Agriculture **2015**, *5*, 2-16; doi:10.3390/agriculture5010002

OPEN ACCESS

agriculture

ISSN 2077-0472

www.mdpi.com/journal/agriculture

Article

Community Perspectives on the On-Farm Diversity of Six Major Cereals and Climate Change in Bhutan

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Academic Editor: Rainer Hofmann

Received: 1 July 2014 / Accepted: 14 January 2015 / Published: 27 January 2015

Abstract: Subsistence Bhutanese farmers spread across different agro-ecological zones maintain large species and varietal diversity of different crops in their farm. However, no studies have been undertaken yet to assess why farmers conserve and maintain large agro-biodiversity, the extent of agro-ecological richness, species richness, estimated loss of traditional varieties and threats to the loss of on-farm agro-biodiversity. Information on the number of varieties cultivated by the farmers for six important staple crops were collected from nine districts and twenty sub-districts spread across six different agro-ecological zones of the country to understand farmers reasons for maintaining on-farm crop diversity, estimate agro-ecological richness, species richness and the overall loss of traditional varieties, to know the famers' level of awareness on climate change and the different threats to crop diversity. The results from this study indicated that an overwhelming 93% of the respondents manage and use agro-biodiversity for household food security and livelihood. The average agro-ecological richness ranged from 1.17 to 2.26 while the average species richness ranged from 0.50 to 2.66. The average agro-ecological richness indicates a large agro-ecological heterogeneity in terms of the different species of staple crops cultivated. The average species richness on the other hand shows that agro-ecological heterogeneity determines the type and extent of the cultivation of the six different staple cereals under consideration. The overall loss of traditional varieties in a time period of 20 years stands at 28.57%. On climate change, 94% of the farmers recognize that local climate is changing while 86% responded that they are aware of the potential impacts of climate change on their livelihoods. Climate change and associated factors was considered the most imminent threat to the management and loss of on-farm agro-biodiversity. The results from this study indicate that on-farm agro-biodiversity conservation, development and utilization programs have to be more specific to the different agro-ecological zones considering the agro-ecological heterogeneity. Attention has to be given to individual crops that have low average species richness and high percentage of loss of traditional varieties. The impact of climate change could offset the traditional seed system which primarily supports the persistence of on-farm agro-biodiversity in several ways.

Keywords: agro-biodiversity; climate change; subsistence farming; average agro-ecological richness; average species richness; threats; traditional seed system

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1. Introduction

Bhutan represents a fragile mountainous ecosystem and is a least developed country. The economy of the country is one of the world's smallest and continues to depend substantially on the Renewable Natural Resources (RNR) sector that comprises Forest, Agriculture and Livestock. The RNR sector accounts for about 15.7% of the total GDP [1]. The livelihood of over 69% of the population is dependent on the RNR sector. The country is located in the southern slopes of Eastern Himalayas between latitudes 26°42′ N and 28°14′ N, and longitudes 88°44′ E and 92°07′ E. The country has a total geographical area of 38,394 km^2 of which about 70.46% is under forest cover with only 2.93% of the total area available for cultivation [2]. Rice, maize, wheat, barley, buckwheat and millets are major staple cereals cultivated by farmers. Bhutanese farmers are largely small holders, marginal and practice a self-sustaining, integrated and subsistence agricultural production system. The average land holding is three acres on which farmers grow a variety of crops under different farming practices and rear livestock to meet their household food security. Despite small farm size, farmers grow many types of crops and varieties where farm level agro-biodiversity is the corner stone for sustainable subsistence agriculture. In Bhutan where subsistence farming is still dominant, agro-biodiversity plays a pivotal role for sustainable agricultural development, food security and poverty alleviation [3]. Bellon [4] has noted that agro-biodiversity is the basis of food security both in subsistence and technologically advanced agriculture production systems. The Bhutanese agricultural production can be classified as a classic "small holder system" because it associates with most of the characteristic of a small holder. A small holder is characterized by small farm size less of than 10 hectares; most of the farming is undertaken using family labor; the major portion of the produce is used for household consumption with small surplus for sale that provide them the cash income [5,6].

Due to the significant influence of the high Himalayas, the Bhutanese agriculture is entirely dependent on the monsoon and prevailing weather conditions where even small variations in the onset and retreat of the monsoon could have considerable impacts on crop production [7]. The increasing frequency of extreme and adverse weather events that are considered as the signals of climate change include the floods from glacial lake outburst, flash floods, insurgence of new pest and disease such as the rice blast of paddy in 1995 and Gray Leaf Spot (GLS) in maize in 1997 indicate that climate change will have a major impact on the Bhutanese farmers [8]. Climate change has been proven to have a pervasive influence on food security and livelihoods of the small holder farmers worldwide [6,9,10]. According to the Sector Adaptation Plan of Action (SAPA) [11] of the Ministry and Agriculture and Forest (MoAF) for climate change, Bhutan is projected to experience a peak warming of about 3.5 °C by the 2050s with the overall significant increase in precipitation but with an appreciable change in the spatial pattern of winter and summer monsoon precipitation. Given this backdrop, the Bhutanese agriculture sector and the farming communities are likely to be most vulnerable.

Bhutan's strategic location as a landlocked country, poor accessibility with mostly rugged mountainous terrain in the high Himalayas and, its relative isolation from other parts of the world until 1960 has made it rely on agro-biodiversity for its domestic food production. In contrast to its geographical size, it has a rich and unique domestic diversity of species and varieties which has been enhanced through natural and human selection and, subsequent conservation by the farmers. The local crops are considered to possess tremendous genetic diversity and are well adapted to the specific requirements of the areas where they are grown. It is estimated that there are about 350 landraces of rice, 47 of maize, 24 of Wheat and 30 of Barley in the country [12]. Generally, agro-biodiversity in the Bhutanese context is understood as the cultivation of different types of crops, their landraces and varieties for direct consumption as food and normally includes cereals, oilseeds, legumes, roots and tuber crops, all types of vegetables and fruits [3]. The National Biodiversity Center (NBC) is the nodal agency of the country, which is mandated to develop programs for the sustainable conservation, development and utilization of the agro-biodiversity resources for food security and poverty alleviation. The conservation and use of agro-biodiversity is fundamental for making the agricultural ecosystems sustainable, productive, and resilient and can contribute to better nutrition and livelihoods of poor farmers throughout the world [13]. Thus, agro-biodiversity has been recognized as one of the potential means of adaptation to climate change mainly through the development and use of biotic and abiotic tolerant varieties, strengthening the traditional seed system and enhancing the on-farm diversity as potential insurance to climate change [3,7,11]. Jarvis *et al.* [14] have established that agro-diversity is maintained by farmers as an insurance to meet future environmental changes and socio-economic needs.

As one of the key strategy for the formulation of the Strategic Action Plan (SAP) for conservation of cereals in the country, the NBC commissioned a rapid baseline research to understand the community perspectives on the on-farm diversity, status and trends of the six major cereals considered in this study.

This study attempted to understand why farmers conserve and maintain agro-biodiversity, the extent of agro-ecological richness, average species richness and the estimated loss of traditional varieties and threats to the loss of on-farm agro-biodiversity.

2. Materials and Methods

This study was undertaken as one of the key process for the formulation of SAP for conservation of cereals. A nationwide community vulnerability assessment study was carried out in 2013 covering the five main agro-ecological zones of the country. This research was undertaken through collaboration between the NBC, the Regional Research and Development Centers (RDC), *Dzongkhag* (district) and *Geog* (Sub-district), agriculture extension staff and farmers. The objectives of this study were to understand why farmers conserve and maintain agro-biodiversity, the extent of agro-ecological richness, average species richness and the estimated loss of traditional varieties and threats to the loss of on-farm crop species diversity in the country.

2.1. Study Sites

This survey covered a total of nine *Dzongkhags* (districts) out of the total 20 *Dzongkhags* and 20 of the total 205 *Geogs* (Sub-districts). The districts and sub-districts were randomly selected to represent the five dominant agro-ecological zones (Table 1). The elevations of the study sites ranged from 200 masl to 2500 masl covering four different types of agro-ecological zones namely the humid subtropical, the dry subtropical, warm temperate and the cool temperate. The dominant production environment in the dry-subtropical and cool temperate agro-ecology was the rainfed dryland farming where crop production entirely depends on monsoon rains. In the warm temperate, humid and wet-subtropical agro-ecological zone, terraced rice paddies which are irrigated and those that depend on rainfed streams for source of irrigation were the prevalent land use practice. The key features of the study sites are summarized in Table 1.

2.2. Data Collection Methodology

In order to start the survey, a core team comprising of biodiversity officers, researchers and policy makers was formed. This team designed a comprehensive survey questionnaire to assess the status, extent and trends of cereals diversity and farmers understanding and perceptions on climate change and, its potential impact on cereals diversity. After the finalization of the questionnaire, the sites were randomly selected to represent the different agro-ecological zones from where the data for this study was gathered. The target crops in this study were rice (*Oryza sativa* L), maize (*Zea mays*), wheat (*Triticum asetivum*), barley (*Hordeum vulgare*), buckwheat (*Fagopyrum esculentum*); millets namely finger millet (*Eleusine coracana*), foxtail millet (*Setaria italaca*) and common millet (*Panicum miliaceum*) that constitute the predominant cereals cultivated by the farmers. Information was collected from 404 respondents (Table 1).

Table 1. Detail of the study sites and respondents.

Agro-ecology/Altitude Range masl	Dzongkhags	Geogs	No. of Informants		Total
			Male	Female	
Cool Temperate 2600–3600	Haa	Isu	8	12	20
		Katsho	7	13	20
Warm Temperate 1800–2600	Paro	Tsento	7	13	20
		Dopshari	8	12	20
	Punakha	Shelngana	10	6	16
		Toewang	9	15	24
	Dagana	Drujegang	13	7	20
		Goshi	18	2	20
Dry Subtropical 1200–1800	Mongar	Chali	13	11	24
		Kengkhar	12	9	21
	Trashiyangtse	Khamdang	4	12	16
		Toetsho	16	9	25
	Pemagatshel	Khar	7	9	16
		Yurung	1	15	16
Humid-Subtropical 600–1200	Samtse	Norgaygang	18	4	22
		Pemaling	15	6	21
		Samtse	14	6	20
Wet-Subtropical 150–600	Sarpang	Gelephu	16	3	19
		Jigmechholing	21	2	23
		Shompangkha	20	1	21
Total	9	20	237	167	404

Source: SAP Survey [3].

During the survey, the survey team collected the data based on the information entirely recalled by the farmers. The surveyors visited the farmers and interviewed them to gather information on the crops, varieties grown and lost, cereals displaced and farmer's perceptions on climate changes. The information on crop varieties is exclusively based on those mentioned by the farmers. The names of the varieties reported by the respondents included those being cultivated now or those that used to be cultivated before 20 years and that they had heard of from the village elders. Information was collected for traditional and improved varieties. Improved varieties in this study refers to those crop varieties that have been introduced from different sources from outside the country and evaluated and adapted to local conditions through adaptive research including those varieties that have been developed through hybridization with local varieties. The improved varieties are formally released for cultivation to the farmers by the Technology Release Committee (TRC) of the Ministry of Agriculture and Forest which is coordinated by the Council for RNR Research of Bhutan (CORRB). The improved varieties are in most cases high yielding compared to the traditional varieties. They also confirm to the three basic characteristics of being distinct, uniform and stable.

The respondents were randomly selected to represent a *Geog*. The survey targeted respondents with age group of 40 years and above in order to get a better perspective on the status and trends of cereals and traditional crop varieties cultivated 20 years ago. The survey also gathered farmer's awareness on the importance of farm level diversity of these cereals, practices and capacity to manage cereals diversity and different challenges faced in maintaining the cereals diversity.

2.3. Data Analysis

The survey data was first compiled using MS Excel and then relevant tables were generated using MS Access. To understand the role of the cereals diversity and the reasons why farmers cultivate different crops and varieties we computed the percentage of respondents assigning different reasons for maintaining agro-biodiversity. The reasons that the highest percentage of respondents assigned was considered the most important factor for maintaining the on-farm agro-biodiversity.

We determined the current status of on-farm agro-biodiversity for individual crop by listing the number of varieties that the surveyed farmers are currently cultivating in their farms (Table 2). In estimating the number of varieties grown for each crop we only used the respondents growing the crops. Individual variety named by the respondents for each crop was used as the basic diversity unit. Wherever we came across with varieties with different local names in the same locality we further probed the farmers and asked them to describe and agree if the variety in question were similar or different. We removed the varieties with similar names to avoid duplicates. Jarvis *et al.* [14] and Kiwuka *et al*. [15] have used variety as a basic diversity and when issue of the same variety being reported with different names occurred they used the farmer's knowledge and description to agree whether a variety in question was actually different. In this study, we also used farmer's knowledge and description as the basis to distinguish whether a variety was similar or different when varieties with different names were reported from the same location.

Table 2. Number of improved and traditional varieties cultivated by the interviewed farmers in the study sites.

Crop	Improved Variety	Traditional Variety	Total Varieties Cultivated
Rice	15	84	99
Maize	5	34	39
Wheat	6	19	25
Barley	0	14	14
Buckwheat	1	13	14
Millet	0	30	30
Total (*n* = 219)	25	194	219

Source: SAP Survey [3].

To estimate the level of current on-farm diversity we took into account number of traditional and improved varieties which are currently grown by the respondents in their farm and listed during the survey. Similarly, we asked the respondents to list of varieties for each crop cultivated 20 years ago (1993) but not found in the respondents farm now (2013). We used the chronological difference between numbers of varieties cultivated now and the number of varieties that used to be cultivated 20 years ago to estimate the percentage of varieties lost for each crop (Table 3). Fowler and Mooney [16] have also used number of varieties in a time series gap of 80 years (1903 and 1983) to estimate the percentage loss of diversity for different vegetables as one of the basis to establish the loss of genetic diversity. Thrupp [17] has used the same basis in his review to indicate the loss of traditional crop varieties over time.

Table 3. Status of traditional varieties of cereals cultivated 20 years ago and now.

Crop	20 Years Ago (1993)	Now (2013)	Loss %
Rice	126	86	31.75
Maize	45	34	24.44
Wheat	31	19	38.71
Barley	14	8	42.86
Buckwheat	15	13	13.33
Millet	35	30	14.29
Total	**266**	**190**	**28.57**

Source: SAP Survey [3].

Richness is one notion of diversity that refers to the number of different kinds of individuals regardless of their frequencies [14]. In this study we have attempted to assess the average species richness for each agro-ecological zone and for six important staple crops (Table 4). We first estimated the average richness per agro-ecological zone and per species, as the average number of varieties of the six staple crops cultivated by farmers in the six different agro-ecological zones. We used all the respondents interviewed in each site to estimate the agro-ecological richness for each crop under consideration (Table 4). We computed the average species richness by taking the mean of the species richness from different agro-ecological zones to compare the richness between the six different crops covered in this study.

Table 4. Average agro-ecological and species richness for six main staples, 2013.

Average Agro-ecological and Species Richness for Six Main Staple Cereals							
Agro-ecological Zones (AEZ)	**Rice**	**Maize**	**Wheat**	**Barley**	**Buckwheat**	**Millet**	**Average Agro-ecological Richness**
Cool Temperate (2600–3600 masl)	0.13	1.65	3.16	1.37	2.20	1.09	1.60
Warm Temperate (1800–2600 masl)	3.70	1.31	0.73	0.09	0.70	0.50	1.17
Dry Sub-tropical (1200–1800 masl)	4.63	5.63	0.73	0.91	0.90	0.78	2.26
Humid Sub-tropical (600–1200 masl)	3.19	2.23	0.16	0.11	0.92	1.94	1.42
Wet Sub-tropical (150–600 masl)	1.50	2.48	0.31	0.03	1.26	1.67	1.21
Average species richness	2.63	2.66	1.02	0.50	1.20	1.19	1.53

Source: SAP Survey [3].

We used the number of respondents (counts) to estimate the percentage of respondents as a simple measure to assess farmers' level of awareness on climate change, their perceptions of climate change and its impact on agro-biodiversity and household food security. Risks and threats to cereals diversity posed by climate change and farmer's current coping strategies for adaptation to climate change were recorded. The threats mentioned by the respondents were listed for each crop. The frequency of threats mentioned was cumulated and ranked to arrive at the seven most widespread threats to cereal diversity (Figure 1). To know which traditional crops were being displaced, we directly asked the farmers for information and synthesized the information and tabulated by *Dzongkhags* and by agro-ecology (Table 5).

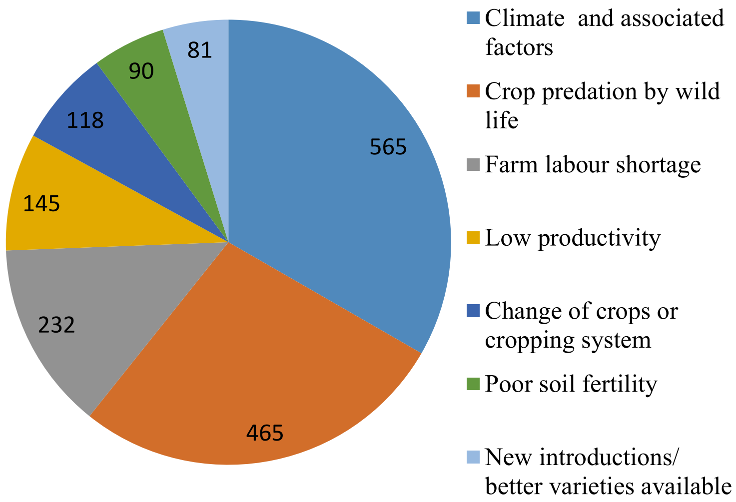

Figure 1. Frequency of different threats to cereals diversity reported by farmers.

Table 5. Information on cereals displaced and crops displacing them in study site.

Dzongkhags	Agro-ecology	Crops Displaced	New Crops
Haa	Cool Temperate 2600–3600	Barley, Buckwheat, Wheat, Millet	Potato, Apple, Vegetable, Pasture
Paro	Warm Temperate 1800–2600	Wheat, Barley, Buckwheat	Potato
Dagana	Warm Temperate 1800–2600	Maize	Citrus
Trashiyangtse	Dry Subtropical 1200–1800	Wheat, Buckwheat	Potato, Vegetables
Samtse	Humid-Subtropical 600–1200	Rice, Maize, Wheat, Barley, Buckwheat, Millet	Ginger, Cardamom, Arecanut, Citrus, Vegetables
Sarpang	Wet-Subtropical 150–600	Rice, Maize, Wheat, Barley, Buckwheat, Millet	Arecanut, Cardamom, Litchi, Vegetables, Citrus, Pasture, Fodder

Source: SAP Survey [3].

3. Results and Discussion

3.1. Importance of On-Farm Agro-Biodiversity

This study indicates that on–farm agro-biodiversity which is dominated by rice, maize, wheat, barley, buckwheat and millet plays a pivotal role in the household food security of the Bhutanese farmers with 93% of the respondents saying that crop and varietal diversity is very important. Of the total respondents

90% ($n = 365$) said that they cultivated six different cereals for household food security and self-sufficiency while 7% ($n = 26$) said that they grow for income generation and only 3% ($n = 6$) mentioned conservation as one of their objective of cultivation. These reasons are highly relevant and valid because at the national level, domestic food production meets 64% of the total cereals requirement [18]. Conservation of diversity of crops is often not the foremost focus of any farmer but Bhutanese farmers primarily perpetuate diversity for household food security and livelihoods. In Ethiopia, small holder farmers in marginal production system use high levels of crop genetic diversity for maintaining food security [19]. Farmers are also known to cultivate traditional varieties because in many situations they still provide the best means of fulfilling their livelihood needs [20]. According to [4], subsistence farmers highly value the diversity of crops mainly for the purpose of spreading the production risks, needs for crops that can adapt to different environments, for protection against pest and diseases, and meeting their social and cultural needs.

3.2. Status of On-Farm Diversity of Six Cereals under Consideration

The information on varieties cultivated by the interviewed farmers in the study sites shows that for each crop the cultivation of traditional variety by far dominates the improved varieties (Table 2). The highest number of variety cultivated was recorded in rice and the least was in barley and buckwheat. No improved varieties are currently cultivated for barley and millets, although two improved millet varieties have been released by the formal breeding program.

The average agro-ecological richness ranged from 1.17 to 2.66 (Table 4) indicating that Bhutanese farmers in the six different agro-ecological zones grow more than one staple crop in their farm. The highest average agro ecological richness of 2.66 was recorded for the dry-subtropical zone. In the dry-subtropical zone farmers have more choice to grow all the six different staples in both terraced wetland paddies and dryland (upland) fields. The low agro-ecological richness in the warm temperate region can be underpinned to rice as the single most dominant crop and fewer farmers growing barley and millet (Table 4). The average species richness for the six crops ranged from 0.50 to 2.66. The highest average richness of 2.66 estimated was for maize and the lowest for barley (Table 4). This can be explained by the fact that maize is a major crop that is widely cultivated by most households across the five different agro-ecological zones as compared to barley which is considered to be a minor cereal and is mostly dominant in the cool temperate zone. Jarvis *et al*. [14] have reported the average farm richness for traditional varieties in the range of 1.38 to 4.25 while Mulumba *et al.* [21] have estimated the household richness for common bean and banana at 2.37 and 8.02 respectively.

In this study the average species richness estimated for some crops is less than one. This can be underpinned to the large altitudinal variation within and among the agro-ecological zones where some of the six staple cereals cannot be cultivated and that some cereals like wheat, barley, buckwheat and millet are cultivated by fewer households as compared to rice and maize. The lower richness of rice than that of maize despite having much higher number of varieties for rice (Table 2) is due to the very low species richness for rice in the cool temperate agro-ecological zone where rice is not cultivated by majority of the respondents. The variation in the agro-ecological richness among the six different agro-ecological zones indicate a much wider agro-ecological heterogeneity in terms of the extent of cultivation of six different cereals under consideration. Some species like barley is more dominant in the cool temperate agro-ecological zone where as in the dry-subtropical zones all the six crops are cultivated. For instance wheat, barley and buckwheat are more predominant in the cool temperate agro-ecological zone whereas millet is more widely cultivated in the humid and wet subtropical agro-ecological zones. The lower average species richness for wheat, barley, buckwheat and millets as compared to rice and maize reveal that households grow much fewer varieties of these crops and these crops are dominant only is a selected agro-ecological zone. This is a cause for concern as growing few varieties entails higher risks of crop failures especially during the outbreak of diseases as in the case of Gray Leaf Spot of maize in 2007 where all the high altitude traditional maize varieties succumbed to the disease and famers lost maize harvest to the tune of 70%–100% [22]. However, Bellon [4] has argued that although it is important to maintain diversity by growing a large number of varieties, it alone does not assure a high level of diversity because the different varieties under cultivation might not be genetically different.

The chronological comparison of the traditional varieties cultivated 20 years before (1993) and now (2013) for each crop shows that quite a substantial percentage of traditional varieties have been lost (Table 3). The overall percentage of traditional varieties lost in all six cereals is estimated at 28.57%. The lowest percentage of traditional varieties lost was 14% for millet and the highest was 43% in barley which is quite alarming (Table 3).

3.3. Farmers Perceptions on Climate Change and Threats to Cereals Diversity

An overwhelming 94% of the respondents in the study sites had the perception that local climate is changing while 86% responded that they are aware of the potential impacts of climate change on their livelihoods. Most farmers' descriptions of climate change interpreted as the fluctuations of weather events and their experiences of droughts, unreliable monsoon, the insurgence of new pest and diseases in crops, rising temperature, prolong occurrence of frost and changing snowfall patterns [23]. A similar study on building farmers' perception and traditional knowledge on climate change undertaken in Peru, Zimbabwe and Vietnam has found that smallholder farmers are aware of the occurrence of climate change and their perceptions of climate change are based on impact on their farming systems, livelihoods and crop performances [24]. As agro-biodiversity is central to the livelihood of the Bhutanese farmers, we asked the farmers to identify and rank potential threats faced in maintaining agro-biodiversity of the staple cereals from their knowledge and experiences. From their experiences farmers assigned climate change and climate associated factors as the most serious threat to the diminishing on-farm cereals diversity in the study sites (Figure 1). The climate associated factors included drought, flood, outbreak of pest and diseases, hail and windstorm, landslide and other forms of natural calamities. The frequency of climate and associated factors was the highest while the threats from the new introduction or from the promotion of high yielding varieties was the lowest. A very unique but a severe threat perceived by farmers to the decline of the on-farm cereal diversity is the crop predation by wildlife. A national review of the status of the human-wildlife conflicts by a task force found that almost 70% of the households attribute losses of crops like maize and paddy to predation by wildlife [25]. The most direct threats to agro-biodiversity that emanates from climate change and increasing human wildlife conflicts could contribute to farmers relinquishing farming, disruption of the traditional seed system, loss of traditional crops, fallowing of productive agricultural lands which ultimately leads to the increasing household food shortages and decrease of the farm level diversity from the extinction of crops and varieties specifically adapted in that area [3].

The Bhutanese subsistence farmers meet 98% of their total cereals seed requirement from the informal traditional seed system managed by themselves [26]. They annually recycle the farm saved seed, select seeds for next season and even exchange seeds from other farmers and communities. Many communities are also engaged in the formal seed production chain as registered seed growers and seed producer groups. Disruption of this established seed system in any form will have a direct implication on the household food security and on-farm agro-biodiversity. The impact of climate change can be very profound on the traditional seed system and can lead to an extreme scenario of no seeds for planting in the next season. The impact on traditional seed system is manifested in the form of entire crop failure and complete loss of source seed for next planting due to drought and untimely monsoon, floods leading to complete crop submergence in low lying areas, early frost and cold temperature affecting seed setting in higher elevations, poor quality seed due to incessant rain during harvesting and curing, higher incidence of storage pest due to inadequate drying resulting from high humidity and poor germination of farm saved seeds. Due to topography that is dominated by high mountains and deep valleys there is a wide variation of micro climate especially rainfall and temperature over short distance and small altitudinal range. Hence Bhutanese farmers often operate on highly location specific crops and varieties that are almost impossible to replace. The diversity and types of agro-ecosystems is known to have a positive influence on the on-farm varietal diversity [27]. The traditional seed system and production of quality seed on-farm are considered the key elements for the perpetuation of the agro-biodiversity [4,28]. In Vietnam, Tin *et al*. [29] have established that the number of rice varieties managed by seed clubs in the informal system was generally very high which lead to high on-farm diversity. Similarly in Mexico a large number of small-scale maize farmers continue to rely on the traditional seed systems which is fundamental for farmers' livelihoods and conservation of maize land races [30].

We considered the hypothesis that the increasing emphasis of the formal research and development programs for the promotion of improved high yielding varieties as one of the key incitement for the loss of diversity of traditional crops and varieties. Although, the displacement of the traditional crops and varieties by the new introductions was ranked as the least threatening to cereals diversity, it is apparent that there is an actual displacement of traditional crops (Table 5). In all the districts across all agro-ecological zones, farmers have identified different cash crops that are displacing the traditional cereals. In the *Dzongkhags* representing the cool temperate and warm temperate agro-ecosystem potato, vegetables, apples and pasture grasses are the new crops that are displacing wheat, barley, buckwheat and millet. Maize is displaced by citrus only in Dagana *Dzongkhag*. In the dry-subtropical agro-ecology represented by Trashiyangtse *Dzongkhag*, wheat and buckwheat is displaced by potato and vegetables. Interestingly, rice has been displaced only in Samtse and Sarpang which is largely attributable to the increasing cultivation of cardamom an attractive plantation crop that fetches a very high cash returns. The standing government policy that restricts the conversion of irrigated wetland designated for rice cultivation to other forms of land use acts as deterrent to the large scale non-displacement of rice by other crops.

The majority of the farmers (61%) responded that during any natural hazards and crop failures, they usually manage themselves; 31% said they report the problems to the local government and seek government support, while 8% said they mobilize community support. The majority of Bhutanese farmers who operate on diverse and risk prone environment have been traditionally known to make key farming decisions to spread risks at household level. Hansen *et al.* [31] have established that the availability of information on climate fluctuations and its potential impact on agriculture to the farmers well in advance immensely help farmers to prepare better to cope and adapt to such adverse extreme events.

4. Conclusions

This study brings into light the perceptions of the farmers on the status and significance of on-farm varietal diversity of six staple crops and climate change based on their experiences. It is apparent that household food security and livelihood of the subsistence Bhutanese farmers largely hinges on the on-farm agro-biodiversity which provides with crops and varieties that have specific adaptation for the diverse risk prone farming environments spread across five different agro-ecological zones.

This study also shows that subsistence Bhutanese farmers still continue to cultivate different types of staple crops and their varieties in their farms maintaining a rich on-farm agro-biodiversity across different agro-ecological zones. The average agro-ecological richness estimated in this study indicates a wider agro-ecological heterogeneity which determines the types and extent of crops cultivated. Some agro-ecological zones like the dry-subtropical agro-ecological zone grow more crops and their varieties as compared to other agro-ecological zones. The average species richness further indicates that some species like barley is more dominant in the cool temperate agro-ecological zone where as in the dry-subtropical zones all the six crops are cultivated. From the six staple cereals included in this study wheat, barley and buckwheat are more predominant in the cool temperate agro-ecological zone whereas millet is more widely cultivated in the humid and wet subtropical agro-ecological zones. The average species richness estimated for wheat, barley, buckwheat and millets was much lower compared to rice and maize. The lower species richness reveals that households grow much fewer varieties of these crops and these crops are dominant only in a selected agro-ecological zone. Maize and rice had much higher species richness as these two crops are undoubtedly the most popular staple grown across all agro-ecological zones in the country. The findings from this study establish that on-farm conservation programs for the six different staple cereals needs to be more specific and concentrated considering the agro-ecological heterogeneity. The on-farm agro-biodiversity conservation program has to focus on individual crops that have low average species richness and high percentage of loss of traditional varieties.

Climate change is a reality at the household level and farmers perceive climate change including all associated climatic factors as the most impending threat to the loss of on-farm agro-biodiversity. The impact of climate change could directly offset the traditional seed systems in several forms and on farm agro-biodiversity that is vital for household food security. There is abundant existing scientific evidence that agro-biodiversity is fundamental to maintain food production and adaption to climate change for small subsistence farmers. The national research and development programs should start giving more attention towards selection, seed production and dissemination of locally adapted traditional varieties or using the local genes in the future crop breeding programs. The six staple cereals under consideration in this study being displaced by plantation crops rather than the perception that local varieties are being displaced by high yielding improved varieties need more in-depth analysis and attention.

The exploitation of the benefits of agro-biodiversity has been rightly recognized in the National Adaptation Programme of Action (NAPA) and the Sector Adaptation Plan of Action (SAPA) of the MoAF as one of the coping strategies for climate change. To harness the existing potential of agro-biodiversity for adaption to climate change, more dynamic on-farm agro-biodiversity conservation, development and utilization programs that enhance household food security and resilience to climate change will be very important. Farmer's current coping strategies at the household level needs to be strengthened for adaptation to climate change through the provision of information on potential adverse extremes, enhancing farm level diversity through participatory variety selection and diversification of food crops by improving and strengthening the traditional seeds system.

Acknowledgments

We are very grateful to South East Asia Regional Initiative for Community Empowerment (SEARICE), Philippines for encouraging us to take up this research as a baseline for the formulation of the national Strategic Action Plan for cereals. This work was supported from the Benefit Sharing Fund (BSF) allocated for the development of the national SAP cereals by the International Treaty for Plant Genetic Resources for Food and Agriculture (ITPGFRA). The authors are grateful to the Program Director, National Biodiversity Center, Ministry of Agriculture and Forest for approving the study. We also acknowledge the valuable support provided by the Renewable Natural Resources Research and Development Centers, *Dzongkhag* and *Geog* Extension Officers that enabled us to undertake this research. We highly appreciate the whole hearted participation and cooperation of the farmers for sparing their time to provide required information. Finally, we take this opportunity to extend our gratitude to Vernooy Ronnie of Bioversity International, Rome for helping us to source useful and relevant references.

Author Contributions

The major research and the development of this manuscript has been done by Tirtha Bdr. Katwal, who is the main author and designated author for correspondence. Singay Dorji who is the second co-author substantially contributed in conceptualizing the research paper and the final analysis. Lhab Tshering, one of the co-authors assisted in data input and generation of information. All the other co-authors have contributed equally in the development and finalization this manuscript.

Conflicts of Interest

The authors declare no conflict of interests and the views expressed herein are those of the authors, and do not necessarily reflect the views of National Biodiversity Center and the Ministry of Agriculture and Forests.

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