Food Security and Climate Change: Role of Plant Genetic Resources of Minor Millets

S Padulosi[1], Bhag Mal[2], S Bala Ravi[3], J Gowda[4], KTK Gowda[4], G Shanthakumar[5], N Yenagi[5] and M Dutta[6]

1 *Bioversity International, Maccarese (Rome), Italy*
2 *Bioversity International, New Delhi, India*
3 *M.S. Swaminathan Research Foundation, Chennai, India*
4 *University of Agricultural Sciences, Bangalore, India*
5 *University of Agricultural Sciences, Dharwad, India*
6 *G.B. Pant University of Agriculture & Technology, Hill Campus, Ranichauri, India*

Recent climate modeling findings regarding climate change in South Asia warn against the impact that predicted modifications in monsoon dynamics will create in the region by the end of this century, including fewer summer precipitations and longer breaks between rainy periods. Rice and wheat cultivation are expected to be affected in terms of cultivation patterns and yield reduction. Such a scenario calls for urgent and strategic interventions towards adaptive agricultural measures that while ensuring a continued food production to an ever growing population, will buffer populations against the threats of climate change. A great ally to that end is represented by the plant genetic resources of minor millets that are well suited to enhance resilience of local production systems and strengthen food and nutrition security, particularly among the rural poor. In case of India, the largest grower of minor millets in the world, the cultivation of these small-seeded millets, has declined steadily over the past few decades due to their lower economic competitiveness with major commodity cereals. Finger millet, *kodo* millet, foxtail millet, little millet, proso millet and barnyard millet, have a wide genetic adaptation and are able to grow successfully in diverse soils, varying rainfall regimes, diverse photoperiods and in marginal, arid and mountainous terrains where major cereals have low success. They have the potential to thrive with low inputs and can withstand severe edapho-climatic stresses, thus being the best candidates to replace commodities like wheat and rice in areas where such crops may gradually become less competitive due to climate change. These qualities are combined with excellent nutritional values and opportunities for strengthening income generation through value addition.

Key Words: Minor millets, Genetic resources, Climate change, Nutrition, Food security

Introduction

A study released by the Climate Change Research Centre of the Purdue University in the USA (Ashfaq *et al.* 2009) depicted a very worrying scenario of the effect that climate change may have in South Asia. The findings which were based on high resolution climate modeling projected a delay in the start of the monsoon season of up to 15 days by the end of the 21st century, accompanied by less summer precipitation and longer breaks between the rainy periods. Similarly, worrying results based on greenhouse gas concentrations emission trends published by the Indian Department for Environment Food and Rural Affairs (DEFRA, 2005a) warned against temperature increase of as much as 3-4ºC towards the same timeline in India. While further research is needed to sharpening spatial resolution for regional and local manifestations of these likely climate impacts, there seems to be increasing scientific evidence that agricultural production will be heavily affected in South Asia in the coming decades. Furthermore, it is speculated that an increase of only 2ºC will have consequences in terms of shifting of cultivation patterns and yield reduction of rice and wheat (DEFRA, 2005b), which are staple crops for more than one third of the world's population concentrated in this region. Governments need to act strategically now to implement adaptive agricultural programmes that while ensuring a continued and stable food production to an ever growing population in the region will mitigate predicted risks, enhance adaptive measures and resilience of production systems.

Neglected and underutilized crop genetic resources are very vital for sustainable agriculture (Eyzaguirre, *et al.*, 1999; Bhag Mal, 2007) and minor millets belong to this important group of crops (Dutta *et al*., 2007). Plant genetic resources play a critical role in enhancing adaptation and resilience of agricultural production systems (Jarvis *et al*., 2007). Lessons learnt from the Green Revolution indicate however that a broader spectrum of species including locally adapted species and landraces are needed to harness their livelihood potential to cope with rainfall, marginal soils and other biotic and abiotic stresses (Martini-Bettolo, 1988; Qualset, *et al*., 1995;

Thrupp, 1998; Toledo and Burlingame, 2006; Burke, *et al*., 2009). The Indian sub-continent is endowed with a great wealth of agrobiodiversity which can be better mobilized to take up this challenge. Although a large number of plants are in cultivation in India, official statistics regarding food grain production report however an over-reliance of the country on just two crops, rice and wheat. Out of 124.4 million ha area under food grains during 2007-08, the area under rice and wheat was 71.9 million ha which accounted for the major share (57.8%). Similarly, out of total annual food grain production of 230.7 million tonnes during the same period, rice and wheat contributed 174.8 million tonnes representing the largest share of 75.8% (MoA, 2008). Many other native species holding comparative advantages in our quest for strengthening food and nutrition security in South Asia in a climate changing scenario need to be better appreciated, enhanced and promoted. One such group of highly promising crops is that of minor millets. In India, this group is represented by six species, namely, finger millet [*Eleusine coracana* (L.) Gaertner], *kodo* millet (*Paspalum scrobiculatum* L.), foxtail millet [*Setaria italica* (L).Pal], little millet (*Panicum sumatrense* Roth ex Roemer & Schultes), proso millet (*Panicum miliaceum* L.) and barnyard millet (represented by two species, *viz.*, *Echinochloa crusgalli* and *E. colona* (L.) Link, latter domesticated in India) (Fig. 1).

The cultivation of minor millets in India has been steadily declining over the last few decades because of their lower economic competitiveness compared with major cereals and more recently with the horticultural crops. Such lower competitiveness is resulting from a variety of factors, including the lack of higher yielding varieties, good quality seed, better cultivation practices, proper food processing technology for households and communities, as well as poor value chains (GFU, 2007; Gautam *et al*., 2009; Gruère *et al*., 2009). These limitations need to be tackled so as to allow economically viable perspectives to farmers in areas where wheat and rice may gradually recede due to climate change, and minor millets may offer a better alternative. Minor millets have also excellent nutritional value in view of their good protein content and better amino acid profile. Their starch composition and low glycemic index (which make them ideal for diabetic patients) are also accompanied by gluten-free status of the flour, thus making them very suitable for the preparation of weaning products.

This paper showcases the importance of minor millet genetic resources and the methods, tools and approaches developed in the context of an international effort spearheaded by Bioversity International and the M.S. Swaminathan Research Foundation in India, and calls for a more supportive policy environment to upscale experiences and good practices to promote minor millets in India and elsewhere in the South Asian region.

2.0 Area, Production and Productivity in India

Within India, the genetic resources of minor millets are represented by six cultivated species. Little millet is reported to be originated in Southeast Asia or India. The Indian barnyard millet (*E. colona*) and *kodo* millet have also Indian origin (de Wet, 1983); the other species of barnyard millet (*E. crusgalli)* is considered to have Japanese origin. Proso millet has central or eastern Asian origin (Anonymous, 1966), whereas foxtail millet is considered to have originated in eastern Asia, probably China (Anonymous, 1972). The origin of finger millet is traced to Uganda and its neighborhood in Africa (Anonymous, 1953), while India is considered as a secondary centre of its genetic diversity. Finger millet's domestication has been traced back to 5,000 years ago in Ethiopia (Hilu, 1977). In India, minor millets are cultivated mainly as rainfed crops and occupy an area of about 2.7 million ha which is about 12% of the whole area under coarse cereals in the country (Seetharam, 2006). Their cultivation extends from the sea level in costal Andhra Pradesh to 2,400 msl in the mountains of Uttarakhand and covers a broad range of eco-geographic conditions, diverse soils, varying rainfall regimes and areas widely differing in thermo and photo periods as a reflection of their wide genetic adaptability (Table 1). With regard to their distribution within the country, *kodo* millet, little millet and foxtail millet are more popular in Madhya Pradesh, Chattisgarh, Orissa, Tamil Nadu, Jharkhand, Karnataka, Andhra Pradesh and Maharashtra States. Madhya Pradesh is the most important state for *kodo* millet and little millet cultivation. Barnyard millet and proso millet are grown in Uttarakhand, Northeast region, Western Uttar Pradesh, Bihar and Maharashtra. The most popular minor millet across India is finger millet (*ragi*), cultivated over nearly 1.6 million ha, with an annual production of 2.4 million tonnes and a productivity of approximately 1,534 kg/ha (Government of India, 2009). In contrast, the remaining area under other minor millets (1.1 million ha) has a production of 0.7 million tonnes and a productivity of around 635 kg/ha. The area under minor millets cultivation in India has significantly decreased since the 1950s (Table 2). However, while production of finger millet has been increasing due to enhanced productivity except for the period 2001-2005, the

Finger millet (*Eleusine coracana* (L.) Gaertner)

Barnyard millet (*Echinochloa colona* L.)

Little millet (*Panicum sumatrense* Roth ex Roemer & Schultes)

Foxtail millet (*Setaria italica* (L.) Pal)

Proso millet (*Panicum miliaceum* L.)

Kodo millet (*Paspalum scrobiculatum* L.)

Fig. 1: Minor millets species cultivated in India

Table 1. Cultivation and ecogeographic distribution of minor millets in India

Common name	Other names	Popular name in India	Latin name	Climate	Max altitude, msl	Maturity (days from sowing to maturity)	Top producing state area ('000 ha); production ('000 t)	Average productivity in India (kg/ha)
Finger millet	African millet	*Ragi, Mandua, Marua Nagli*	*Eleusine coracana*	Wide adaptation	2,300	90-130	Karnataka (606.0; 816.0)	1,226
Foxtail or Italian millet	Italian millet	*Kangni, Kauni, Korra, Tenai, Navane*	*Setaria italica*	Temperate	2,000	70-120	Karnataka (34.7; 16.7)	565
Kodo millet	Kodra millet	*Kodo, Varagu, Haraka, Arikalu*	*Paspalum scrobiculatum*	Tropic/ Sub-tropic	1,800	120-180	Madhya Pradesh (152.5; 41.2)	312
Barnyard millet*	Japanese millet	*Sanwa, Samai Jhangora, Mdira, Oodalu Sanwak*	*Echinochloa colona E. frumentacea*	Wide adaptation	>2,000	45-60	Uttarakhand (74.0; 87.0)	857
Little millet	–	*Kutki Sawa Samai Samalu*	*Panicum sumatrense*	Tropic/ Sub-tropic	2,100	70-110	Madhya Pradesh (112.5; 24.8)	349
Proso millet	Common millet, Hog millet	*Cheena, Varagalu Pannivaragu Variga Baragu*	*Panicum miliaceum*	Wide adaptation	3,500	60-90	Maharashtra (28.2; 7.1)	323

* There are two species of barnyard millet, *Echinochloa colona* and *E. crusgalli*

production of other minor millets has constantly been dropping. The areas cultivated with minor millets are characterized by poor agroecosystems and largely inhabited by socio-economically fragile, very traditional farming communities (large sections of whom fall below the poverty line (DRDA, 2008; Gruère, 2007). The production systems followed for their cultivation are generally marginal, based mainly on locally available seeds, with minimum or no external inputs or often under default organic farming conditions. Most commonly, they are grown only in one season coinciding with the main monsoon season (June-November). For this reason, they are predominantly grown as mixed or intercrop along with fodder-yielding crops like maize and sorghum, high value crops such as grain legumes (pigeonpea, green gram or black gram) or oilseed crops (mustard or niger).

Table 2. Mean area, production and productivity of finger millet and other small millets (1951-2008)

Year	Finger millet			Other small millets		
	Area ('000 ha)	Production ('000 t)	Productivity (kg/ha)	Area ('000 ha)	Production ('000 t)	Productivity (kg/ha)
1951-55	2246	1520	678	5189	2143	411
1956-60	2414	1874	778	5096	1976	389
1961-65	2519	1991	791	4755	1960	413
1966-70	2465	1721	703	4697	1697	361
1971-75	2409	1975	820	4609	1747	379
1976-80	2609	2726	1042	4465	1813	385
1981-85	2499	2593	1036	3623	1462	403
1986-90	2346	2544	1084	2890	1219	423
1991-95	2015	2542	1267	2077	954	457
1996-00	1826	2586	1420	1490	658	441
2001-05	1630	2098	1276	1078	490	459
2006-08	1593	2443	1534	1107	700	635

Source: Govt. of India, 2009

The decline of minor millets cultivation can be ascribed to a number of reasons related to agronomic aspects (lack of suitable improved varieties, lack of improved cultivation practices); socioeconomic aspects (low economic competiveness; lack of more attractive and modern food recipes; lack of specific post-harvest and processing technologies for small users; poor capacities at both household and market level; poorly organized or non existent value chains; insufficient awareness of nutritional value and income opportunities, and policy aspects (lack of enabling policies to support their cultivation and use as in case of major cereals).

Today, among minor millets, finger millet has received better R & D inputs in terms of agronomy and improved varieties. About 86 improved varieties of finger millet have been released during 1935-2008 with seed production

system available for a few of these varieties. These crops are virtually free from insect-pests in the field, while they are affected by a few major diseases. Plant protection measures, which are seldom used by farmers, can contribute to productivity increase by minimizing the disease-induced yield losses.

3.0 Genetic Resources of Minor Millets, their Conservation and Use

Millets are among the oldest cultivated crops in the world (Chang, 1968; National Research Council, 1996; Lu *et al*., 2009) and cultivated over more than 35.8 million ha around the world as per estimates for 2007 (FAO, 2009). They are generally referred to as 'coarse' cereals and this term is highly misleading in view of their nutritional profile and strategic importance to the livelihood of millions of people (Bala Ravi, 2004). Millets comprise two main groups of species, major millets (sorghum and pearl millet) on the one end and minor millets (characterized by small seeds and represented by wild, semi-domesticated and cultivated species) on the other. Minor millets constitute a very heterogeneous group and include also species such as teff [*Eragrostis tef* (Zucc.)Trotter], which is a very popular crop in Ethiopia and not essentially minor in the sense of its utilization. It is used to prepare '*injera*', a main cereal-based meal of that country (Costanza *et al*., 1979). 'Kreb' presents an opposite state, where the crop is a mixture of mostly wild and cultivated species (like fonio, *Digitaria exilis*) used traditionally in the Sahel by pastoralists, who harvest these seeds from the open grasslands and manage the wild species to ensure a sustainable seed production for human consumption as well as fodder, which is a highly strategic product in these harsh environments (Burkill, 1994). Wild barnyard millet (*Echinochloa colona*) that is commonly found in rice fields is harvested for food during drought years in many states of India.

Many cultivated and wild species of finger millet exist. However, *Eleusine coracana* and *E. africana* are most commonly used species in varietal developmental programmes. The cultivated *E. coracana* is a tetraploid species (2n=4x=36) and has morphological similarity to both *E. indica* (L.) Gaertn (2n=18) and *E. africana* (2n=36). The cytological evidences indicate that *E. indica* has contributed one of the genomes (AA) to the cultivated *E. coracana* (AABB). Both the tetraploids, *E. africana* and *E. coracana* are closely related and the gene flow occurring between them in nature suggests that *E. coracana*, possibly originated from *E. africana* through selection (Hilu, 1977). The very small size of the spikelets makes artificial hybridization very difficult in minor millets.

3.1 Current Status of Conservation of Minor Millet Genetic Resources

With regard to the conservation of the genetic resources of minor millets, the largest *ex situ* collection at international level is maintained by the Consultative Group on International Agricultural Research (CGIAR). These collections hold 46,231 accessions (Table 3) and 16.7% of them has been duplicated and deposited with the Global Crop Diversity Trust for safe storage at the Svalbard Gene Bank in Norway. The largest CGIAR collection is being held at ICRISAT (10,193 accessions). India holds the largest national collection at the National Bureau of Plant Genetic Resources (21,226 accessions) in New Delhi. A working collection of 13,296 accessions is being maintained by the All India Coordinated Small Millet Improvement Project at the University of Agricultural Sciences, Bangalore (Karnataka). Minor millets germplasm collections are also maintained at the N.I. Vavilov Research Institute of Plant Industry (VIR) in Russia and at CIRAD, France.

Very scarce information is available with regard to *in situ*/on-farm conservation of minor millets. On-farm conservation is a dynamic process, because varieties managed by the farmers continue to evolve in response to natural and human selection leading to crop populations with better adaptive potential for the future (Brush, 2000). This is particularly relevant in the context of climate change.

Table 3. Number of accessions of minor millets in main *ex situ* genebanks around the world[1]

Crop	CGIAR genebanks[2]	ICRISAT genebank[3] (India)	NBPGR genebank[5] (India)	Svalbard genebank[4] (Norway)	Total
Finger millet	22,766	5,949	10,334	5,379	44,428
Foxtail millet	9,494	1,535	4,473	1,442	16,944
Proso & little millet	9,188	1308	2,428	730	13,654
Kodo millet	2,418	658	2,273	108	5,457
Banyard millet	2,365	743	1,718	44	4,870
Total	46,231	10,193	21,226	7,703	85,353

[1]Gowda and Seetharam, 2007; [2]CGIAR, 2006; [3]ICRISAT, 2009; [4]SGSV, 2009; [5]Radhamani, 2009.

In addition, on-farm conservation alone can safeguard and enrich indigenous knowledge (IK) and cultural traditions associated with genetic diversity, which are as critical as the genetic diversity itself and for its sustainable use. The loss of cultural diversity and IK affects the self-esteem and visibility of local community members, in particular women, who have been generously safeguarding and transmitting knowledge over generations and for whom these represent important assets of their own food culture and identity (Thies, 2000; Williams and Haq, 2002; Sajise, 2003). The lack of information on geographic distribution of on-farm conserved minor millets is a common feature to many other neglected and underutilized species (Padulosi *et al.*, 1999). This situation should receive high attention by the international and national community in view of the on-going genetic and cultural erosion and climate change scenarios which call for urgent mapping out of local plant genetic resources so as to better mobilize their comparative advantages in risk copying measures.

3.2 Relevance of Minor Millets to Climate Change and People's Livelihood

A strategic feature in minor millets with regard to climate change is their short biological cycle, a trait important for risk avoidance under rainfed farming. They also have a root system efficient in water extraction from soil under drought situation. They have a comparative advantage of successful cultivation with scarce water/low rainfall as against high water requirement of rice and wheat and thus India needs to bring back these forgotten crops because of dwindling water resource. Their ability to offer a modest yield under marginal farming conditions, poor soil and low or no input, has made them attractive crop option in mountain, hill and tribal agriculture. This adaptive feature is particularly pronounced in barnyard millet (Table 1) which is the fastest growing of all millets, produces a crop in six weeks and considered most resilient species among minor millets. It is a favoured millet providing food, feed and fodder under harsh growing conditions of low rainfall and steep mountain slopes. The deployment of plant genetic resources in risk copying strategies has been practiced by farmers for centuries in their traditional production systems. With regard to the use of minor millets in these strategies, an interesting example is provided by the '*Akdi'* system, a traditional mix-cropping system still in use in some parts of the Karnataka state. Under this system, minor millets are mixed with maize, sorghum, chickpea, pigeonpea, lablab bean, mustard and niger to build-up a crop package, which may buffer against possible failure of major crops due to erratic rainfall, pests or diseases attacks. A similar system called '*Barahnaja'* (literally, a "*dozen types of crops"* or grains), is still prevalent among the farmers in the Himalayan region in the Uttarakhand state.

From a more general livelihood perspective, minor millets offer numerous advantages when compared with major cereals. These include: 1) Ecological advantages e.g. suitable to organic agriculture practices, eco-friendly nature; 2) Agronomic advantages e.g. highly adapted to low rainfall conditions, able to withstand fairly long dry spells, recover fast after delayed rain, root system efficient in soil moisture extraction, sustainable but modest yield under low management conditions in marginal areas, negligible pest and disease problems; 3) Socio-economic advantages such as very rich food cultural traditions, comparatively cheaper grains, hence more accessible to the poor, longer storability of grain, seeds known for their long shelf life, good quality fodder, which is highly valued in dry land livestock production, strategic role in local food systems, particularly in hilly, mountainous regions characterized by low and erratic rain fall, income generating opportunities for marginalized groups of society including women through value addition interventions; and 4) Nutritional and neutraceutical superior quality and functional food properties e.g. the data (Table 4) show their comparatively very good nutritional profile in protein and amino acids, Vitamin A, minerals and fibre. It has strategic value for addressing hidden hunger among the poor people, nourishing the weaning and lactating women, offering neutraceutical and functional food benefits to diabetic people due to its low glycemic index.

4.0 Status of Minor Millets Research and On-going Efforts in India

With a view at enhancing the sustainable conservation and use of minor millets in India, a major UN project was initiated in 2001 through a community-based, multi-stakeholder and inter-disciplinary action framework (Padulosi, 2007). The Project supported by the International Fund for Agricultural Development (IFAD) currently in its second phase of implementation is being carried out at different Indian locations in Southern, Eastern and Northern regions, chosen as representative of different agro-ecological, economic, ethnic and cultural conditions. They represent marginal agricultural lands with scarce rainfall in the Deccan plateau, hilly rainfed regions in the

Table 4. Nutrient composition of small millets and other cereals (per 100 g edible portion; 12% moisture)**

Food	Protein* (g)	Fat (g)	Ash (g)	Crude fibre (g)	Carbohy-drate (g)	Energy (kcal)	Ca (mg)	Fe (mg)	Thiamin (mg)	Riboflavin (mg)	Niacin (mg)
Rice (brown)	7.9	2.7	1.3	1.0	76.0	362	33	1.8	0.41	0.04	4.3
Wheat	11.6	2.0	1.6	2.0	71.0	348	30	3.5	0.41	0.1	5.1
Maize	9.2	4.6	1.2	2.8	73.0	358	26	2.7	0.38	0.2	3.6
Sorghum	10.4	3.1	1.6	2.0	70.7	329	25	5.4	0.38	0.15	4.3
Pearl millet	11.8	4.8	2.2	2.3	67.0	363	42	11.0	0.38	0.21	2.8
Finger millet	7.7	1.5	2.6	3.6	72.6	336	350	3.9	0.42	0.19	1.1
Foxtail millet	11.2	4.0	3.3	6.7	63.2	351	31	2.8	0.59	0.11	3.2
Proso millet	12.5	3.5	3.1	5.2	63.8	354	8	2.9	0.41	0.28	4.5
Little millet	9.7	5.2	5.4	7.6	60.9	329	17	9.3	0.3	0.09	3.2
Barnyard millet	11.0	3.9	4.5	13.6	55.0	300	22	18.6	0.33	0.10	4.2
Kodo millet	9.8	3.6	3.3	5.2	66.6	353	35	1.7	0.15	0.09	2.0

* N X 6.25

** Source: Hulse *et al.,* 1980; United States National Research Council/National Academy of Sciences, 1982; USDA/HNIS, 1984

Eastern Ghats and the highly fragile, subtropical to temperate Himalayan mountains. The project is being implemented as a whole in 31 villages spread across four states, *viz.*, Tamil Nadu, Orissa, Karnataka and Uttarakhand and is estimated to influence, directly or indirectly, some 753 households. It is coordinated by Bioversity International through the M.S. Swaminathan Research Foundation (MSSRF), Chennai and implemented by the MSSRF, the University of Agricultural Sciences (UAS), Bangalore, UAS, Dharwad, G.B. Pant University of Agriculture and Technology (GBPUAT), Hill Campus, Ranichauri and the Central Food Technology Research Institute (CFTRI), Mysore. Activities cover a wide spectrum of research focus areas addressing bottlenecks along the whole value chain of the minor millets, from lack of characterization and improved varieties; lack of quality seeds, poor knowledge about cultivation practices, nutrition and value addition technology to disorganized markets and absence of marketing strategies. Efforts are highly interlinked internally and with cross-cutting themes such as germplasm conservation, capacity building, policies and public awareness (Padulosi, 2007; Padulosi, 2009; Rojas *et al.*, 2009). The impact pathway of the project in which plant genetic resources play a critical role is provided in Figure 2.

4.1 Genetic Diversity, Variety Selection, Quality Seed Production and Cultivation Practices

The on-farm conservation of local varieties is being pursued through a blend of *ex situ* (e.g. maintenance of local varieties at the MSSRF Community Gene Bank in Chennai) and on-farm conservation methods (e.g. dissemination of the "village gene-seed-grain bank" approach of MSSRF). Example of the genetic diversity surveyed, documented and sampled in Kolli Hills is provided in Figure 3 and Table 5 and that in Kundra (Orissa) in Table 6. Locally available varieties as well as other 6,000 accessions (landraces and/or improved varieties) obtained from ICRISAT, Pattencheru (Andhra Pradesh), the All India Coordinated Small Millet Improvement Project at UAS, Bangalore and other institutions in India were deployed in the initial farmer participatory variety selection (Joshi and Witcombe 1996) carried out at Kolli Hills (Tamil Nadu) and Jeypore, (Orissa) during 2002-2004. On elimination of several low yielding exotic and photosensitive accessions, the initial selection short listed 180 accessions. During the second selection cycle, 33 promising varieties (14 finger millet, 11 little millet, 8 foxtail millet) at Jeypore and 29 varieties (9 finger millet, 9 little millet and 11 foxtail millet) at Kolli Hills were identified by farmers as the best accessions. During the

Table 5. Local varieties of minor millets sampled during the survey by MSSRF at Kolli Hills (Tamil Nadu) in 2004

Species	No.	Local name of varieties
Little millet	8	Vellaperumsamai, Malliasamai, Sadansamai, Kattavettisamai, Karunsamai, Thirikulasamai, Perunsamai, Kottapattisamai
Italian millet	7	Perunthinai, Sentinai, Palanthinai, Killanthinai Koranthinai, Karunthinai, Mosakkanthinai
Finger millet	6	Karakelvaragu, Arisikelvaragu, Krunmulian Kelvaragu, Sattaikelvaragu, Perunkelvaragu, Sundangi Kelvaragu
Kodo millet	1	Thirivaragu

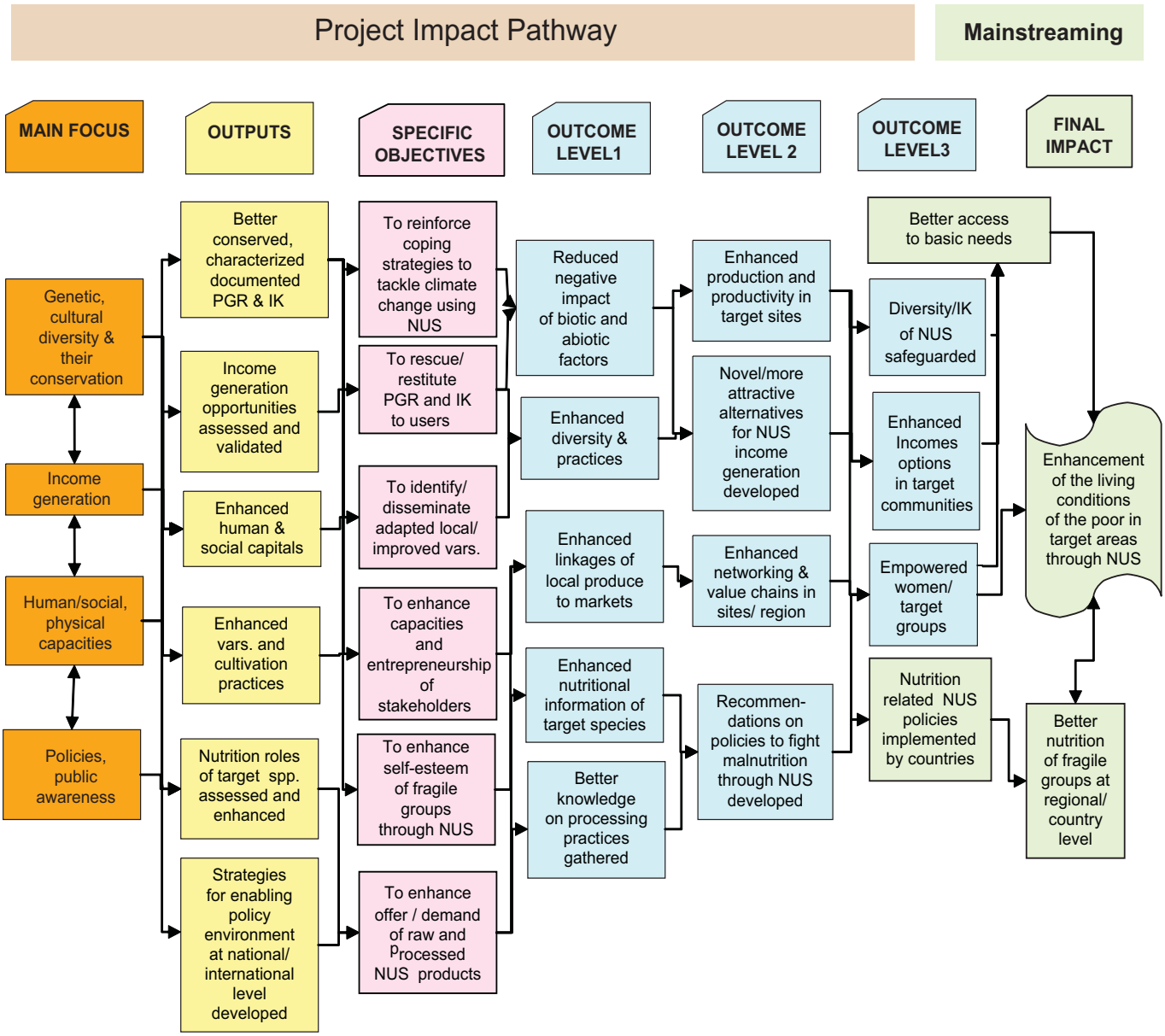

Fig. 2: Scheme of the IFAD NUS Project impact pathway and ultimate impact due to mainstreaming of project results

third cycle of selection, based on farmers' choice and critical agronomic data, three highest ranking varieties in each of these millets were identified (Table 7). It is interesting to note that while the Kolli Hills farmers preferred varieties with mid-early or medium maturity range, the Jeypore farmers by and large preferred late maturing varieties in finger millet, which was consistent with the rainfall pattern and distribution at these locations. These selection processes helped to confirm the agronomic superiority of some of the locally adapted farmer varieties in comparison with their improved counterparts as well as identification of some improved varieties superior to local varieties. It also helped farmers to identify a rarely available white-grained variety of finger millet, which they prefer for the production of certain recipes. Similar selections in little millet, foxtail millet and finger millet were carried out by the UAS, Bangalore and UAS, Dharwad in Kolar, Haveri and Bellary districts (Karnataka state) using local varieties and five improved varieties adapted to the respective regions (Table 8).

In addition to introducing improved varieties into millet production systems, the project focused also on

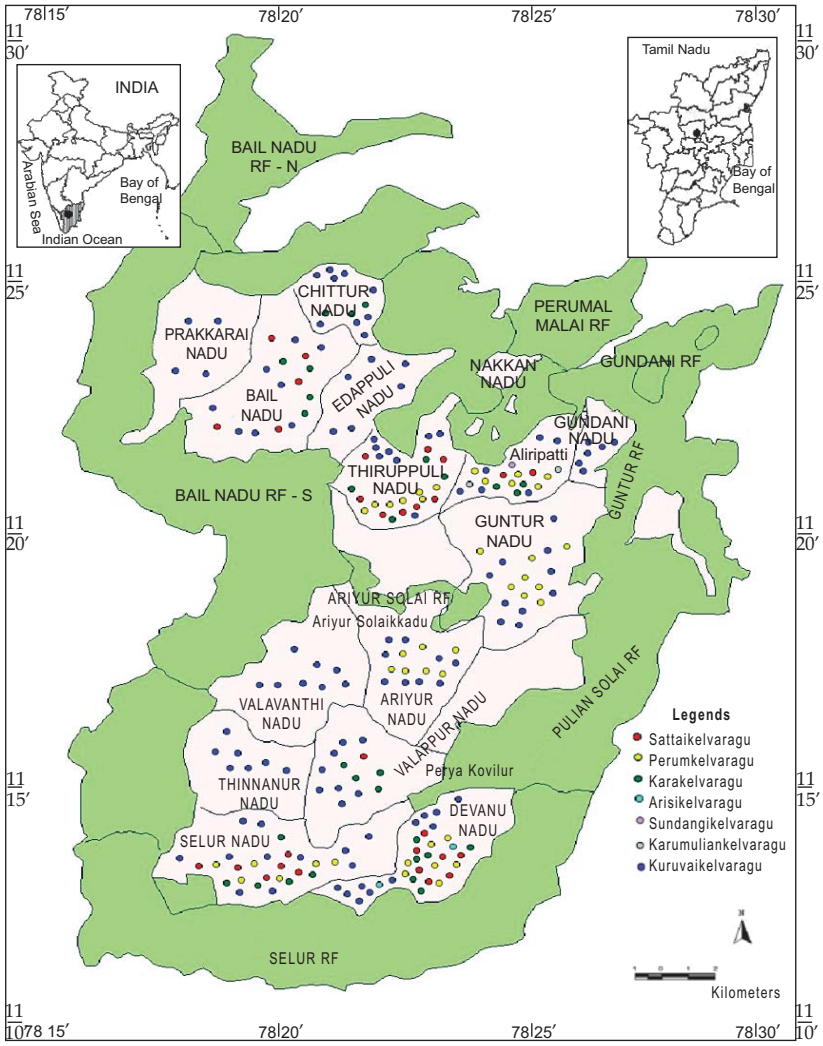

Fig. 3: Distribution of finger millet landraces in Kolli Hills (Tamil Nadu)

Table 6. Local varieties of little millet sampled during the survey by MSSRF at Kundra (Orissa) in 2004 and their main features as recorded during farmers' interviews

Variety name	Main features
Baunsha ganthi Mandia	Short duration variety
Sana Mandia	Sana means short- Short duration variety
Dashera Mandia	Medium duration variety, which matures during Dashera festival time falling in September-October
Janha Mandia	Jahna means maize-Variety preferred to intercrop with maize
Biri Mandia	Biri means black gram-Variety preferred for mixed crop with black gram
Bada Mandia	Bada means long-Long duration variety
Athangula Mandia	Variety with head having eight fingers
Dashera Suva	Little millet maturing during a festival falling in September-October
Dashera Kala Suva	Black colored version of Dashera suva

ways to improve agronomic practices, such as optimizing seed rates and sowing times, seeding in rows instead of broadcast method, using need-based proportions of crop components in appropriately chosen row ratios and application of farm-yard manure and fertilizers, the latter on farmers' option. The finger millet-based intercropping system normally followed in Kolli Hills used a crop choice of finger millet, little or Italian millet, rapeseed mustard and pigeonpea, while in Jeypore, finger millet-based intercropping included little millet, pigeonpea and black gram or green gram with niger as a border crop. Cost-benefit analyses for cultivation practices were also conducted. Costs of cultivation using farmers' practices and improved practices varied across farmers and field sites. In 2004, for example, the cultivation cost of intercrop system according to farmers' practice varied from

Table 7. Varieties chosen by participatory selection and their critical agronomic data

Rank	JEYPORE					KOLLI HILLS				
	Variety selected	Days to flower	Grain yield kg/ha	Fodder yield kg/ha	Grain colour	Variety selected	Days to flower	Grain yield kg/ha	Fodder yield kg/ha	Grain colour*
Italian Millet										
1	Bada Kangu (Local)	88	1,149	7,472	Lt Y	Senthinai (Local)	61	833	4,668	R
2	ISE-809	53	932	6,639	Lt Y	ISE-38	61	775	4,625	Y
3	ISE-1269	53	1,051	5,694	Lt Y	TNAU-173	61	907	4,458	Y
Little Millet										
1	OLM-203	99	1,283	3,037	Lt Y	IMPR-393	55	695	3,375	Lt gr
2	Kalakosla (Local)	109	1,144	3,759	Br	Kattavetti Samai (Local)	113	715	3,400	D Gr
3	IMPR-393	71	950	2,250	Br	Sukshema	64	650	3,293	Gr
Finger Millet										
1	GPU 49	82	2,632	6,046	Lt Br	IE-2863	87	1205	4,875	Lt Br
2	Athangulia Mandia (Local)	90	2,429	6,139	R	GPU-49 VHC3880	64 57	1225 793	4,093 3,743	Lt Br Pl Br
3	IE-3093	86	1,727	4,694	Lt R	IE-3023	87	763	2,968	Pl Wh

* Y-yellow; Lt Y- light yellow; Gr-grey; D Gr-dark grey; Lt Br-light brown; Pl Br-pale brown; Wh-white; Lt R-light red; R- red

Rs. 3,090/acre ($64.4 @ 1$ = Rs. 48, August 2009) in Kolli Hills to Rs. 7507/acre ($156.4) in Jeypore. Based on the demonstration trials on farmers fields, the application of supplementary doses of fertilizers to little millet and finger millet was found to enhance productivity significantly. Among the cropping systems, growing six rows of little millet or finger millet or foxtail millet with two rows of pigeonpea proved to be more productive and profitable. Data gathered from 198 field demonstrations carried out in 2003-2004 revealed that use of improved cultivation practices contributed to an increase of 39.8-62.8% in grain yield and 34.1-47.3% in fodder yield over traditional practices. Additional 41 field demonstrations of little millet in Haveri district during 2008 revealed 41% increased mean grain yield (3.98 q/acre) for the improved variety over the local variety.

Table 8. Results of participatory variety selection in Kollar, Haveri and Bellary districts (Karnataka)

Species	Best performing varieties selected	Grain yield (q/ha)	Increase over local variety (%)
Little millet	Sukshema	10.30	73.7
	TNAU 98	8.88	49.7
	OLM 20	8.32	40.3
	PRC 3	7.58	27.8
	Co 2	7.58	27.8
	Local variety	5.93	
Foxtail millet	HMT 100-1	15.35	36.4
	Krishnadevaraya	13.73	22.0
	TNAU 173	13.50	20.0
	Narasimharaya	13.15	16.9
	RS 118	12.46	10.7
	Local	11.25	
Finger millet	GPU 28	20.52	49.6
	L 5	19.90	45.0
	GPU 26	16.42	19.7
	MR 1	15.22	10.9
	Indaf 9	14.30	4.2
	Local	13.72	

Quality seed is an important component in yield enhancement and therefore the project placed considerable emphasis on quality seed production as well as on training farmers in scientific methods for quality seed production, variety identity maintenance and safe seed storage. Training efforts were thus directed towards variety characterization, purification and seed handling during harvest, threshing, drying and storage. Farmers were encouraged to produce quality seeds of local and selected varieties and share with others. Seed banks were deployed to provide seed loans to farmers lacking resources to buy seeds. As a result of these activities, the area grown under quality seeds progressively increased during the project timeframe and doubled in few project locations. The spread of quality seeds also helped in disseminating improved agronomic practices demonstrated by the project.

4.2 Processing, Value Addition, Product Development and Marketing

The local acceptability and high nutritional quality of all millets species make them good candidates for food product development. While the crispy texture of foxtail millet rendered it very suitable for making biscuit and fried products (Yenagi *et al*., 2004), the soft, non-sticky starch

consistency of finger millet is found good to make '*halwa'* and the light and puffy characteristics of little millet have the advantage to make fermented ethnic products like '*idli*' and '*dosa*'. These grains in combination with other cereals and pulses offered to develop a wide range of novel and attractive recipes widely acceptable to both the rural and urban populations. Natural storage stability of some of these products at room temperature was found satisfactory for about two months.

Hundreds of community members, particularly belonging to women Self Help Groups (SHGs), were trained in preparing value-added products, focusing particularly on those recipes that commanded higher local acceptability and demand. Products like finger millet '*laddu'* (an ethnic badminton ball sized sweet preparation), *'chakkli'* (an extruded coiled product fried crisp in oil), finger millet malt, finger millet flour and 'rice' of little and Italian millet were found marketable at Kolli Hills and Jeypore. In addition, SHGs made a few specific products from flaked little millet and semolina-like mixes. Among these, malt, '*chakkli'* and 'rice' of little and Italian millet are found to be the products most fast moving in the market. The other important value-added products being developed and locally marketed are *papadams*, millet cakes, pancakes, sweet powder mixes and hand pounded little millet rice. A detailed cost-benefit analysis of value-added product development showed that the highest benefit comes from malt and little and Italian millet 'rice' followed by '*laddu*' and '*chakkli'* and the lowest benefit is from finger millet flour. The market potential for malt, little millet rice and Italian millet rice is large in India in view of their importance in weaning and health foods.

On an average, a tonne of fast-moving, value-added nutritious millet products offered net income ranging from Rs. 15,000 – 45,250 ($312.5 – 942.7 @ 1$ = Rs. 48) from every tonne of grain. The value addition, in addition to enhanced income, also generated additional employment, particularly for women to the tune of 140-300 person days per every tonne of value added grain.

Nutritious millets can play an important role in the development of healthy bakery products. A study in this direction was conducted at UAS, Dharwad for enriching the nutritional quality of biscuits by blending 25%, 50%, 75% flour of finger millet, foxtail and little millet with wheat flour and using 100% of these millet flours. It is found that biscuits made from 100% finger millet flour had an astringent taste while there was very good spreading quality and breaking strength. Biscuits developed from 100% foxtail millet flour were very tasty with good spreading quality and a crispy, light texture. However, the study concluded that 50% blending of any millet flour was ideal for biscuit production and brought out the potential of millet biscuits in bakery industry (Yenagi and Masur, 2005). Similar studies were carried out on production of cookies and muffins. In the case of cookies it was found that use of foxtail millet compared with refined wheat flour increased the mineral content. The study also evaluated the effect of the addition of foxtail millet flour and malted finger millet on the functional, nutritional and sensory qualities of muffins. The studies showed also that finger a 100 g millet muffin provided a significant amount of calcium, protein, fat, calories and minerals. These results revealed the ample scope for promoting value-added products from minor millets in reinforcing nutritious diets at community level, including youth, in ways that are socially and culturally acceptable.

The SHGs engaged in product development in the states of Karnataka, Tamil Nadu, Orissa and Uttarakhand are operating at different levels of infrastructure, scale and market connectivity. Availability of simple grain processing equipments to dehull and make flour made a huge difference in the capacity of community in taking up value addition as well as increasing household consumption. Provision of such infrastructure under the project as well as by a grant provided by the Mc Gill University, Canada was accompanied by training of women and men on machinery operation, production of diverse value added products suited for domestic consumption and commerce, standard codes on product quality, hygiene, packaging, labeling, marketing and account keeping. Steps are currently being taken to scale up production and marketing. Value addition offers a far higher scope than increase in productivity for income generation as well as generation of additional non-farm employment. The cost-benefit analysis on finger millet malt production using 100 kg raw material showed a net profit of Rs. 2,800 ($58.3 @ 1$ = Rs. 48). In the value chain, the processed malt is packaged and passed on to the distributor, who in turn supplies the produce to retail outlets in nearby towns and cities. The production and marketing of value-added millet products by some of the SHGs and Farmers' Clubs (FCs) is slowly growing as a small-scale industry and hence requires government approval for the operation of the production unit. In Kolli Hills, the project team facilitated the SHGs and FCs concerned to get the required certificates from the Department of Small Scale Industries, Tamil Nadu. Steps are now underway at Kolli Hills and Jeypore to secure

suitable public land from the local *Panchayat* to build an independent production centre for value addition in accordance with legal requirements. Product marketing is also being improved with shift to designed packaging with logo and labeling standards.

UAS, Dharwad was approached by the Department of Women and Child Welfare, Government of India, to develop low cost nutritional meals from local cereals and millets for the purpose of school feeding programme. In response to this, four millet-based recipes were developed by the group and their overall nutritional profile and costing are presented in Table 9. Efforts are also in progress at UAS, Bangalore to include millet grain products in school feeding programmes in Karnataka.

4.3 Human Resources, Policies and Public Awareness

Several training programmes were organized as a part of human and social capital building. The themes of these trainings included improved crop management, quality seed production, variety selection, intercropping systems, soil health management, vermi-compost production, value addition and product development, packaging, account keeping and marketing. Some of the farm women and men, as part of the capacity building, took part in on-farm exposure visits and training trips. These contributed substantially to farmers' knowledge levels and skills leading to change in their outlook on agricultural practices and their overall self confidence and esteem, in particular the women.

During 2008 alone, 75 training days were organized covering 1,399 trainees, of which 824 were women. Similar training programmes were conducted every year under this project at all locations. More than 95% of the trainees belonged to the farming or rural community and the rest were housewives or practicing bakers. Such trainings were followed up with infrastructure and institutional support such as provision of grain processing machinery, storage bins for safe storage of seeds, devices for row seeding and mechanical weeding and establishment of SHGs, FCs and village gene-seed-grain banks.

Table 9. Nutrient composition and cost of millet based school feeding recipes

Recipe	Quantity of little & foxtail millets	No. of servings	Approximate wt/serving (g)	Nutrients and cost per serving		
				Energy (Kcal)	Protein (g)	Cost (Rs)
Bisibele bath	1 kg	50	170	188	6.8	2.50
Vangibath	1 kg	47	125	123	3.3	1.40
Kichadi	1 kg	39	170	178	6.4	1.74
Pudina rice	1 kg	41	110	174	3.8	1.58

One profound impact of provision of grain processing machinery was the elimination of the drudgery experienced by the farm women, who undertake the grain processing at domestic level using traditional threshing with bare feet and dehulling with a pestle and mortar or grain milling with hand-operated stone grinder. The use of the grain processing machinery made a huge difference to them in terms of empowerment and elevated social status and self esteem. This opened new opportunity for them to earn extra income from value addition independent of their men folk and strengthening their financial security. In Kolli Hills and Jeypore, these women formed SHGs and operated in groups. In some cases, men also joined the women SHGs for value addition, where men largely assisted in assembling raw material and marketing the products outside the village. Such SHG-centered value addition is being promoted at project locations in the states of Karnataka and Uttarakhand. All seminal trainings on value addition were provided by the Rural Home Science Colleges under the UAS, Bangalore and Dharwad. For all these SHG women, it was a first time travel outside their villages and visiting a university campus. This training experience gave them remarkable confidence and skills to discern which of the value-added products are appropriate for domestic use and for commercial purpose. Their slow transformation from housewives and farm labourers to market based product developers has huge social implications.

Instrumental in building the sustainability of the project had been the numerous SHGs and FCs established in all project sites. These consortia played a fundamental role in the implementation and dissemination of project deliverables. Some of these grassroot consortia started functioning by saving on a daily basis to build up group capital and establishing group bank accounts and thereby becoming eligible to receive bank loans for economic activities under the government provisions for financial assistance to SHGs. They have a regular structure with an elected chair and secretary and conduct regular meetings for work review, thrift and enterprise building. The accounts they regularly maintain is periodically reviewed by the members. Since the start of its Phase I in 2001, the project has led to the establishment of more than 35 SHGs with a total membership exceeding 386, of which 214 are women. These groups represent a strategic element of the project's 'exit strategy' and contribute to mainstreaming its tools, methods and approaches within the community and at district level. Close linkages built by the project with government extension agencies and local NGOs are also instrumental to that end.

5.0 Discussion and Conclusions

This multi-partner and multi-activity project has so far been successful in conserving local genetic resources of minor millets while providing a framework for their improved cultivation and use through farmer participatory approach, involving integration of traditional knowledge and scientific techniques, value addition, product development and marketing, training, capacity building, establishing self help groups and farmers' clubs/ cooperatives, creating links among actors in the value chain and raising awareness at local regional and international levels. However, it is imperative that more thrust is given to research and development on the genetic diversity of minor millet species in order to harness their untapped potential in adaptation and economic benefits. Such a call in the present context, where only a few grains are promoted to meet the food demand, should receive a special attention by scientists and policy makers. The importance of this policy shift is more relevant today than ever before in view of the advancing climate change and the strength of these species and other NUS in providing better adaptation to the agricultural scenario unfolding under climate change. Another strategic advantage of minor millets is their unique strength in countering hidden hunger and thereby providing wholesome nutrition security. While substantial progress has been made towards the improvement of minor millets in India, more efforts and investments are needed in the following specific areas:

Specific Areas Needing Greater Attention

Survey, collection, conservation, and characterization of the genetic resources

- Well organized exploration programmes need to be undertaken to collect the existing diversity including the landraces, primitive cultivars and the wild relatives. There is also a need to collect the germplasm possessing specific desirable traits such as photo-insensitivity, early maturity and resistance to drought, diseases and pests. Valuable germplasm of these species also need to be introduced from other millet growing countries.
- The genetic diversity of minor millets including landraces and wild relatives needs to be better conserved in genebanks as well as on-farm where community conservation needs to be given utmost attention by local authorities. The latter represents a strategic priority particularly in the context of climate change.

Participatory Selection and Crop Improvement

- Appropriate selection and breeding efforts, including participatory approach, need to be taken up to develop high yielding and nutritive varieties of minor millets, particularly those other than finger millet, for different production systems under varying edapho-climatic situations.
- Valuation of diversity collected and conserved in genebanks needs urgent attention in order to identify accessions possessing specific genes governing traits valuable for adaptation to climate change and use them in breeding programmes aimed at developing better varieties for enhanced adaptive strength under harsh environments.

Value Addition

- This project could bring out the far inadequacy of appropriate grain processing technology, particularly in the scale appropriate to the far placed rural areas, which is essential to promote the conservation, cultivation, consumption and commerce of these millets.
- There is a great need to develop and disseminate appropriately processed whole grain products from minor millets to meet modern consumers' needs and tastes. Considering the recent increase in the consumption of refined wheat flour-based bread and bakery products in urban India, their nutritional load could be significantly enhanced by blending minor millets flour at appropriate proportions suitable to the baking industry.
- Minor millets are both health and nutraceutical foods. Their low glycemic index makes them appropriate health food for diabetic and obese people. Greater attention needs to be paid in developing superior varieties and processing technologies to meet these demands.
- Value-addition to millet grain offers good opportunity to rural and tribal women farmers for income generation. This opportunity can be realized with the availability of appropriate and relevant low cost technology and a policy regime promoting such production and marketing.
- Skill development to rural and tribal women for developing value added millet products, maintaining acceptable hygiene standards, packaging, labeling and marketing is as important as the technology for processing. Building rural entrepreneurship and

financial assistance on favourable terms under food processing sector would promote these crops to the larger human benefit.

Marketing

- Most of the small millets are consumed by the producer farmers leaving very little market surplus. In the event of increase in millet production, there is need to strengthen production-processing-value addition-marketing-consumption chain with built-in system to ensure fair price to the produce at the market. Strategic and rule-based alliances with agencies and organizations having experience in marketing, processing and product development may also help farmers.

Policy and Public Awareness

- Greater public awareness about the nutritional and other benefits from cultivation of these crops need to be raised through awareness campaigns, exhibitions, farmers' fairs, radio and TV programmes, workshops, conferences, symposia, publications, etc. by the research institutions, State Agricultural Universities and the agriculture development departments.
- Urgent attention needs to be given for promoting policies, laws and regulations that ensure that benefits from the increased use of millets reach communities, particularly women and other disadvantaged members of the society. Introduction of these grains in school feeding programmes has strategic advantage of using low cost grain to provide nutritionally superior meals to children.
- These grains can be good candidates for the subsidized public distribution system (PDS) with minimum support price in regions of their availability. Such a policy would strategically address both food and nutrition security of the poor and the strengthening of their sustainable production systems.
- More investments should be directed towards the promotion of minor millets and their effective deployment to fight climate change. Research topics deserving greater focus range from better understanding of genetic diversity distribution in on-farm, *ex situ* conservation, screening for adaptation traits, assessing formal and informal seed systems and ways to strengthen them within a climate changing scenario.

Acknowledgements

The authors are highly grateful to the Chairman, M.S. Swaminathan Research Foundation, Chennai, and the Vice Chancellors of University of Agricultural Sciences at Bangalore and Dharwad and the Dean, College of Forestry, Hill Campus, G.B. Pant University of Agriculture and Technology, Ranichauri, for their support and encouragement in implementing the project. The authors are also thankful to the Director, Central Food Technology Research Institute, Mysore for his interest in this project and technical assistance extended. Thanks are also due to the International Fund for Agricultural Development for funding support and to the Management of Bioversity International for facilitating the execution of the project in India. The village communities in the project villages deserve all credit for their total participation in all project activities, which led to the success that this project could claim.

References

Anonymous (1953) The Wealth of India: A Dictionary of Indian Raw Materials and Industrial Products. **Vol. III:** D-E. Publications and Information Directorate, Council of Scientific and Industrial Research, New Delhi, India. 236 p.

Anonymous (1966) The Wealth of India: A Dictionary of Indian Raw Materials and Industrial Products. **Vol. VII:** N-Pe. Publications and Information Directorate, Council of Scientific and Industrial Research, New Delhi, India. 330 p.

Anonymous (1972) The Wealth of India: A Dictionary of Indian Raw Materials and Industrial Products. **Vol. IX**: Rh-So. Publications and Information Directorate, Council of Scientific and Industrial Research, New Delhi, India. 472 p.

Ashfaq M, Y Shi, W Tung, RJ Trapp, X Gao, JS Pal and NS Diffenbaugh (2009) Suppression of south Asian summer monsoon precipitation in the 21st century, *Geophys. Res. Lett.*, **36** L01704, doi: 10.1029/2008GL036500.

Bala Ravi S (2004) Neglected millets that save the poor from starvation. LEISA India, **6(1):** 34-36.

Bhag Mal (2007) Neglected and underutilized crop genetic resources for sustainable agriculture. *J. Plant Genet. Resour.* **20(1):** 1-14.

Brush SB (2000) Ed. Genes in the Field.On-Farm Conservation of Crop Diversity. IDRC/IPGRI/Lewis Publishers. 288 p.

Burke MB, DB Lobell and L Guarino (2009) Shifts in African crop climates by 2050, and the implications for crop improvement and genetic resources conservation. Global Environ. Change, doi: 10.1016/ j.gloenvcha. 2009.04.003.

Burkill, HM (1994) The Useful Plants of West Tropical Africa. 2nd Edition. Volume 2, Families E-I. Royal Botanic Gardens, Kew, Richmond, United Kingdom. 636 p.

CGIAR (2006) SINGER database. http://www.singer.cgiar.org/index.jsp?page=fulldistribution&search=all.

Chang K (1968) Archeology of ancient China. *Science* **162:** 519-526.

Costanza SHJMJ, de Wet and JR Harlan (1979) Literature Review and Numerical Taxonomy of Eragrostis tef (T'ef). *Economic Botany,* **33(4):** Pp. 413-424.

DEFRA (2005a) Department for Environment Food and Rural Affairs.Climate Change Scenarios for India. Investigating the Impacts of Climate Change in India. http://www.defra.gov.uk/environment/ climatechange/internat/devcountry/pdf/india-climate-2-climate.pdf.

DEFRA (2005b) Department for Environment Food and Rural Affairs. Climate Change Impacts on Agriculture in India. Investigating the Impacts of Climate Change in India. http://www.defra.gov.uk/environment/climatechange/internat/devcountry/pdf/india-climate-6-agriculture.pdf

de Wet, JMJ, DE Brink, KE Prasada Rao and MH Mengesha, (1983) Diversity in Kodo millet, *Paspalum scrobiculatum Economic Botany* **37(2):** 159-163.

DRDA, (2008) District Rural Development Agency, Namkel. Annual Employment Record 2007-2008. http://rural.nic.in/aer/tn/aer_namakkal.pdf.

Dutta M, BS Phogat and BS Dhillon (2007) Genetic improvement and utilization of major underutilized crops in India. In S Ochat and SM Jain (eds) *Breeding of Neglected and Underutilized Crops, Spices and Herbs.* Science Publishers, Enfield (NH), USA, pp 251-298.

Eyzaguirre P, S Padulosi and T Hodgkin (1999) IPGRI's strategy for neglected and underutilized species and the human dimension of agrobiodiversity. In S Padulosi (ed) *Priority Setting for Underutilized and Neglected Plant Species* of the Mediterranean Region. Report of the IPGRI Conference, 9-11 February 1998, ICARDA, Aleppo. Syria. International Plant Genetic Resources Institute, Rome, Italy.

FAO (2009) FAOSTAT, assessed on 10 June 2009 (http://faostat.fao.org/site/567/default.aspx#ancor).

Gautam R, R Suwal and B Sthapit (2009) Securing family nutrition through promotion of home gardens: underutilized production systems in Nepal. In H Jaenicke, J Ganry, I Hoeschle-Zeledon and R Kahane (eds) Proceedings of the International Symposium on Underutilized Plants for Food Security, Nutrition, Income and Sustainable Development. *I Acta Horti.* **806:** 99-106.

GFU (2007) Inviting all the World's Crops to the Table, Supporting Traditional Crops to Supply Future Needs. The Global Facilitation Unit for Underutilized Species (GFU), Bioversity International, Rome, Italy, 24 p.

Government of India (2009) Area, Production and Productivity of Millets in India. Directorate of Millets, Ministry of Agriculture, Jaipur, India.

Gowda KTK and S Seetharam (2007) *Food Uses of Small Millets and Avenues for Further Processing and Value Addition.* Pp. 4-22. All India Coordinated Small Millets Improvement Project, Indian Council of Agriculture Research, UAS, GKVK, Bangalore-560065.

Gruère, G, L Nagarajan and EDI Oliver King (2007) Collective Action and Marketing of Underutilized Plant Species: The case of Minor Millets in Kolli Hills, Tamil Nadu, India, CAPRI working papers 69, International Food Policy Research Institute (IFPRI).

Gruère G, L Nagarajan and EDI Oliver King (2009) The role of collective action in the marketing on underutilized plant species: lessons from case study on minor millets in South India. *Food Policy* **34:** 39-45.

Hilu KW (1977) Domestication of *Eleusine coracana* (L) Gaertner. *Economic Botany* **30:** 199-208.

Hulse JH, EM Liang and OE Pearson (1980) Sorghum and the Millets: their Composition and Nutritive Value. New York Academic Press. 1997 p.

ICRISAT (2009) *Crops: Pearl Millet, Sorghum, Small Millets.* International Crop Research Institute for the Semi-Arid Tropics. http://www.icrisat.org/index.htm.

Jarvis DI, C Padoch and HD Cooper (eds) (2007) Managing Biodiversity in Agricultural Ecosystems. Columbia University Press, New York, USA, Bioversity International, Rome, Italy. 492 p.

Joshi A and JR Witcombe (1996) Farmer participatory crop improvement. II: Participatory varietal selection a case study in India. *Exp. Agri.* 32.

Lu H, J Zhang, KB Liu, N Wu, Y Li, K Zhou, M Ye, T Zhang, H Zhang, X Yang, L Shen, D Xu, Q Li (2009) Earliest domestication of common millet (*Panicum miliaceum*) in East Asia extended to 10,000 years ago. *Proc. Natl. Acad. Sci.* USA. **106:** 7367-7372.

Martini-Bettolo GB (ed.) (1988) Towards a second green revolution. From Chemical to New Biological Technologies in Agriculture in the Tropics. *Proceedings of the International Meeting,* Rome, Italy, 8-10 September 1986. 530 p. Elsevier Publ.

MoA (2008) Agricultural Statistics at a Glance. Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India. http://dacnet.nic.in/eands/latest_2006.htm

National Research Council (1996) Lost Crops of Africa. **Volume I:** Grains. National Academy Press, Washington DC, USA.

Padulosi S, P Eyzaguirre and T Hodgkin (1999) Challenges and strategies in promoting conservation and use of neglected and underutilized crop species. In: J Janicke (ed.) *Perspectives on New Crops and New Uses*. ASHS Press, Alexandria, VA 140p.

Padulosi S (2007) Neglected No More. Achievements of the IFAD-NUS project (2001-2005) and Framework for its follow-up initiative (2007-2009). Bioversity International. Rome, Italy. 19 p.

Padulosi S (2009) Nutritional security and biodiversity: Meet the women who strengthen the link. *Geneflow* 2008. Bioversity International, Rome, Italy.

Qualset CO, PE MC Guire and ML Warburton (1995) "Agrobiodiversity": key to agricultural productivity. *California Agri.* **49 (6):** 45-49.

Radhamani J (2009) Pers. Comm. National Bureau of Plant Genetic Resources, New Delhi.

Rojas W, R Valdivia, S Padulosi, M Pinto, JL Soto, E Alcocer, L Guzman, R Estrada, V Apaza and R Bravo (2009) From neglect to limelight: issues, methods and approaches in enhancing sustainable conservation and use of Andean grains in Bolivia and Peru. In: A. Buerkert and Jens Gebauer (ed) *Agrobiodiversity*

and Genetic Erosion, Contributions in Honor of Prof. Dr. Karl Hammer. Supplement 92 to the Journal of Agricultural and Rural Development in the Tropics and Subtropics, Kassel university press GmbH. (87-117 pp). 87-117 pp. ISBN: 978-3-89958-680-0.

Sajise P (2003) The Role of Plant Genetic Resources In: Poverty Reduction. In P Batugal and JT Oliver (eds) *Poverty Reduction in Coconut Growing Communities* Volume I: The Framework and Project Plan. International Plant Genetic Resources Institute Regional Office for Asia, the Pacific and Oceania (IPGRI-APO), Serdang, Selangor, Malaysia. 3-20 pp.

Seetharam A (2006) Millets. Pp 892-912 In: *Handbook of Agriculture.* Directorate of Information and Publications of Agriculture Indian Council of Agricultural Research, Krishi Anusandhan Bhavan, Pusa, New Delhi-110012. India. 1346p.

SGSV. (2009) Seed Portal System, Svalbard Global Seed Vault. http://www.nordgen.org/sgsv/.

Thies E (2000) Promising and Underutilized Species, Crops and Breeds. Deutsche Gesellschaft Für Technische Zusammenarbeit (GTZ) GmbH, 23 pp. http://www.ilri.org/html/thies3.pdf

Thrupp LA (1998) *Cultivating Diversity*: *Agrobiodiversity and Food Security.* Washington DC: World Resources Institute, 79.

Toledo A and B Burlingame (2006) Biodiversity and nutrition: A common path toward global food security and sustainable development*. J. Food Composition Analysis* **19:** 477-483.

United States National Research Council/National Academy of Sciences (1982) *United States Canadian Tables of Food Composition.* Washington DC. National Academy Press, 3rd rev.

USDA/HNIS (1984) Composition of Foods: Cereal Grains and Pasta. United State Department of Agriculture/Human Nutrition Information Service, Agriculture Handbook 8-20. Washington DC, USA.

Williams JT and N Haq (2002) Global Research on Underutilized Crops. An assessment of Current Activities and Proposals for Enhanced Cooperation. ICUC, Southampton, UK.

Yenagi NB, Usha Malgi, GS Shantakumar and SA Patil (2004) Promotion of valueaddedminor millet products to enhance the contribution to food security and incomes of the rural poor. Scientific programme, abstracts of talks and abstracts of posters, Nutrition Society of India, Annual Meeting 5-6 November 2004. 74 p.

Yenagi NB and S Masur (2004) Effect of incorporation of millet flour on nutritional, functional and sensory qualities of biscuit. Scientific programme abstracts of talks and abstracts of poster, Nutrition Society of India, Annual meet 5-6th November 2004. Pp 119-120.

Yenagi NB and S Masur (2005) Effect of incorporation of millet flour on nutritional, functional and sensory qualities of biscuits. *Wheat Update* **IV(1):** 38-41.