diaminopimelate epimerase</i> <i>Pyridoxal 5'-phosphate synthase, dihydrofolate synthase, tetrahydrofolate</i> Triterpene saponin biosynthesis activating regulator (<i>TSAR1</i> and <i>TSAR2</i>)	Amino acid lysine biosynthesis pathway Key enzymes involved in vitamin biosynthesis Triterpene Saponin Biosynthesis	Lysine content Vitamin B6 and vitamin E content Saponin content	Zou et al. (2017) Zou et al. (2017) Jarvis et al. (2017)
4	Amaranth	<i>Granule-bound starch synthase 1</i> <i>Cytochrome P450, 4,5-DOPA dioxygenase extradiol 1</i> <i>Aspartate kinase 1</i> and <i>dihydrodipicolinate synthase</i>	Physicochemical properties of starch Natural pigments for food, cosmetic and medicine industry Key enzymes of amino acid biosynthetic pathways	Amylose content Betalain content Lysine content	Brown et al. (2015) Lightfoot et al. (2017) Clouse et al. (2016)
5	Buckwheat	<i>Granule-bound starch synthase 1</i>	Physicochemical properties of starch	Amylose content	Yasui et al. (2016)

of crop plants, use of practices such as crop rotation, conservation tillage and sustainable farm management maintain biodiversity and foster the development and maintenance of healthy ecosystem. It is a high time now to reconsider and scientifically study the traditional mixed cropping system (*Barahnaja*) still prevalent in Himalayan region of India. This system could provide many scientific leads for rainfed agriculture, organic agriculture, product quality and bio-fortification, PGPRs, ecological and economical efficiency, biotic stresses resistance, water and nutrient use efficiency, important genetic and genomic resources for food and agriculture to combine traditional knowledge of diversity with modern techniques. Innovations in *Barahnaja* system are required not only to give input to the scientific community but also needed for the welfare of local population cultivating these crops, economically as well as nutritionally.

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Compliance with ethical standards

Conflict of interest Authors declare no conflict of interest.

Informed consent All the authors give the consent for publication of the article.

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