Horticultural Biodiversity: Where We Are and What We Need to Do?

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Abstract

Horticultural biodiversity includes fruits, vegetables, spices and condiments, ornamental, medicinal and herbal, pesticidal, green manuring and beverages and narcotics plants. These species are either domesticated, semi-domesticated, wild relatives, or wild economical species. Among the total 320,000 plant species in the world, 70,000 are under cultivation. The species richness of vegetables, fruits and ornamental plants are 1097, 2000 and 30,000 respectively. In Nepal, a total 1012 species are reported as horticultural plants. In farming areas, the majority of the varieties are exotic and uniform. Many different horticultural practices and climate changes have eroded native and local horticultural genetic resources (HGRs). About 50% of the genetic diversity of horticultural biodiversity had been lost from Nepal. HGRs are being conserved through more than 70 good practices and approaches which fall under four strategies, ex-situ, on-farm, in-situ and breeding. Some of them are seed banks, tissue banks, DNA banks, field genebank, school field genebank, potato parks, community genebank and agro gene sanctuaries, etc. Genesys database has 301123 accessions of vegetables and 51291 accessions of fruits. Ten international genebanks have conserved 99552 accessions of vegetables and 7276 accessions of fruit species. The strategy of conserving genetic diversity in building and growing static varieties in the fields is not climate-smart technology. Advanced technologies, e.g. DNA markers, sequencing, anti-sense RNA technology, gene editing and genetic engineering have also been extensively used on HGRs. Major policy frameworks for HGRs are CBD, Cartagena Protocol, Nagoya Protocol, ITPGRFA, WIPO and UPOV. The multilateral system of ITPGRFA has 135110 accessions of vegetables and 27426 accessions of fruit species. Policy for favoring a broad genetic base in the field should be promoted along with focusing on developing site-specific varieties and treating landraces as private good. Agroecosystem-based HGRs should be genetically enhanced and promoted for food, nutrition, business, health and the environment.

Keywords: Fruit, vegetable, species richness, conservation bank

Introduction

Agrobiodiversity is the major component of biodiversity and it is directly related to human survival. It has six components (Figure 1) and horticultural genetic resources (HGRs) are part of crop genetic resources. Horticultural biodiversity is all types and kinds of HGRs that include species, cultivars, genotypes and alleles. All countries are very rich in HGRs and many successful businesses are dependent on HGRs. With the higher rate of movement of HGRs across the countries, many localized and native HGRs are undervalued and underutilized. The significant role of HGRs has been realized in food, nutrition, health, business and environmental security across the world (FAO and CIRAD, 2021; Harris et al., 2022; Lutaladio et al., 2010; Pradhan et al., 2016). However, due to many intensive and modern technologies, genetic diversities in the fields are drastically reduced. This resulted in difficulties to tackle the stresses faced by uniform varieties (FAO, 2019). Genetic diversity in horticultural species is a must for developing suitable and high-yielding varieties for diverse localities, growers and consumers. Even in the context of climate changes, increased genetic diversity plays a crucial role to sustain the production of horticultural crops.

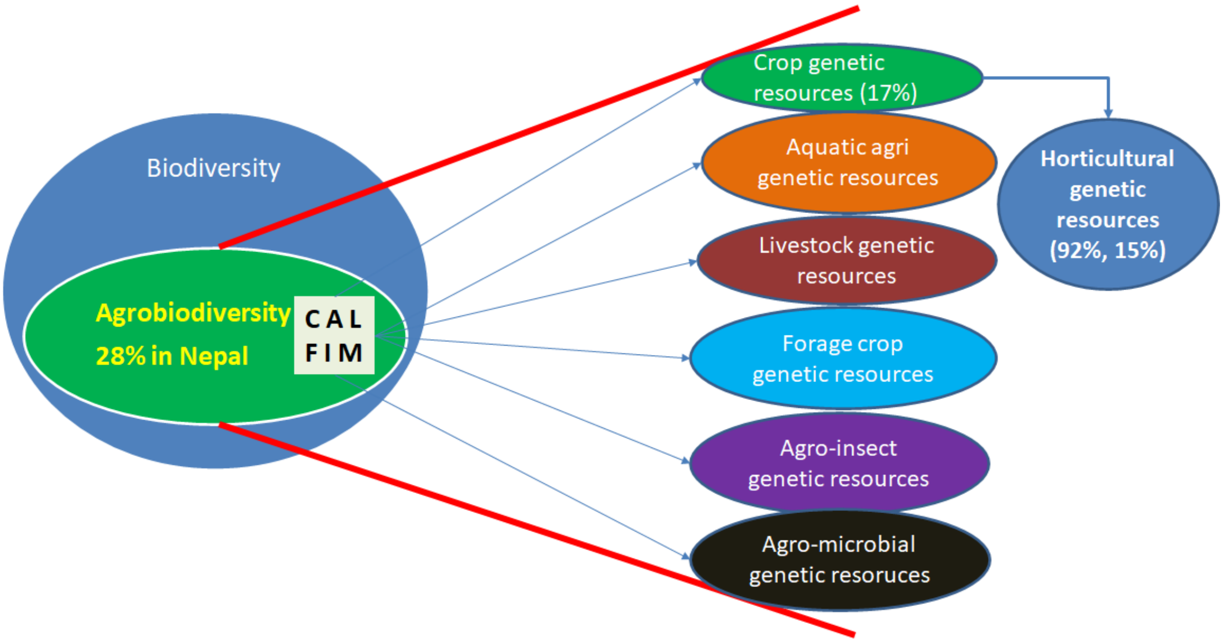


Figure 1. *Partitioning of biodiversity and agrobiodiversity into components. Percent figures share values of species richness in Nepal.*

Source: MoFSC, 2014; Joshi et al., 2020

The global scenario of vegetables and fruits areas, productions and productivities are given in Tables 1 and 2, respectively. The percent changes over the last decade in vegetables and fruits statistics are given in Figures 2 and 3 respectively. There is a large number of vegetable and fruit species, however, Food and Agricultural Organization (FAO) has maintained just 75 vegetable items and 50 fruit items in their database. On average, the percent increment over a decade in productivity of vegetables and fruits are 6.89 and 11.04% respectively. In the same decade, areas increment is 14.79 and 16.97% in vegetables and fruit cultivation respectively (Figures 2 and 3).

Table 1. Global areas, production and yield of vegetables along with % increment from 2011 to 2021

SN	Vegetables	Area harvested, ha		% increment	Total production, t		% increment	Yield, hg/ha		% increment
		2011	2021		2011	2021		2011	2021	
1.	Anise, badian, coriander, cumin, caraway, fennel and juniper berries, raw	1085459	2300303	111.92	953714	2698095.59	182.90	8786	11729	33.50
2.	Artichokes	127641	116350	-8.85	1476939.21	1470332.21	-0.45	115710	126371	9.21
3.	Asparagus	1454758	1594380	9.60	8191163.66	8501442.93	3.79	56306	53321	-5.30
4.	Broad beans and horse beans, green	257832	277445	7.61	1608614.93	1725395.71	7.26	62390	62189	-0.32
5.	Cabbages	2422430	2450601	1.16	69856412.95	71707238.96	2.65	288373	292611	1.47
6.	Carrots and turnips	1203531	1096007	-8.93	36568317.28	41666714.44	13.94	303842	380168	25.12
7.	Cassava leaves	7700	7798	1.27	85000	86574.72	1.85	110390	111015	0.57
8.	Cassava, fresh	22619846	29652105	31.09	265227404.5	314806747.6	18.69	117254	106167	-9.46
9.	Cauliflowers and broccoli	1199285	1378085	14.91	21995567.31	25843741.37	17.50	183406	187534	2.25
10.	Chicory roots	20244	3199	-84.20	596269.06	32176.95	-94.60	294547	100571	-65.86
11.	Chilies and peppers, dry (Capsicum spp., Pimenta spp.), raw	1652999	1619924	-2.00	3175497.58	4839309.17	52.40	19211	29874	55.50
12.	Chilies and peppers, green (Capsicum spp. and Pimenta spp.)	1903086	2055310	8.00	30284468.13	36286643.77	19.82	159133	176551	10.95

SN	Vegetables	Area harvested, ha		% increment	Total production, t		% increment	Yield, hg/ha		% increment
		2011	2021		2011	2021		2011	2021	
13.	Cinnamon and cinnamon tree flowers, raw	242133	304921	25.93	198837.07	226752.81	14.04	8212	7436	-9.45
14.	Cloves (whole stems), raw	403198	674200	67.21	104356.43	186969.31	79.16	2588	2773	7.15
15.	Cocoa beans	10253973	11535884	12.50	4614809.82	5580432.37	20.92	4501	4837	7.47
16.	Coffee, green	9929405	11331985	14.13	8387100.1	9917257.69	18.24	8447	8752	3.61
17.	Cowpeas, dry	10706537	14911307	39.27	4983975.48	8986191.25	80.30	4655	6026	29.45
18.	Cucumbers and gherkins	2090677	2172193	3.90	67916723.64	93528796	37.71	324855	430573	32.54
19.	Currants	114353	130336	13.98	640462.82	728730.08	13.78	56008	55912	-0.17
20.	Edible roots and tubers with high starch or inulin content, n.e.c., fresh	619719	705432	13.83	5509244.5	8293419.31	50.54	88899	117565	32.25
21.	Eggplants (aubergines)	1799292	1961799	9.03	45354775.29	58646098.21	29.31	252070	298940	18.59
22.	Ginger, raw	314340	449851	43.11	2415177.55	4895972.32	102.72	76833	108835	41.65
23.	Green garlic	1385130	1659236	19.79	23091949.65	28204854.32	22.14	166713	169987	1.96
24.	Hempseed	5573	11422	104.95	2839.1	5566.02	96.05	5094	4873	-4.34
25.	Leeks and other alliaceous vegetables	130663	134168	2.68	2126209.89	2213183.35	4.09	162725	164956	1.37
26.	Lettuce and chicory	1149499	1213340	5.55	25106875.44	27011747.55	7.59	218416	222623	1.93
27.	Locust beans (carobs)	44964	14722	-67.26	157418.73	51906.58	-67.03	35010	35258	0.71
28.	Lupins	964544	984191	2.04	1322543.77	1384963.65	4.72	13712	14072	2.63
29.	Maté leaves	267984	274610	2.47	774524	1515231.05	95.63	28902	55178	90.91
30.	Natural rubber in primary forms	9639623	12929189	34.13	11619706.89	14021987.53	20.67	12054	10845	-10.03
31.	Nutmeg, mace, cardamoms, raw	303874	469631	54.55	73958.42	146952.34	98.70	2434	3129	28.55
32.	Okra	1696069	2478132	46.11	8029022.45	10822248.74	34.79	47339	43671	-7.75
33.	Olives	10067577	10338179	2.69	21304445.43	23054310.6	8.21	21161	22300	5.38
34.	Onions and shallots, dry (excluding dehydrated)	4364246	5778769	32.41	85192519.39	106592088.9	25.12	195206	184455	-5.51
35.	Onions and shallots, green	236122	215934	-8.55	4594672.72	4562530.02	-0.70	194589	211292	8.58
36.	Other beans, green	1499284	1586086	5.79	20149490.75	23411172.66	16.19	134394	147603	9.83
37.	Other stimulants, spice and aromatic crops, n.e.c.	1363205	1408950	3.36	2784879.72	3152943.3	13.22	20429	22378	9.54
38.	Other vegetables, fresh n.e.c.	18422626	20498902	11.27	261176479.7	292200232.7	11.88	141769	142544	0.55
39.	Peas, green	2212922	2590367	17.06	16916713.58	20529759.32	21.36	76445	79254	3.67
40.	Pepper (Piper spp.), raw	541403	678215	25.27	419450.8	793817.98	89.25	7747	11705	51.09
41.	Peppermint, spearmint	2691	2070	-23.08	62930.81	37987.7	-39.64	233848	183488	-21.54
42.	Poppy seed	129006	43160	-66.54	107268.04	23670.7	-77.93	8315	5484	-34.05
43.	Potatoes	18699490	18132694	-3.03	368983872.2	376119974.4	1.93	197323	207426	5.12
44.	Pumpkins, squash and gourds	1786300	1501696	-15.93	23666261.79	23783936.41	0.50	132488	158380	19.54
45.	Pyrethrum, dried flowers	19089	19008	-0.42	7459	6082.97	-18.45	3907	3200	-18.10
46.	Spinach	862713	921158	6.77	21183697.91	32294452.3	52.45	245547	350585	42.78
47.	String beans	219677	136328	-37.94	1925561.72	1310002.11	-31.97	87654	96092	9.63
48.	Sugar beet	5074334	4399396	-13.30	278756560	270156001.2	-3.09	549346	614075	11.78
49.	Sweet potatoes	7853702	7410026	-5.65	94303980.84	88867913.29	-5.76	120076	119929	-0.12

S N	Vegetables	Area harvested, ha		% increment	Total production, t		% increment	Yield, hg/ha		% increment
		2011	2021		2011	2021		2011	2021	
50.	Taro	1287634	1793703	39.30	10435313.64	12396248.5	18.79	81043	69110	-14.72
51.	Tea leaves	3409725	5245319	53.83	19550189.42	28191556.18	44.20	57337	53746	-6.26
52.	Tomatoes	4589578	5167388	12.59	159820652.6	189133955	18.34	348225	366015	5.11
53.	True hemp, raw or retted	45250	74307	64.21	96589.05	287318.37	197.46	21346	38666	81.14
54.	Unmanufactured tobacco	4220304	3132322	-25.78	7450252.96	5888763.52	-20.96	17653	18800	6.50
55.	Watermelons	3205294	3031544	-5.42	94572802.21	75142630.14	-20.55	295052	335257	13.63
56.	Yams	6529156	8685624	33.03	53114164.08	378774.11	-99.29	81349	86514	6.35
57.	Yautia	43636	30674	-29.70	394480.47	101634719.7	25664.20	90404	123483	36.59

nec, not elsewhere classified. Source: FAO, 2023

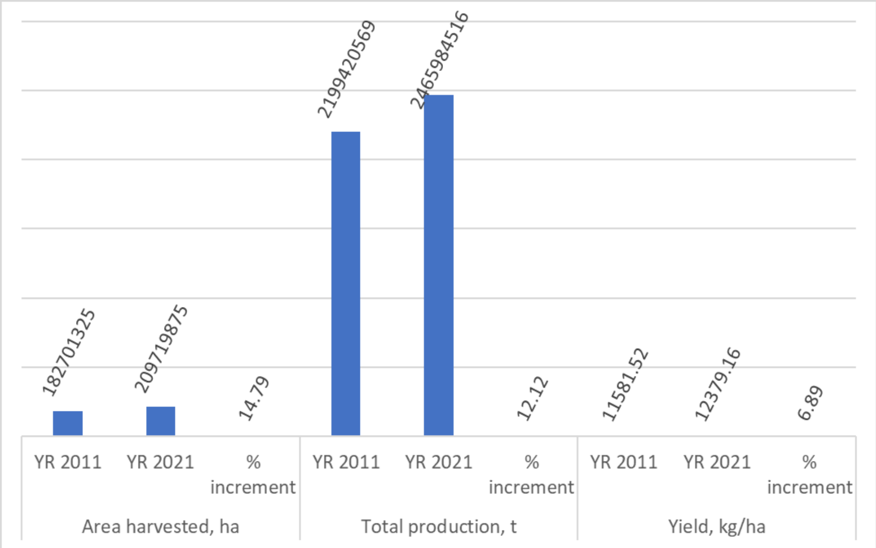


Figure 2. *Vegetable statistics in the world over the last decade.*
57 vegetable items have been listed in FAO database

Source: FAO, 2023

Table 2. Global areas, production and yield of fruits along with percent increment from 2011 to 2021

S N	Fruits	Area harvested, ha		% increment	Total production, t		% increment	Yield, hg/ha		% increment
		2011	2021		2011	2021		2011	2021	
1.	Almonds, in shell	1748085	2283414	30.62	3078565.68	3993998.06	29.74	17611	17491	-0.68
2.	Apples	4961558	4822226	-2.81	77073275.75	93144358.2	20.85	155341	193156	24.34
3.	Apricots	535877	551874	2.99	3811997.27	3578412.14	-6.13	71136	64841	-8.85
4.	Areca nuts	873694	1568461	79.52	1213600	2434584	100.61	13890	15522	11.75
5.	Avocados	445261	858152	92.73	4066609.72	8685672.44	113.59	91331	101214	10.82
6.	Bananas	5477518	5336862	-2.57	109503176.5	124978578	14.13	199914	234180	17.14
7.	Blueberries	89630	163741	82.69	438728.46	1113260.6	153.75	48949	67989	38.90
8.	Cantaloupes and other melons	1109073	1077369	-2.86	25992318.57	28617598.4	10.10	234361	265625	13.34
9.	Cashew nuts, in shell	5538555	6564818	18.53	3231813.66	3708153.12	14.74	5835	5649	-3.19
10.	Cashew apple	833645	495167	-40.60	2023560.13	1363452.62	-32.62	24274	27535	13.43
11.	Cherries	402182	451064	12.15	2155190.39	2732413.19	26.78	53587	60577	13.04
12.	Chestnuts, in shell	522090	568175	8.83	2037260.9	2269923.97	11.42	39021	39951	2.38
13.	Coconuts, in shell	11755208	11307699	-3.81	59747574.22	63683595.4	6.59	50826	56319	10.81
14.	Cranberries	23457	23591	0.57	462723.77	495172.83	7.01	197262	209899	6.41

S N	Fruits	Area harvested, ha		%	Total production, t		%	Yield, hg/ha		%
15.	Dates	1125277	1301979	15.70	7265034.05	9656377.75	32.92	64562	74167	14.88
16.	Figs	309401	299541	-3.19	1066508.2	1348254.74	26.42	34470	45011	30.58
17.	Gooseberries	30265	17939	-40.73	167508.67	91017.56	-45.66	55348	50736	-8.33
18.	Grapes	6919264	6729198	-2.75	69120685.62	73524196.2	6.37	99896	109261	9.37
19.	Hazelnuts, in shell	624554	1039147	66.38	744976.17	1077117.1	44.58	11928	10365	-13.10
20.	Jojoba seeds	309	296	-4.21	152.24	140.07	-7.99	4927	4732	-3.96
21.	Kapok fruit	194259	183820	-5.37	324623.82	280970.94	-13.45	16711	15285	-8.53
22.	Kiwi fruit	175801	286934	63.22	2908199.35	4467099.33	53.60	165426	155684	-5.89
23.	Kola nuts	534041	565857	5.96	278231.53	311331.44	11.90	5210	5502	5.60
24.	Lemons and limes	954255	1338321	40.25	15046902.92	20828739.4	38.43	157682	155633	-1.30
25.	Mangoes, guavas and mangosteens	5128651	5974437	16.49	39718599.17	57011282.8	43.54	77445	95425	23.22
26.	Melon seed	911393	1842737	102.19	834526.55	953581.05	14.27	9157	5175	-43.49
27.	Oil palm fruit	20383880	28909789	41.83	296436243.6	416396560	40.47	145427	144033	-0.96
28.	Oranges	4039990	3932648	-2.66	72443805.66	75567951.8	4.31	179317	192155	7.16
29.	Other berries and fruits of the genus vaccinium n.e.c.	115281	156316	35.60	823551.13	999633.51	21.38	71438	63950	-10.48
30.	Other citrus fruit, n.e.c.	1309569	1481503	13.13	11122884.54	13896888.9	24.94	84935	93803	10.44
31.	Other fruits, n.e.c.	5100779	5428549	6.43	31668977.21	39804664	25.69	62087	73325	18.10
32.	Other nuts (excluding wild edible nuts and groundnuts), in shell, n.e.c.	574031	908778	58.32	849836.91	1032723.16	21.52	14805	11364	-23.24
33.	Other pome fruits	11000	19019	72.90	39910	130901.08	227.99	36282	68825	89.69
34.	Other stone fruits	70226	69942	-0.40	497894.89	572730.66	15.03	70899	81887	15.50
35.	Other tropical fruits, n.e.c.	3166845	3354594	5.93	20865789.67	25771992.4	23.51	65888	76826	16.60
36.	Papayas	411476	486161	18.15	11623295.49	14097721.4	21.29	282478	289981	2.66
37.	Peaches and nectarines	1545625	1504682	-2.65	21222568.98	24994352.1	17.77	137307	166110	20.98
38.	Pears	1575849	1399484	-11.19	24055494.85	25658713.1	6.66	152651	183344	20.11
39.	Persimmons	879815	1032183	17.32	3951126.03	4332166.55	9.64	44909	41971	-6.54
40.	Pineapples	969906	1046712	7.92	22792377.21	28647865.7	25.69	234996	273694	16.47
41.	Pistachios, in shell	536915	817025	52.17	624147.91	915717.92	46.71	11625	11208	-3.59
42.	Plantains and cooking bananas	4560935	6792294	48.92	28827036.79	45321643	57.22	63204	66725	5.57
43.	Plums and sloes	2503741	2602436	3.94	11007174.87	12014481.7	9.15	43963	46166	5.01
44.	Pomelos and grapefruits	324296	360892	11.28	7922822.45	9556999.07	20.63	244308	264816	8.39
45.	Quinces	68146	75894	11.37	571713.86	697562.6	22.01	83896	91913	9.56
46.	Raspberries	107201	110567	3.14	599451.08	886538.58	47.89	55918	80181	43.39
47.	Sour cherries	227003	224425	-1.14	1251546.71	1514664.81	21.02	55133	67491	22.41
48.	Strawberries	324084	389665	20.24	6377556.57	9175384.43	43.87	196787	235468	19.66
49.	Tangerines, mandarins, clementines	2296311	3109051	35.39	27546384.18	41950301.7	52.29	119959	134930	12.48
50.	Walnuts, in shell	1121902	1137788	1.42	3210852.52	3500172.86	9.01	28620	30763	7.49

nec, not elsewhere classified. Source: FAO, 2023

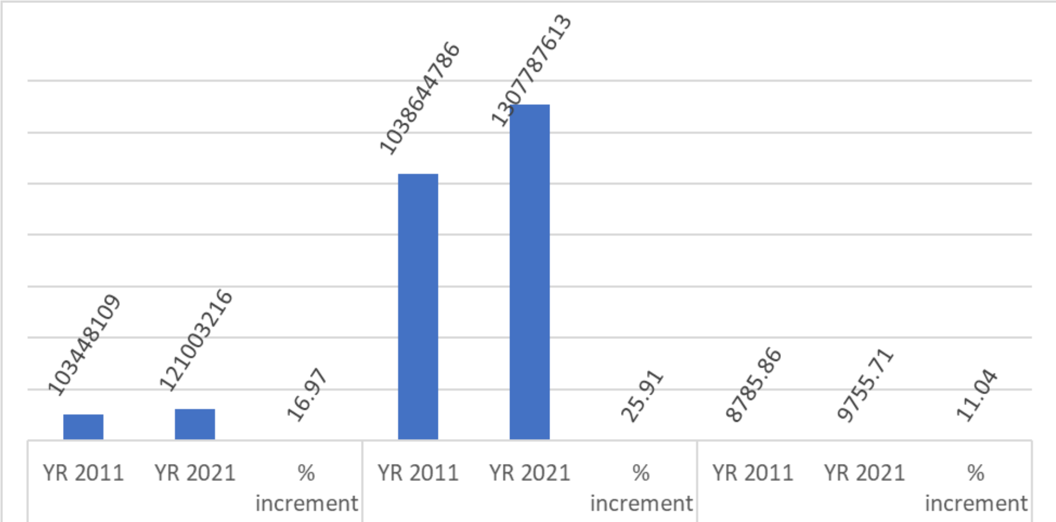


Figure 3. *Fruit statistics in the world over the last decade. 50 fruit items have been listed in FAO database.*

Source: FAO, 2023

A high degree of horticultural biodiversity is directly related to the success of the production and other horticultural business in a diverse environment and the context of climate changes. The advancement in science has expanded the horizon of these HGRs. Knowledge of horticultural biodiversity is very useful to develop technologies for food, nutrition, health, business and environmental security. This paper is developed, therefore, to document the status of HGRs along with their conservation, utilization and drivers on shaping HGRs around the world. This paper is based on a literature review and many different databases along with the authors' experiences.

Grouping horticultural plant genetic resources

HGRs are very diverse and include many species. Among the three systems of grouping (namely botanical, economical and operational classification), economical grouping is very common and familiar to many diverse people. This grouping is also widely used to manage HGRs in Genebank, research and the market. The common groups of HGRs are given in Figure 4. The figure above the group box is the total number of species reported in Nepal. HGRs in Nepal have been distributed from 60 to 4700 m asl.

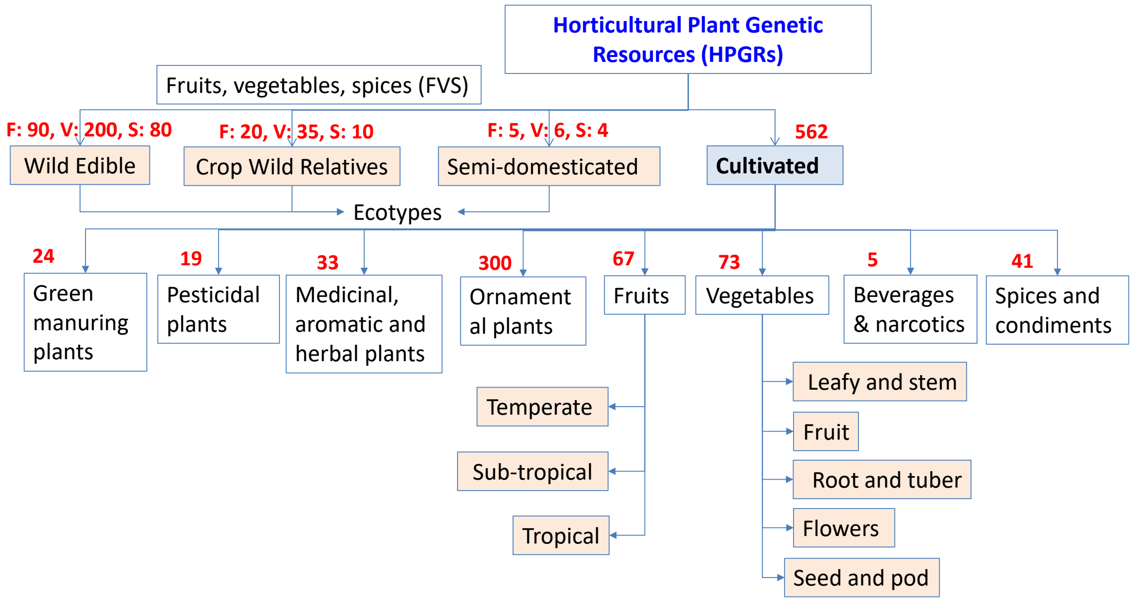


Figure 4. *Grouping of horticultural genetic resources based on economic values and uses*

Source: Joshi et al., 2017, 2020; Joshi, 2022; Pandey et al., 2017; Shrestha et al., 2017; Upadhayay and Joshi 2003.

Horticultural biodiversity

The exact number of plant species in the world is not known, as new species are still being discovered and described by scientists. In the world, a total 320,000 plant species have been reported. Bryophytes contain over 10,000 species of mosses and worts. Pteridophytes contain slightly more, at 12,000 species of ferns. Gymnosperms are individually numerous but are divided into a very small number of species, about 1,100. Angiosperms contain by far the highest number, with almost 300,000 different species of flowering plants (https://a-z-animals.com/blog/how-many-plants-are-in-the-world/). Among them, 50,000 are edible and 7,000 are under cultivation (Figure 5). but only 30 crops provide about 95% of the world's food energy intake (https://www.fao.org/3/y5609e/y5609e02.htm).

In the world, more than 1,097 species of vegetables are present. According to the FAO, there are more than 1,000 known species of vegetables that are used for food and this number doesn't include all the wild vegetables that are not commonly cultivated or consumed. The most popular vegetables in the world are cassava, potato and cowpea in terms of area and potato, cassava and sugar beet in terms of production. In the case of fruits, there are around 2000 fruits in the world (https://www.javatpoint.com/list-of-fruits). According to the FAO, there are more than 1,000 known species of fruits that are used for food. However, this number does not include all the wild fruits that are not commonly cultivated or consumed. The top four most popular fruits in the world are coconut, plantain, grape and cashew nut in terms of area. Based on production quantities, the most popular fruits worldwide in order are bananas, apples, oranges and grapes.

According to the Royal Botanic Gardens, Kew, there are approximately 30,000 species of plants that are used for ornamental purposes worldwide. The most popular ornamental plant species in the world are roses, tulips and orchids. Roses are one of the most popular and widely grown ornamental plants in the world. They are prized for their beautiful flowers, which come in a variety of colors and fragrances. Tulips are another popular ornamental plant that is grown for their brightly colored flowers. They are commonly used in flower beds and as cut flowers. Orchids are a diverse group of ornamental plants that are prized for their exotic beauty and unusual flowers. They are commonly used as houseplants and in floral arrangements (ChatGPT, personal communication March 2023).

Information around the world is not available on species richness of medicinal, pesticidal, green manuring, beverages and spices plants. In Nepal, there are a total of 1012 horticultural species and 94 agronomic species. Species richness under different groups is given in Table 3. At varietal levels, the number of released, registered and denotified varieties are given in Figure 6. HGRs are very important for food, nutrition, health, business and the environment. Many insects and animals depend on HGRs for their survival. Therefore, farming areas should be insects friendly, birds friendly and microbes-friendly.

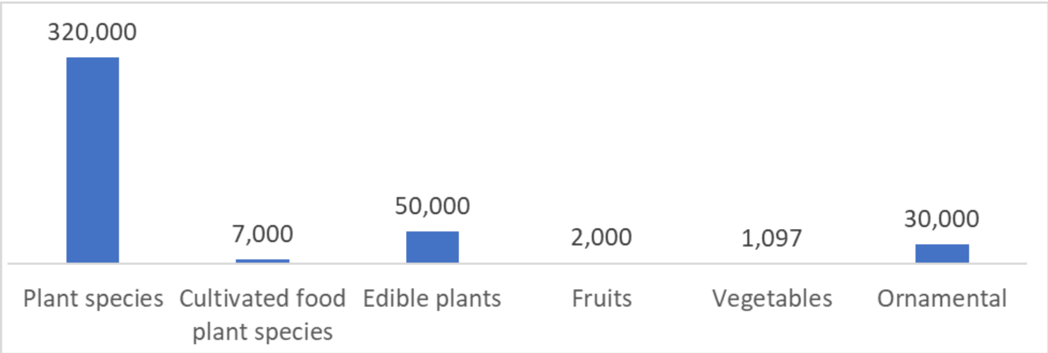


Figure 5. *Number of plant species in the world*

Source: FAO, 1999; MacEvilly, 2003; Joshi et al., 2017, 2022; https://www.javatpoint.com/list-of-fruits

Table 3. Number of horticultural plant species available in Nepal

SN	Horticultural plant group	Domesticated	Semi domesticated	Wild relatives	Wild edible	Landraces	Exotic species (varieties)
1.	Vegetables	73	6	35	200	7000	15
2.	Fruits	67	5	20	90	4500	20?

S N	Horticultural plant group	Domesticated	Semi domesticated	Wild relatives	Wild edible	Landraces	Exotic species (varieties)
3.	Spices and condiments	41	4	10	80	500	5
4.	Ornamental plants	300	-	-	-	-	100
5.	Medicinal, aromatic and herbal plants	33	-	-	-	-	-
6.	Pesticidal plants	19	-	-	-	-	-
7.	Green manuring plants	24	-	-	-	-	-
8.	Beverages and narcotics	5	-	-	-	-	-
	Total	562	15	65	370	12000	140

Source: Bhatta, 2021; Gautam and Gotame, 2020; Joshi et al., 2022, 2020, Pandey et al., 2017; Poudel and Joshi, 2020; Pradhan et al., 2016; Shrestha et al., 2017; Upadhayay and Joshi, 2003; MoFSC, 2014

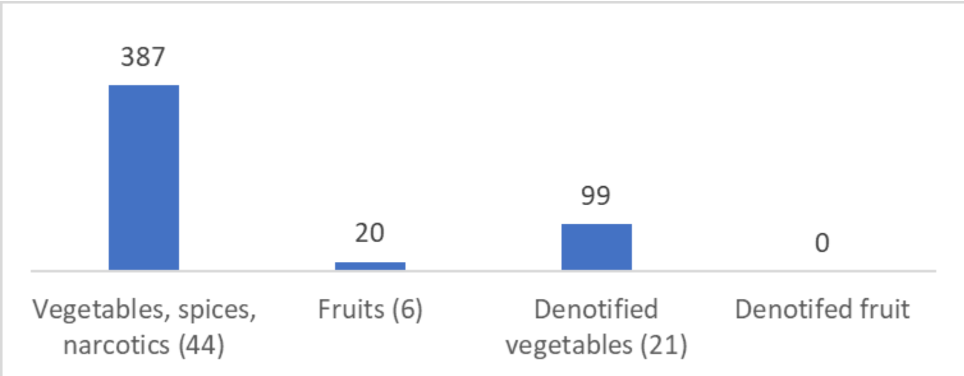


Figure 6. *Total released and registered varieties and denotified horticultural varieties in Nepal*

Source: SQCC, 2023

Horticultural Practices and genetic erosion

A very common practice is to promote and grow uniform and homogenous varieties i.e. monoculture. In many cases, the same rootstock has been used for many varieties and species. Asexual propagation is widely adopted to maintain genetic purity whereas this technique completely arrests the meiotic variation and evolution is almost zero. Evolution and development of new genotypes are very common in a sexual method of propagation but this is almost zero in the asexual system. Protected agriculture is also a common practice in horticulture, which also does not favor the associated biodiversity e.g., agro-insects, pollinators, microbes, etc. The genetic diversities of HGRs are now confined in buildings by the name of Genebank and in certain areas by the name field genebank. The genetic diversity in the production fields is very narrow. These practices have triggered the loss of HGRs across the world. FAO reported that since the 1900s, some 75% of plant genetic diversity were lost as farmers worldwide have left their local varieties and landraces for genetically uniform, high-yielding varieties (FAO 1999). In Nepal, 50% of horticultural biodiversity has been lost (Joshi et al 2020).

Conservation

Major strategies for the conservation of HGRs are ex-situ, on-farm, in-situ and breeding based on action sites. Other strategies based on governance are local-level conservation, province-level, national-level and international-level conservation (Figure 2). Within these strategies, more than 70 good practices and approaches are in practice for the conservation and utilization HGRs (Joshi et al., 2020; Sharrock, 2020; FAO, 2019). Some of them are Seed banks, Field genebank, Agro gene sanctuary, Tissue bank, DNA bank, School field genebank, Community gene banks (seed and field genebank), Household genebank, agro-garden/ park, aqua pond genebank, herbal conservation gardens, etc. Pollinators are also very important for the maintenance of genetic diversity, therefore, agro-insect field genebank is also found in many countries. Some of the techniques under conservation through use are cultivar mixture, evolutionary plant breeding, product diversification, site-specific variety development, geographical indication, agro-plantation, etc. Red zoning and red listing of HGRs are rarely used to identify the priority germplasm for conservation and germplasm rescue. Agrobiodiversity impact assessment (AIA) of any projects is also not integrated before project implementation. AIA promote to manage important and endangered HGRs along with agricultural genetic resources following different actions and strategies.

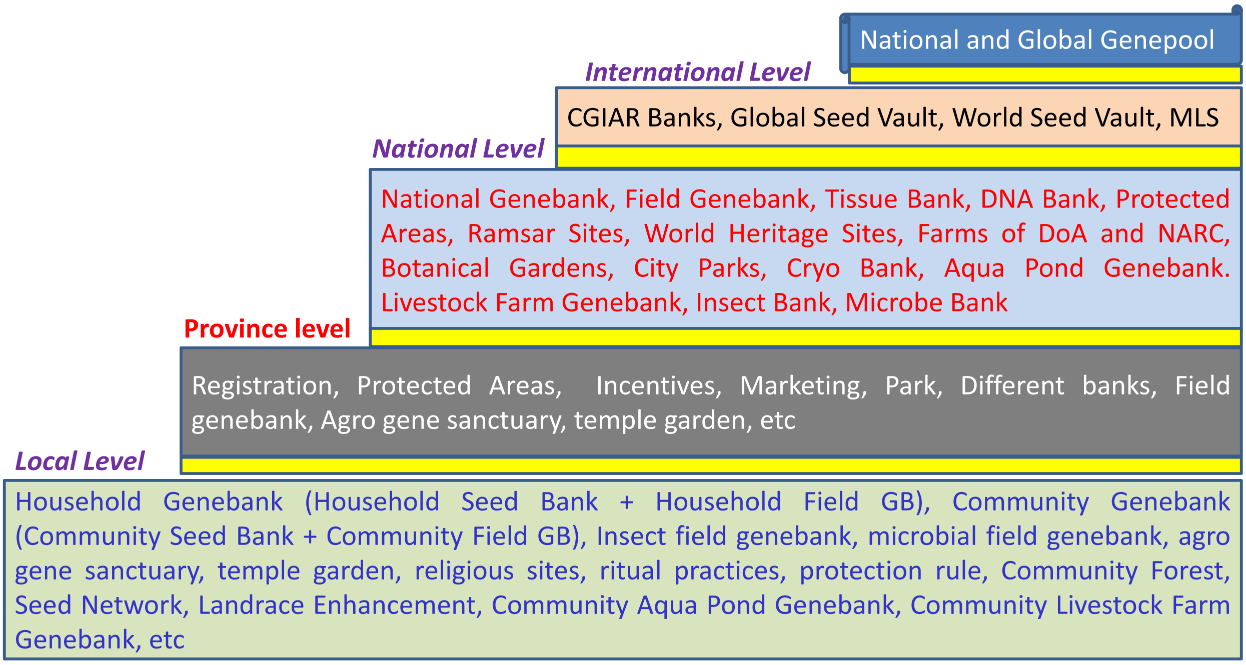


Figure 7. *Governance-based strategy and methods for conservation of HGRs*

Source: Joshi et al., 2017

Box 1. Conservation status of HGRs in global genebank

Total genebanks in the world: 1,750 genebanks with about 7.4 million samples of crop diversity

1. Svalbard global seed vault: 1,214,827 seed samples of 5,000 plant species
2. MLS: 135110 accessions of vegetables, 27426 accessions of fruits
3. World vegetable center: 65,152 accessions of 330 species from 155 countries
4. CGAIR: Total 11 genebanks and among the 6 (Africa rice, CIMMYT, ICARDA, ICRISAT, ILRI, IRRI) does not deal HGRs
    - Bioversity international (ITC): >1,500 accessions of banana
    - CIAT: 6000 varieties of cassava
    - CIP: 9000 accessions of potato, 5,500 accessions of sweet potato, 2500 accessions of Andean root and tuber crops
    - IITA: 4000 accessions of cassava, 4000 of yam and 283 of banana
    - World agroforestry: 5,393 accessions of 190 fruit and multipurpose tree species
5. Potato park in Peru: >1,400 native varieties of potato
6. Centre for Pacific Crops & Trees (CePaCT): 358 accessions of yam and taro
7. International Cocoa Genebank: 2,000 types of cocoa
8. Mutant Germplasm Repository of the FAO/IAEA: Mutant of few vegetatively propagated crops
9. International Coconut Genebank for the South Pacific: 55 accessions
10. International Coconut Genebank-South Asia and Middle East: 45 accessions

Source: https://www.genesys-pgr.org/; https://www.cgiar.org/research/program-platform/genebank-platform/, https://www.fao.org/plant-treaty/areas-of-work/the-multilateral-system/collections/en/

Total accessions of HGRs conserved in different banks are given in Box 1 and Figure 2. The majority of these accessions are available through the Genesys web portal (https://www.genesys-pgr.org/). Nepal Genebank has conserved a total of 1951 accessions. Conservation is more focused on orthodox types of HGRs and mainly vegetables and fruits. Other groups of HGRs, e.g., medicinal, green manuring, pesticidal and crop wild relatives (CWRs) are poorly conserved.

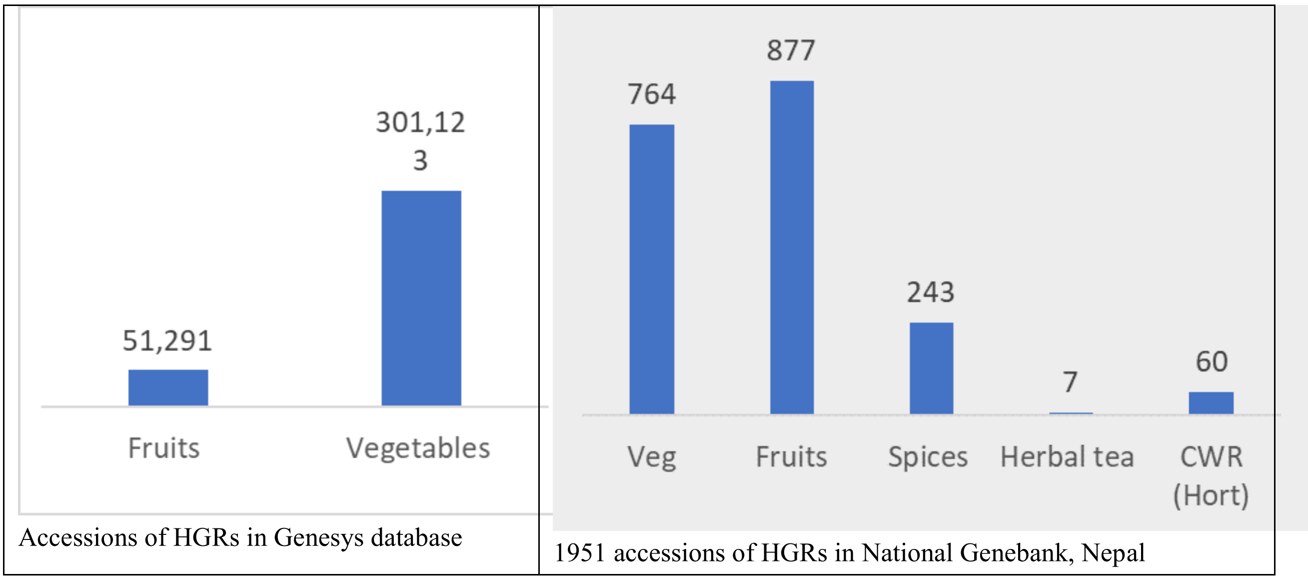


Figure 8. *Accessions of HGRs in Genesys database and Nepal Genebank*

Source: https://www.genesys-pgr.org/; NAGRC, 2022.

Utilization and Breeding

A large number of HGRs are being conserved in many national and international genebanks. Utilizations of these HGRs are limited to breeding, characterization, molecular screening, DNA and nutrition profiling, tissue culture, hybridization, selection, stress tolerance capacity, etc. An introduction is the major breeding method adopted widely across the country. This sometimes resulted in a higher degree of environmental shock which causes crops to produce and adapt poorly. Many wild HGRs and crop wild relatives are very poorly utilized in research and production. A formal system of variety registration and release has also limited the utilization of many native HGRs in many countries.

Advanced technology for conservation and utilization of HGRs

Omics technology has been applied in temperate, tropical and subtropical fruits, fruit nuts, berries, vegetables, tuberous crops, ornamental and floricultural crops and medicinal aromatic plants. Information covering phenomics, genetic diversity, phylogenetic studies, genome sequencing and genome barcoding through the utilization of molecular markers is available. This information is a valuable resource for researchers and academics seeking to improve cultivar productivity through enhanced genetic diversity while also retaining optimal traits and protecting the growing environment. Significant advancement has been made in molecular breeding, genome sequencing, genome editing (Xu et al., 2019) and in-vitro technology for HGRs conservation and utilization. 181 crops of HGRs have been sequenced (Figure 4) (Chen et al 2019). Advanced conservation banks of HGRs have been well established e.g., DNA banks, cryobank, tissue banks, pollen banks, etc. Through the conventional breeding system, a highly resistant to greening disease variety of sweet orange has been developed in 2006 in the USA. This variety called Sugar Belle Mandarins was the cross-product of Clementine/Minneola tangelo.

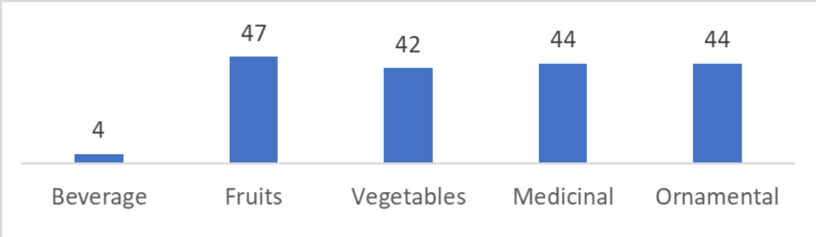


Figure 9. *Distribution of genome-sequenced horticultural plants under different groups*

Source: Chen et al., 2019

Many HGRs have been genetically engineered and widely cultivated around the world (Baranski et al 2019). The first-ever commercialized genetically modified (GM) product was a horticultural crop plant, the Flavr Savr™ tomato, that appeared on the US market in 1994. The use of RNAi technology (gene silencing tech) to develop PRSV-resistant transgenic papaya is a very successful case (Jia et al 2016). GMO varieties have been developed on vegetable species (eg chicory, common bean, eggplant, melon, squash and tomato), fruit species (eg apple, papaya, pineapple, plum) and ornamental plant species (eg. carnation, petunia, rose) (Baranski et al., 2019). In horticulture, OTO (organ transplanted organism) is a very old and common technology used for yield increment, stress management and rapid multiplication. GMOs and OTO differ from each other in that the transgene inherits generation to generation in GMOs but not in OTO. The economic yields of OTO is not natural and pure as there is a combination of two different genotypes.

Horticultural biodiversity and climate changes

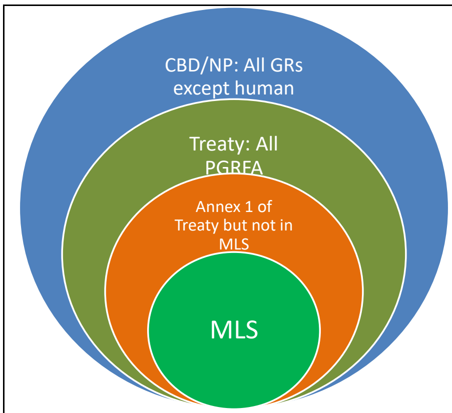
Earth's temperature has risen by an average of 0.08° Celsius per decade since 1880 (www.climate.gov, 2023). The global surface temperature for 2022 was the sixth highest since record-keeping began in 1880 (NOAA, 2022 Global Climate Summary). These climate changes have caused genetic erosion of HGRs, failure of crop production and poor adaptation of HGRs (Alemnew and Assefa, 2021; Muluneh, 2021). To cope with climate changes, we need more genetic diversity and a high degree of intra and inter-varietal diversity along with the site-specific evolving population (Sthapit et al., 2012). Advanced tech is necessary to apply for developing stress tolerance genotypes using climate-smart germplasm and climate-smart plant breeding.

Policy Framework and Protection of HGRs

Major international treaties and agreements are CBD and ITPGRFA which govern the management and utilization aspects of biodiversity. The Convention on Biological Diversity (CBD) was established in 1992 and has 196 parties. Nepal became a party in 1994. The Convention has three main objectives, conservation, sustainable use and fair and equitable sharing of the benefits of biological diversity. Two very common protocols, called Cartagena and Nagoya are the global agreement to implement and support CBD objectives. After CBD there is a paradigm shift in biodiversity access and uses. Biodiversity is a national resource, conservation efforts shifted to in-situ, access to genetic resources is based on negotiation and under property rights, benefits should be shared and biodiversity is becoming a more legal issue, rather than technical issue.

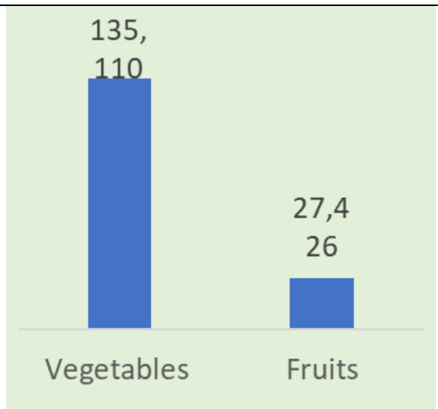
The Cartagena Protocol on Biosafety to the Convention on Biological Diversity is an international agreement that aims to ensure the safe handling, transport and use of living-modified organisms (LMOs) resulting from modern biotechnology that may have adverse effects on biological diversity, taking also into account risks to human health. It was adopted on 29 January 2000 and now there are 173 parties. Nepal is not a party. The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity is an international agreement that aims at sharing the benefits arising from the utilization of genetic resources fairly and equitably. It entered into force on 12 October 2014. Currently, there are 138 parties and Nepal became a party in 2019. The member countries can develop their own access and benefit sharing (ABS) mechanism. Nepal still has not developed ABS, but India has well-functional ABS. The benefit sharing provision in India is that if the user himself commercializes the process/product/innovation, the monetary sharing shall be 0.2% on the annual gross ex-factory sale minus government taxes. If the user assigns/licenses the process/product/innovation to a third party for commercialization, the user shall pay NBA 3.0% of the fee received (in any form including the license/assignee fee) and 2.0% of the royalty amount received annually from the assignee/licensee.

The international treaty on plant genetic resources for Food and Agriculture (ITPGRFA) aims at guaranteeing food security through the conservation, exchange and sustainable use of the world's plant genetic resources. It is adopted in 2001 and has now 150 parties. Nepal became a party in 2009. It has a provision for a Multilateral system (MLS), ABS and benefit sharing fund (BSF) and Farmers' rights. MLS is a global gene pool of the most important crop genetic resources shared and managed jointly by all contracting parties (COPs) and has Annex 1 with 64 crops. Scope and total HGRs under Annex 1 and MLS are given in Figure 3.



Scope of ITPGRFA and Nagoya Protocol

HGRs in Annex 1 of ITPGRFA



Total accessions of vegetables and fruits in MLS (https://www.genesys-pgr.org/)

Figure 10. *Coverage of ITPGRFA and Nagoya Protocol and HGRs in Annex 1 and MLS*

UPOV and WIPO are the two global forums that support, promote, provide and guide the protection of HGRs. The International Union for the Protection of New Varieties of Plants (UPOV) was adopted in 1961 and currently, there are 78 countries as members. Nepal is not a member. Up to the end of 2021, 331,078 titles of protection had been granted by members of the Union. More than 800 taxa have been protected, which are mostly vegetables, fruits and ornamental plants. The World Intellectual Property Organization (WIPO), is a global forum for intellectual property (IP) services, established in 1967. It has 193 member states including Nepal and she joined WIPO in 1997. HGRs are protected through UPOV and geographical indication (GI). GI has been applied to 314 items from 2010 to 2023.

National policy and awareness events

Many national policies in Nepal have a provision for the conservation and utilization of native and local genetic resources. However, it is very common to promote a single commodity (uniform and homogenous) in large-scale commercialization areas. Value addition and domestication are not commonly implemented in Nepal for the promotion of native and wild HGRs.

To recognize the value and importance of HGRs, many countries around the world have declared national fruit (eg mango, apple, durian, banana, jackfruit, pineapple), national vegetable (pumpkin, lady's finger), national flower (lotus, rhododendron, jasmine, poppy). Nepal has also initiated to declare a national fruit and sweet orange (Suntalaa) is recognized as potential one. The importance of HGRs has also been promoted by celebrating decades, years and days as given below,

- 2011–2020: United Nations Decade on Biodiversity
- 2021–2030: United Nations Decade on Ecosystem Restoration
- 2021: International Year of Fruits and Vegetables
- 22 May: International Day for Biological Diversity
- 21 May: International Tea Day
- 2074-2083BS: Fruit decade (in Nepal)
- 2079BS: National agrobiodiversity year (in Nepal)

Key Issues and a way forward

Very few varieties of HGRs have dominated the world and therefore high degrees of genetic erosion is being observed. Modern production techniques of the horticultural crop also negatively affected the native HGRs and associated biodiversity (agro-insects, agro-microbes, etc.). Productions of many HGRs are not region and season based. Focus has been given due attention to developing uniform, widely adopted and non-evolutionary varieties. However, in an earlier period, there were many site-specific, evolutionary and broad genetic varieties around the world. Dependency is very high in foreign countries for seeds and saplings of HGRs. Policy and breeding strategies should therefore, be reoriented to promote and support increasing the genetic diversity in the fields (for resilient agriculture) as well as having nature +ve production.

Conclusion

Horticultural science is very advanced in terms of manipulating genetic makeup, production and developing diverse genotypes. On the other hand, these advances have caused genetic erosion of HGRs from the fields. Thousands of HGRs are now statically conserved in Genebank. Many species are also available in the wild (Poudel and Joshi, 2020) and it is necessary to work for domestication. Fruits and vegetables have been given a lot of effort but very limited works have been carried out on medicinal, green manuring, ornamental and pesticidal plant species. Thousands of germplasm and huge database are available online however their utilization and contribution have not been realized at the ground level (both to farmers, consumers and researchers). The policy should favor site-specific with broad genetic base genotypes. Different conservation approaches have been adopted across the world and some of them are seed bank, tissue bank, DNA bank, field genebank, school field genebank, community genebank, park and agro gene sanctuaries, etc. In addition, there is a need of diversifying the rootstock and propagating from seeds (to maintain and create genetic diversity). Production and research domains should be insect, bird and microbe friendly. Agroecosystem-based HPGRs should be genetically enhanced and promoted for food, nutrition, business, environment and conservation. Some potential methods are marker-assisted selection, site-specific variety development through hybridization, heterosis breeding, domestication, evolutionary plant breeding, participatory landrace enhancement, etc.

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