

Review Article

Advances in fruit breeding in Nepal

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Received: June 27, 2019; Accepted: October 18, 2019; Published: January 7, 2020

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ABSTRACT

Nepal has spent about six decades on fruit development and research in different species. Fruit breeding particularly local and exotic germplasm collection started after 1950s and has gained momentum after the formation of commodity programme in 1972 AD. Major researches in the past were focused on indigenous and exotic genotype collection, evaluation, selection, propagation protocol standardization and adoptive trials. Some good ground works have already been done in major fruits such as apple, pear, plum, persimmon, kiwifruit, citrus, litchi, guava, pomegranate, walnut, papaya, banana and mango. The major public institutions involved in fruit breeding are Nepal Agricultural Research Council (NARC) following Agriculture and Forestry University. Some of the private nurseries like Everything Organic Nursery, Kavre and Technology Demonstration Centre of ICIMOD, Lalitpur were also involved in introduction and maintenance of indigenous and exotic fruit species. National Centre for Fruit Development, Kirtipur; Tropical Region Horticulture Centre, Nawalpur; Temperate Horticulture Farm, Satbanj, and Horticulture Farm, Marpha collected many local and exotic fruits and maintained at field gene bank. Horticulture Research Station, Rajkot has introduced 25 spur type apple cultivars and maintained in field gene bank. National Citrus Research Programme, Paripatle has introduced, collected and maintained 130 genotypes including exotic and indigenous landraces of citrus. Two varieties of acid lime 'Sunkagati-1' and 'Sunkagati-2' have been released and one variety 'Terhathum Local' has been registered. 'Khoku Selection' of mandarin orange has also been registered. Banana varieties 'Malbhog', 'William Hybrid' and 'G9' has been selected by participatory varietal selection and registered. To strengthen fruit breeding in the nation, NARC needs to be restructured with special focus on fruit researches. Establishment of national fruit commodity programs along with establishment of Tropical Fruit Research Station in Province 2 and Temperate Fruit Research Station in Province 5 at national level can streamline NARC's fruit breeding researches.

Keywords: Fruit genotypes, Germplasm collection, Germplasm evaluation, Exotic varieties, Indigenous fruits

Correct citation: Gotame, T.P., Gautam, I. P., Shrestha, S. L., Shrestha, J., & Joshi, B. K. (2020). Advances in fruit breeding in Nepal. *Journal of Agriculture and Natural Resources*, 3(1), 301-319. DOI: <https://doi.org/10.3126/janr.v3i1.27183>

INTRODUCTION

Diverse genetic resources base of fruits and nuts in Nepal is contributed by wild, indigenous and exotic sources (Gotame *et al.*, 2014). Among 6,500 species of flowering plants reported by Chalise (1993), the total number of agro-horticultural crops found in Nepal is roughly estimated to be about 400 as species and subspecies (Regmi, 1990). There are 45 species belonging to 37 genera and are reported as wild edible fruits (Kaini, 1994). It is believed that Nepal is original home of many fruit species. About 107 indigenous fruit and nut species have been reported (Joshi *et al.*, 2007). Department of Agriculture (DoA) prior to 1990 and Nepal Agricultural Research Council (NARC) after 1990s have played a key role in fruit varietal research and development. Over 60 years of period high number of local and exotic fruit germplasm have been collected and maintained in the field gene bank at different research stations. There are several duplicate collections and also in the absence of inventory many elite types are not yet utilized commercially. Agronomic and breeding works in fruits were started only after 1950s and has gained momentum after the formation of commodity program in 1972. From the reviews of the past research initiatives on fruits, it showed that many exotic fruit germplasms have been introduced since 60 years in many public farms.

For the first time, germplasm introduction and evaluation were started during 1960s when 13 horticultural farms were established in different agro-ecological conditions with the help of Indian Aid. Most of these public farms established progeny orchards, introduced and evaluated exotic germplasms, produced and distributed planting materials to farmers and nursery men. From the 6th five-year plan (1980-85), efforts were made in fruit development in road accessible areas. At the end of the 7th five-year plan, government developed a long term plan for horticulture development and a 20-year Master Plan for Horticulture Development (MPHD). The Japan International Co-operation Agency (JICA) funded Horticulture Development Project was commenced in 1985 and promoted sweet orange in Ramechhap and Sindhuli; pear, persimmon and chestnut in Kathmandu, Bhaktapur and Lalitpur and grapes in Banke and Bardiya. Germplasm introduction and selection, fruit quality assessment, packaging and demonstration of production technologies were the main activities carried out by this project.

Moreover, Nepal is also an original place of many species of fruits. Many of the indigenous fruit species are performing as good as or better than exotic varieties. For example, cv. 'Pharping Local' (Asian sand pear), 'Junar' (sweet orange), 'Dhankuta Local' (mandarin), 'Kagaji Lime' (acid lime) are superior compared to exotic varieties due to many desirable economic characters. Besides the traditional and exotic varietal crops, there are some fruits which are traditionally or wildly grown in Nepal. There are many underutilized fruits in the country. There is ample scope for selection of promising clones from these existing wild relatives through evaluation and selection breeding procedure.

METHODOLOGY

Relevant literatures from 1982 to 2018 were collected from journal articles, proceedings papers, books, annual reports on fruit breeding history, recent activities on fruit breeding in NARC stations, advances in tropical fruit, sub-tropical fruit, temperate fruit and citrus breeding in Nepal. Web pages were visited and the relevant information was collected.

Author's experience in fruit breeding is also internalized in the paper. Finally, information collected from different sources were analyzed and presented.

RESULTS AND DISCUSSION

History of fruit breeding in Nepal

Though the horticultural crop cultivation started since time immemorial, systematic introduction of horticultural crops was done effectively during the period of 1948-1967 with the establishment of number of horticulture farms and stations in the country. Cultivating indigenous fruit species in home garden was a traditional culture of Nepal, but the introduction, selection and recommendation of exotic fruit species in Nepal on scientific basis is of recent initiation. The first introduction of fruit genetic resources in Nepal dates back to 1850 when Prime Minister Janga Bahadur Rana brought saplings of fruits from UK (Acharya and Atreya, 2013). It is believed that King Rana Bahadur Shah established a well designed garden at Sera Phant (Sera Bagaincha) of Nuwakot focusing mango orchard for the first time in Nepal. Later on, the Prime Minister Bhimsen Thapa established fruit orchard at Jalbire of Kavre. Similarly, Janga Bahadur Rana established Khinchet Bagaincha in Khinchet Phant and Gadakhar Bagaincha in Gadakhar village of Nuwakot. Bir Shamsheer Rana established mango orchard in Sripur Palace, Chandra Shamsheer established orchard in Hazabania Palace and Colonel Harka Jung Thapa established citrus orchard in Ilam. Many introduced varieties of fruit crops such as mango, litchi, persimmon, pomegranate, guava, pommelo and fig are still producing fruits in the palace gardens of many Rana families.

USAID Project was the first foreign funded project supported and funded for Kakani Station in 1952. A total of 13 horticulture farms/stations were established by the support of Indian Cooperation Mission in 1960. Swiss Government Integrated Hill Development Project (IHDP) implemented in Dolakha and Sindhupalchowk from 1975 to 1985 and Hill Agriculture Development Project (HADP) during 1976 to 1979 introduced fruit germplasms in Nepal. New cultivars of fruits were imported from India, Japan, China, Pakistan, Thailand and USA during the Horticulture Development Project (JICA Phase I and II) period from 1985 to 1995. Some of the important germplasms were apples, Japanese pear, grape, persimmon and chestnut (Gotame *et al.*, 2014; Kaini, 1994).

In 1951/52, two trial orchards were established at Godawari as 'Plant Introduction Unit' and Kakani as 'Hill Nursery' (renamed as 'Kakani Fruit Station' in 1956). Farms at Kakani and Parwanipur were established as the progeny cum demonstration orchards. Apple, peach, pear, plum persimmon and cherry varieties were introduced and their performance was investigated at Godawari. Similarly, apple varietal performance was investigated in Hill Nursery, Kakani, Nuwakot. Horticulture Section under the Department of Agriculture was created in 1955 and Horticulture Unit was added to Parwanipur Agriculture Station in 1959 where several tropical fruit varieties were introduced from India and evaluated. Department of Horticulture was created in 1966 and National Temperate Horticulture Research Station was established in Marpha, Mustang in 1967. Fruit research in citrus, apple, pear, peach, grapes, guava, pineapple and mango were carried out at different horticulture farms after the commencement of Hill Agriculture Development Project (HADP) in 1973.

Hill Agriculture Development Project (HADP) sponsored by FAO had introduced considerable number of exotic germplasms during 1978/79, but due to the lack of proper recording system very few are known to date (Verma, 1995). Similarly, Janakpur Agriculture Development Programme (JADP) aided by Japan, introduced different cultivars of mandarin, sweet orange and grapes in Sindhuli, Ramechhap and Janakpur during the tenure of the project, but details are not available (Verma, 1995).

NARC stations for fruit breeding

Recently, Horticulture Research Division, Khumaltar has developed a national network assigning lead centre and collaborators on fruit researches including breeding and fixed the targets of 18 fruit varieties to be released by the end of 2023 (Table 1 and Table 2) (HRD, 2018). To take the momentum in fruit breeding and varietal development, the conventional breeding method should be superseded by the biotechnological and molecular breeding approaches.

Table 1. Responsibilities assigned to NARC stations for fruit breeding and variety development

Station	Commodity	Theme	Rajikot	Dailekh	Surkhet	Nepalgunj	Lumle	Malepatan	HRD, Khumaltar	Parwanipur	Taraha-ra	Paripatle	Pakhribas
HRS, Jumla	Walnut	Breeding-collection	Lead	Colla									
	Almond	Breeding-collection	Colla				Lead						
	Peach	Breeding-collection	Colla	Colla			Colla		Lead				Colla
	Apple	Breeding-collection	Lead										
HRS, Dailekh	Citrus	Disease-greening		Colla				Colla	Colla			Lead	
	Pomogranate	Breeding-collection		Colla	Colla	Colla		Colla	Lead				Colla
RARS, Nepalgunj	Mango	Breeding-collection			Coll	Colla				Colla	Lead		
	Litchi	Breeding-collection			Colla	Colla				Lead	Colla		
	Banana	Breeding-collection			Colla	Lead				Colla	Colla		
	Papaya	Breeding-collection			Colla	Colla				Lead	Colla		
	Aonla	Breeding-collection			Colla	Lead				Colla	Colla		
	Bael	Breeding-collection			Colla	Lead				Colla	Colla		
	Ber	Breeding-collection			Colla	Lead				Colla	Colla		
	Grape	Breeding-collection				Lead							
HRS, Malepatan	Mecademia nut	In-situ characterization						Lead	Colla		Colla	Colla	Colla
	Avocado	In-situ characterization						Colla	Colla				Lead
HRD, Khumaltar	Kiwifruit	Varietal	Colla	Colla			Colla		Colla				Lead
	Pomegranate	Breeding-screening		Colla	Colla	Colla			Lead				Colla
	Guava	Breeding-screening							Colla		Lead		
	Dragon Fruit	Breeding-screening							Lead				
	Berries	Breeding-screening							Lead				
NCRP, Paripatle	Mandarin	Breeding-screening		Colla		Colla		Colla				Lead	
	Sweet orange	Breeding-screening		Colla				Colla				Lead	
	Acid lime	Breeding-screening		Colla		Colla		Colla	Colla		Colla	Lead	
	Tangor	Breeding-screening				Colla		Colla				Lead	
	Citrus	Insect-fruit fly						Colla				Lead	
	Citrus	Insect monitoring		Colla				Colla				Lead	
	Mandarin	Greening management		Colla				Colla				Lead	

Note: HRD= Horticulture Research Division; RARS= Regional Agricultural Research Station; ARS = Agriculture Research Station; HRS = Horticulture Research Station; and Coll for collaborative center, Lead for leading center

Table 2. Target of fruit varieties to be released/registered by 2023

Fruits	Number of fruit varieties targeted to register/release by 2023
Banana	3
Pomegranate	2
Kiwifruit	1
Guava	1
Apple	3
Pear	1
Mango	2
Mandarin orange	1
Sweet orange	1
Acid lime	1
Dragon fruit	1
Pineapple	1
Total	18

Advances in temperate fruit breeding

Recently, some promising germplasm of temperate fruits such as apple, pear, walnut and cherries were introduced by Horticulture Research Division, Khumaltar with the support of Association Du Bessin Au Nepal, France and Kam For Sud, Switzerland in 2017 (Table 3) (HRD, 2018). In the same year, three plants of each four walnut cultivars namely Xinjiang, Yanyuam, Chuanzhan and Xianglin were introduced from China and planted for variety evaluation in HRD, Khumaltar.

Table 3. Fruit germplasm imported by HRD, Khumaltar with support of Association Du Bessin Au Nepal, France and Kam For Sud, Switzerland

Fruit	Cultivars	Remarks	Supporting institution	Year
Apple	Canada Gris, Baskoop, Malrose, Idared, Cox Orange, Belchard, Akane, Judaine, Reine des, Reinettes	Grafted sapling	Association Du Bessin Au Nepal	2016
	Boskoop, Florina, Mutterapfel, Prime Red Schneider Apfel, Sparton, Beauty of Kent, King of Pippin,	Grafted sapling	Kam for Sud	2017
	MM111, MM106	Clonal rootstock	Kam for Sud	2017
Walnut	Franquette	Grafted sapling	Association Du Bessin Au Nepal	2017
Hazelnut	Coutard	Grafted sapling	Association Du Bessin Au Nepal	2017
Black Currant	Neva, Andega	Grafted sapling	Association Du Bessin Au Nepal	2017
Himlayan Goji	GT8, 100/130 3L	Grafted sapling	Association Du Bessin Au Nepal	2017
Raspberry	Zeva	Rooted cutting	Association Du Bessin Au Nepal	2017
Peach	Benedite, Surprise	Grafted sapling	Association Du Bessin Au Nepal	2017
Plum	Mirabelle	Grafted sapling	Association Du Bessin Au Nepal	2017
Nectarin	Big Van, Burlat	Grafted sapling	Association Du Bessin Au Nepal	2017
Apricot	Hargrand, Bergeron	Grafted sapling	Association Du Bessin Au Nepal	2017

Source: HRD, 2018

Apple

After the establishment of 13 horticulture farms during 1960s, about 40 apple (*Malus pumila* L.) genotypes were introduced to Nepal, and evaluated for many years at Horticulture Farm in Kirtipur before 1985 (Shrestha, 1993). Sixteen cultivars were introduced and evaluated for flowering habit and found that Ruby Spur, Ed Gold Golden, Gallia Beauty, June Gold, Ida Red, Granny Smith were bloomed in March (Ranjit and Rana, 1986). Clonal rootstocks M9, M26, M27 of Malling series and MM101, MM106, MM111 of Malling Merton series were introduced to a few horticultural stations and were used for propagation in a very limited scale (Devkota, 1999). Gautam et al. (1995) and Subedi et al. (1995) evaluated the suitability of low chilling cultivars 'Anna' and 'Vered', of apple for the PAC and LARC conditions.

In 2011, NARC has imported 10 spur type apple cultivars from the Horticulture Research Station, Solon and the Regional Horticulture Research Station, Mashobra, India along with 15 apple cultivars from Canada and planted them in germplasm evaluation block for morphological and pomological characterization at Agriculture Research Station (Horticulture) (HRS), Rajikot, Jumla (HRS, 2014). Spur type germplasms namely Red Spur, Top Red, Red Chief, Oregon Spur, Golden Spur Starkrimson and Golden Delicious were compared with non-spur type germplasms (Subedi et al., 2013). These germplasms have been evaluated at HRS, Rajikot since 2011. The name of Apple germplasms introduced in Nepal in 2010/11 is given in Table 4.

Table 4. Apple germplasms introduced during 2010/11 in Nepal

SN	Indian cultivars	No of transplanted apple saplings	Canadian cultivars	No of transplanted apple saplings
1	Oregon Spur II	35	Ambrosia	3
2	Red Chief	35	Blushing Susan	3
3	Bright N Early	20	Honey Crisp	3
4	Red Gold	20	Gala	3
5	Vance Delicious	20	Red Gravenstein	3
6	Top Red	20	Jonagold (P)	3
7	Starkrimson Delicious	15	Jubile Fuji	3
8	Well Spur	15	Pristine	3
9	Red Spur	15	Redfree	3
10	Stark Spur Gold	15	Robinete	4
11			Sinta	3
12			Sunrise	4
13			Tsagaru	3
14			Zestar	3
15			Jim	4
Total		210		48

Source: ARS-Hort, 2014

The recent result showed that three Indian spur cultivars 'Oregon Spur II', 'Starkrimson Delicious' and 'Red Spur' were found promising for good fruit quality, storability and disease pest resistant, and therefore proposals are being developed for variety release by the year 2019. Characterization and evaluation are continued for registration of other promising Indian and Canadian apple cultivars.

In 2017, Department of Agriculture in the leadership of Fruit Development Directorate, Kirtipur introduced 5 spur type apple cvs. Fuji, Gala, Starkspur Gold, Honey Crips and Red Gravestein and dwarfing rootstocks from the Himanchal Pradesh, India and planted at different DoA farms including HRS, Rajikot, Jumla (Table 5).

Table 5. Spur type apple varieties introduced from the Himanchal Pradesh, India and planted at different DoA and NARC's farms, 2017

SN	Cultivars	Apple cultivars						Apple rootstocks		
		Fuji	Gala	Starkspur Gold	Honey Crips	Red Gravestein	Total	M-9	MM-106	MM-111
1	Central Horticulture Centre, Kirtipur	41	36	36	39	44	196	50	32	35
2	Temperate Horticulture Development Centre, Marpha	50	50	50	50	50	250	100	100	100
3	Temperate Horticulture Nursery Development Centre, Daman	30	30	30	30	30	150	70	70	70
4	Horticulture Centre, Solukhumbhu	35	30	35	35	35	170	45	30	28
5	Dry Fruit Development Centre, Satbanj	20	20	20	20	20	100	70	70	70
6	Temperate Fruit Rootstock Dev. Centre, Bonch	10	10	10	10	10	50	35	20	25
7	Floriculture Development Centre, Godawari	20	20	20	20	20	100	0	0	0
8	Horticulture Research Station, Rajikot	0	10	0	0	0	10	10	10	10

Pear

During Horticulture Development Project Phase-I (1985-1990) and Phase-II (1992-1997), major research was focused on characterization of pear, particularly 'Pharping Local' (Sakuma, 1995). During this period, Japanese pear (*P. pyrifolia*) cvs. Shinsui, Shinko, Kosui, Hosui, Chojuro and Okusankichi were introduced. Even before the start of the JICA funded Horticulture Development Project, some European pears (*P. communis*) cvs. Bartlett, Quince, Anjou and Conference were introduced and evaluated at cool temperate regions of the country. It has been also reported that four Japanese pear varieties namely Kosui (early maturing), Hosui, Shinko and Okusankichi (late maturing, large fruit size) were introduced and found that Kosui, Hosui and Okusankichi were suitable varieties for Nepal. European

pear varieties (*P. communis*) (Bartlett, Quince, Anjou and Conference) were also introduced and evaluated for cool temperate regions of Nepal. Presently, Nepal Agricultural Research Council has developed a proposal on importing Chinese pear with the financial and technical support of Chinese government. The proposal is due consideration and due for agreement by the both countries.

Peach and plum

Over 40 cvs. of peach (*Prunus persica*) were introduced in Nepal and grafted on a wild species of peach (*Prunus* spp) (Schnell, 2012). Similarly, 44 improved varieties of peach have also been introduced and evaluated and found that Peregrine, Triumph, Elberta, Baby Gold, Sun Crest, Rhodes, Red Haven and Florida Red were high chilling varieties while Orion, Spring Time, French Early, Cardinal, Arm Gold, Florida, Kuratake Wase, Texas, Spring Time, Early Red were low chilling varieties.

During Horticulture Development Project period, European plum cvs. Green Gage, Early Transparent Gage, Stanley, Ruth Gestetner and Japanese plum cvs. Santa Rosa, Methley, Satsuma, Formosa, Mariposa, Burbank, Kelsey, Oishi Wase and Shiro were introduced during this period. Peach cvs. Orion and Spring Time for upper mid hills and Flordasun for low hills were found suitable for May harvest (Gupta et al., 1989). Flordasun was the earliest cv. but highest yield (27.0 mt/ha) was found in Orion (Gautam et al., 1990a). At Pakhribas conditions, some plum cultivars were evaluated and found that Methley yielded the highest (22.5 mt/ha) but TSS was highest (7.7%) in Marjory Seedlings (Gautam et al., 1990b). At Pakhribas condition, out of Methley, Greengage, Formasa, Starking Delicious and Marjory Seedling, Methley produced the highest (22.5 t/ha) yield but TSS was highest (7.7%) in Marjory Seedlings (Gautam et al., 1990b). Similarly, Texas, B. B. Gold, Spring Time and Orion of peach; Methely (early), Santarosa and Black Champa (ripens during monsoon) of plum were also evaluated and recommended for Lumle Agriculture Research Centre (LARC) command area of Nepal (Subedi et al., 1995).

Apricot, nectarine, chestnut, cherries and persimmon

About 13 varieties of apricot were introduced into Nepal at different times but unfortunately only a few of them have been successful under Nepalese conditions (Devkota, 1999). Among those introduced varieties (Blenheim, Titon, Bulida, Rcale Dimola, Prete, Canino, Kaisha, Charmagz, Shakarpara), Shakarpara was found to be the most successful variety in Nepal.

Nectarine cvs. Independent, Panamint, Arm King, Ruby Gold, Fantasy, Nectaret-2 and Neyorkert were introduced. Persimmon cultivars Fuyu, Jiro, Zenjimoru, Hiratanonashi, Hachiya were introduced and evaluated along with local selections (Devkota, 1999). The astringent cvs. Hiratanenashi and Aizumisirazu, and non-astringent cvs. Matsumoto Wase and Maekawajiro of persimmon were also introduced from Japan and found suitable for cultivation at Kathmandu conditions (Sakuma, 1995). Farmers accepted cvs. Jiro and Fuyu around Kathmandu valley.

Six exotic chestnut cvs. were introduced to LARC. It was found that Kumini and Tsukaba were the best at LARC conditions (Subedi et al., 1995). Sweet cherry was mostly available in private nurseries such as Everything Organic Nursery (EVON), Kavre and international organization ICIMOD, Godawari. The list of temperate fruit cultivars introduced in Nepal is given in Table 6.

Table 6: List of temperate fruit cultivars introduced in Nepal

SN	Common name	Introduced germplasms
1	Apple	Alkin Apple Liberty, Ambri, Ambrosia, Anna, Baldwin, Bell Flower Milberg, Benoni, Beauty of Bath, Blushing Susan, Brameley, Bright N Early, Chaubattia Princess, Chaubattia, Anupam, Chaubattia Swarnima, Chaubattia Alankar, Chaubattia Anuraj, Commercial, Cox's Orange Pippin, CO Op 12, CO Op 13, Co-Op-12-20, Co-Op-13-20, Crimson Gold, Crippin (Mutsu), Dorsett Golden, Ein Shemer, Fall Russet, Fuji, Gala, Gold Spur, Golden Delicious, Grany Smith, Green Graveinston, Honey Crispin, Jim, Jonagold, Jonathan, Jonared, Jubile Fuji, Kashmiri, Katja, King of Pippin, Kullu, McIntosh, Masadi, Neomi, Oregon Spur II, Pine Apple, Pristine, Red Chief, Red Delicious, Red Gold, Red Gravenstein, Red Fuji, Red Spur, Redfree, Rich-a-Red, Robinete, Royal Delicious, Rome Beauty, Rymer, Sansa, Scarlet Gala, Sinta, Stark Spur Golden, Stark All Bledge, Starkrimson Delicious, Spintzen Berg, Summer Pippin, Tore, Tsuqura, Ushyu (seed purpose), Sunrise, Summer Pippin, Sweet Ambri, Top Red, Tori Kullu, Tsagaru, Vance Delicious, Vered, Well Spur, Winter Banana, Zestar, M series, MM series clones
2	Almond	All in One, Big Early King, Chaubattia Madhu (Indian), Erzhuanzhi (Chinese), Garden, IXL, Kashmir, Lanzhoudajixin (Chinese), Meixin (Chinese), Prince, Ne-Plus Ultra, Non-Pareil, Sunflower, Safaida Special (Indian), Taxes Spring, Mission
3	Apricot	Blenheim (Indian), Shakarpara, Tilton (Indian), Kaisha, Royal, Shakarpara, Xinli (Chinese)
4	Blackberry	Amarand, Loganberry, Mestry, Ollalie, Sunshine
5	Blueberry	Patriot, Misty
6	Chestnut	Liangxiangbanli (Chinese), Chukoba, Eshizuchi Ebuki, Tanjawa, Tsukuba, Kumini, Mori Wase, Yamane Wase (Japanese Chestnut)
7	Gooseberry	Captivator
8	Hazelnut	Green Leaf, Purple Leaf
9	Pear	Barlett, Chinese, Havana, Bask Pear, Bosc, Comice, Danjou, Seckel, Red Hosui, Hosui, Kosui, Chojuro, Nijusaki, Shinko, Atago, Golden Ichigonijiseki Nitaka, Okisangkichi, Yakumo, Waseka, Suli, Xuili, Changxili, Kikusui, Nitaka, Tsugaru, Anju, Kikusui, Patal, Golden Nijisekki, Okisankichi, Megatchu
10	Peach	Orion, Texas, Peregrine, Arm Gold, French Early, Florida Bell, Florida Red, Hakuto, Matsumori Wase, Odamahakuho, Red Haven Tekeihakuto, Texas, Yamanehakuto Cardinal, Arm Gold, Early Red, Juna Gold, Stark Early Glow, Springtime, Sun Crest, June Pride, Sangita, Desert Gold, Elberta, Yuhuala, Youtao, Beijing-8, Sharbati, Alton, July Alberta, Spring Time, Golden Cline, Red June, Red Hawana, Orayin, Armgold, Panamint (Nectarin), Florida Bell
11	Plum	Green Gage, Santa Rosa, Methley, Satsuma, Formosa, Mariposa, Prunas, Margong, Starking Deliciosa, China, Beauty, Rome Beauty, Black Chamba, Frontier, Gaili, Huahuan, Li-3, Umewasi (Japanese)
12	Pecan nut	Mahan, Mohak, Choctaw, Bichita, Steward
13	Persimmon	Mayakawa Jiro (Non- astringent), Jiro (Non- astringent), Fuyu (Non- astringent), Matchumotowase fuyu (Non- astringent), Ubeni (Non- astringent), Jengimaro (Pollinizer), Hiratanenasi (Astringent), Mompe (Astringent), Hachiya (Astringent), Hanagoso (Astringent), Suruga (Astringent), Atago (Astringent), Songbenzhaosheng, Qianchuan Cilang Cilang, Hiratanehashi, Mayakabajiro, Matsomotowasefuyu, Hanna Golo Jengimaro (Polinizer), Hiratasenamy
14	Raspberry	Autumn Bliss, Cascade Delight, Malling Jewel, Willamtte
15	Sweet Cherry	Bigarreau, Noir Gross, Stella, Red Heart, Van Lambert, Sun Burst, Summit Bing, Rainier
16	Sour Cherry	Montmorency
17	Strawberry	Sally, Red Cavendish, Nyoho
18	Spur type apple cultivars	Red Spur, Red Chief, Oregon Spur II, Top Red, Starkrimson Delicious, Bright N Early, Red Gold, Vance Delicious, Well Spur, Stark Spur Gold

Source: Gotame et al., 2014; ARS-Hort, 2014

Advances in citrus breeding

Thirty-two different genotypes of citrus (22 mandarin, 14 sweet orange, 5 grapefruit, 3 tangor and 3 tangelo) were introduced from the French National Institute for Agriculture Research (INRA)-CIRAD, France in 2005 and have been preserved and are being evaluated in field gene bank of NCRP, Dhankuta (NCRP, 2013). A study was conducted to identify the superior indigenous mandarin genotype and found that 'Khoku Local' was superior with respect to fruit weight (100.2 g per fruit), juice content (46.4%), total soluble solids (TSS) and titrable acid (TA) than 'Dhankuta Local'. Therefore, 'Khoku Selection' was registered for eastern mid-hill conditions of Nepal (HRD, 2018).

Several germplasms of mandarin, sweet orange, grapefruit, tangor, and tangelo have been collected from local and exotic sources since the establishment of NCRP. Currently, a total of 130 germplasms of different cultivars of citrus were collected from exotic and local source and maintained at NCRP, Paripatle (Table 7). Collected germplasm have been preserved and being evaluated in field gene bank of NCRP, Dhankuta (NCRP, 2018).

Table 7. Collection and conservation of citrus germplasms at NCRP, Dhankuta, 2018

Species	No of germplasms	Source
Mandarin Oranges	32	France, Japan and Local
Sweet Orange	34	India and France
Tangelo	3	France and Japan
Tan gore	4	France and Japan
Acid Lime	21	Local
Lime	6	Local
Grape fruit	8	France and Vietnam
Muntala	3	India
Rootstocks	19	Local and France
Total	130	

Source: NCRP, 20018

An eco-geographic survey was conducted to identify the highest diversity areas of citrus genotypes during 2000 to 2003 in four hill districts of Nepal (Budathoki *et al.*, 2004a). Fifteen hill citrus genotypes from different villages were characterized and evaluated. It was found that some of the local landraces of mandarin orange of Banskharka-1, Banskharka-2, Parbat district, sweet orange (Mousami Local) of Birauta, Dadeldhura district and Junar of Ratnachura-2, Sindhuli district have high commercial values. Shah (2010) carried out mother tree selection of mandarin orange for varietal establishment and characterized quantitative and qualitative characters at Dhusa VDC, Dhading and Khoku of Dhankuta. Paudyal *et al.* (2011) characterized 26 mandarin seedlings at Jyamire mother stock of NCRP and tree with accession number J-90 (Jyamire 90) reported to be an elite type. It was selected as the mother plant. Disease indexing in Nepal and Corsica, France showed that this accession (J-90) was free from graft-transmissible diseases such as HLB free in polymerase chain reaction (PCR) test.

NCRP (2015) has continued varietal evaluation of sweet orange including 23 exotic and local landraces since 2008/09. NCRP has recommended sweet orange cv. 'Washington Navel' for early season, 'Pineapple' and 'Hamlin' for mid-season and 'Valencia' for late season

production for the mid-hill conditions of Nepal (Paudyal and Subedi, 2008). Among them cvs. Washington Navel is suitable for low altitude, seedless, matures in October-November. Valencia Late is seedless, matures in March-April and is a leading variety of the world.

In situ germplasm evaluation was carried out on acid lime (*Citrus aurantifolia* Swingle) in Terathum, Jhapa, Morang, Sunsari and Chitwan districts in 2002 and 2003 to identify a superior genotype for off-season production (Paudyal and Shrestha, 2004). Two accessions, maturing during rainy season with better fruit quality, were selected for extended harvesting from four to seven months (July-January) at terai and mid hill conditions. Similarly, eighteen landraces of acid lime were evaluated based on flowering season, productivity and fruit quality at IAAS, Rampur, Chitwan during September 2004 to June 2005 and found potentiality to improve cultivars through selective breeding (Sapkota and Dhakal, 2008).

Participatory varietal selection on acid lime was carried out by NCRP, Dhankuta in farmers' fields of Jhapa, Morang, Susnsari and Chitwan districts during 2005/06 to 2009/10. Based on *In situ* germplasm evaluation, and participatory varietal selection, two varieties of acid lime 'Sunkagati-1' and 'Sunkagati-2' have been released and one variety 'Terhathum Local' has been registered so far. These varieties are widely adopted under upland conditions of terai, inner terai, foot hills and river basins. Similarly, 'Khoku Selection' of mandarin orange has also been registered (Table 8). The released varieties of acid lime are given in Figure 1 and Figure 2.

Table 8. Lists of citrus fruits released/registered in Nepal, 2018

S.N.	Name of fruit	Name of variety	Year of released/registered	Yield potential mt/ha	Recommendation domain
1	Acid Lime	Sun Kagati -1	2015	34.5	Terai, inner terai and foot hills where water drainage facility exists
2	Acid Lime	Sun Kagati -2	2015	26.9	Terai, inner terai and mid-hills, foot-hills where water drainage facility exist
3	Acid Lime	Tehrathum Local (Registered)	2018	15	Frost free areas of eastern hills from 1000 m to 1600 m
4	Mandarin orange	Khoku Selection (Registered)	2018	16-24	Frost free areas of eastern hills from 1000 m to 1600 m



Figure 1. Released variety of acid lime: Sun kagati -1 (source: NCRP, 2018)



Figure 2. Released variety of acid lime: Sun Kagati -2 (source: NCRP, 2018)

Similarly, eighteen landraces of acid lime were collected and evaluated at IAAS, Rampur, Chitwan in 2000 to 2004 with the financial support of HARP (Hill Agriculture Development Project). However, these accessions were not available at AFU now.

Advances in other sub-tropical fruit breeding

Pomegranate

Realizing the scanty production of pomegranate in Nepal, and dependency on imports from India, genotype collection and evaluation works has also been started in pomegranate in 2010. Three cultivars of pomegranate (Safeda, Seedless, Spinesh) along with one local landrace were evaluated in Guthitar, Dhankuta (ARS, 2015). Similarly, twelve germplasms were collected from various parts of the country and maintained at the mother stock block of HRD, Khumaltar, Lalitpur (HRD, 2015). Eight germplasms with accessions number HRDPOM001, HRDPOM002, HRDPOM003, HRDPOM004, HRDPOM005, HRDPOM006, HRDPOM007 and HRDPOM008 were planted in the FY 2013/14 at HRD mother stock block. Two germplasms with accession HRDPOM009 and HRDPOM010 were collected from Manakamana Nursery, Birgunj, Parsa. Additional two genotypes with accession HRDPOM011 and HRDPOM012 were collected from farmer's field, Milanchowk, Tandhi, Chitwan in the FY 2014/15 (HRD, 2015). Among them, 5 of the germplasm (HRDPOM01, HRDPOM03, HRDPOM04, HRDPOM04M, HRDPOM05) has also been under multiplication evaluation at different stations of NARC (Malepatan, Salyan, Khajura, Surkhet, Dailekh) including horticulture farm of DOA, Trisuli. These are still under evaluation and selection for variety release.

Kiwifruit

International Centre for Integrated Mountain Development (ICIMOD) introduced some kiwifruit cultivars from India and established a demonstration orchard at Godawari during 1990s. Kiwifruit cvs. Hayward, Bruno, Monte, Allison and Tomori were cultivated in Horticulture farms of Kirtipur and Daman since the year 2000. Eight germplasms of exotic cultivars were evaluated following the Test Guidelines for *Actinidia* developed by International Union for the Protection of New Varieties of Plants (UPOV), Geneva, Switzerland at Surya Kiwifarm, Kavre (Paudyal, 2013). Red Kiwi, Hayward (both round and oblong), Bruno, Monte, Abbolt, Allisan and ICIMOD Oblong were evaluated for fruit characters, yield efficiency, quantitative and qualitative characters at different harvesting period from 2 September to 20 November and recommended three cvs. Soyou, Bruno and Hayward for commercial cultivation (Paudyal, 2013). Among these varieties, Red Kiwi was recommended for early harvesting (September) with special character of hairlessness and

good fruit quality. Similarly, six cvs. Hayward, Monte, Abott, Bruno, Allison and Red Kiwi were planted in 2012 at ARS, Pakhribas, Dhankuta for characterization and evaluation (ARS, 2015). In 2013, Horticulture Research Division has imported three Chinese cultivars (*Acinidia chinensis*) of kiwifruit and planted them at ARS, Pakhribas; NCRP, Paripatle; RARS, Lumle; HRS, Dailekh and HRS, Jumla for evaluation (HRD, 2014) but the vegetative growth was very poor and most of the plants were died due to graft incompatibility. In 2017, HRD, Khumaltar has planted six kiwifruit varieties and it is under evaluation and selection process

Grape

Evaluation of grape cultivars was initiated in 1980s in Nepal. Three years old grape cvs. were introduced by Janakpur Agriculture Development Project, Janakpur and evaluated for growth behavior for four consecutive years at Horticulture Farm, Nepalgunj (Joshi, 1986). Four cvs. Stuben, Muscut Bailey A, Kyoho and Black Olympia were introduced from Japan and compared with other cvs. Himrod, Delawar, Opymphia, and Tonored and found that Stuben was the best at Kirtipur conditions. Indian grape cvs. were also evaluated at RARS, Nepalgunj during 1995, 1996 and 1997 and found that Perlette and Beauty Seedless and were good yielders and early in flowering and maturity. Growers preferred Perlette and Beauty Seedless because of the seedlessness and earliness (KC, 1999). Cultivar Stuben also performed good and preferred by vicinity farmers.

Olive

Hartmut Bauder, a German national had introduced olive in his own interest and planted at Daman, Makawanpur. The Italy funded FAO project had brought twenty-eight cultivars of olives from Italy and planted in three locations at Kirtipur (Kathmandu), Kolti (Bajura) and Dolpa farm (Dolpa). Some of cvs. Leccino, Marina, Pendolino, Femminella and Coratina were found successful for production of good fruits with extra virgin quality oil in Bajura (Bartolucci and Dhakal, 1999). They were further supported and established with the financial and technical support of FAO in 2006. Following varieties and quantity of olive saplings were being introduced by FDD from Rajasthan, India in 2016. The olive cultivars introduced by FDD, Kirtipur is given in Table 9.

Table 9. Olive (*Olea europaea* Linn.) cultivars introduced by Fruit Development Directorate, Kirtipur, 2016

SN	Cultivars	Total number	Year of introduction	Source
1	Arbequina	2550	2016	India
2	Picholine	2550	2016	India
3	Frantoio	2550	2016	India
4	Coratina	2800	2016	India
5	Koroneiki	2125	2016	India
6	Picual	2125	2016	India
7	Total	17500		

Avocado

Thirteen accessions of avocado (ARS P A-01, ARS P A-02, ARS P A-03, ARS P A-04, ARSP A-05, ARSP A-06, ARSP A-07, ARSP A-08, ARSP A-09, ARSP A-10, ARSP A-11, ARSP A-12, ARSP A-13) were collected from on station and outreach sites of ARS, Dhankuta and evaluation process is ongoing. The highest fruit weight was found in ARS PA-

09 (399 g) followed by ARS PA-10 (338 g). The highest weight of flesh after ripe was found in ARS PA-10 (200 g) followed by ARS PA-09 (196 g). Therefore, these two lines could be the potential germplasms for further evaluation and selection at Pakhribas conditions.

Advances in tropical fruit breeding

Large number of mango, litchi and other tropical fruit varieties were collected and conserved in TRHCN/Sarlahi. These varieties were collected from India, Pakistan, Thailand and USA and from different parts of the country. Most of the cultivars of tropical fruits grown in Nepal were introduced from India. Bombay Green, Bombay Yellow, Maldaha, Dasherri, Calcuttia, Mallika, Amrapali of mango; William Hybrid, Harichhal, Chinia Champa, Robusta, Cavendish Dwarf of banana; Giant Kew and Queen of pineapple; Lucknow-49 and Alahabadi Safeda of guava; Early Seedless, Early Large Red, Late Large Red, Rose Scented of litchi; and Washington and Honey Dew of papaya were the popular cultivars of introduced tropical fruits (Kaini, 1994). Amrapali, the regular bearing mango was introduced into Tropical Horticulture Farm, Sarlahi. Pakistan government has gifted kinnow, mango and pomegranate which were planted at Sarlahi, Kirtipur, Nepalgunj, Panchkhal, Dhankuta farms (Verma, 1995). Genotype evaluation of some tropical fruits (mango, banana and papaya) was also carried out in different places in Nepal.

An eco-geographic survey and genetic diversity study on mango was carried out during 2002 to 2003 and reported that Siraha, Saptari, Dhading, Kavre, Parbat, Baglung and Dadelehura districts have high diversity of mango genotypes. Fruit samples of 216 trees were collected and evaluated for 19 morphological characters to understand the genetic relationships (Subedi *et al.*, 2004). Similarly, 15 local mango diversity sites for Terai mango and 7 sites for local hill mango were identified. About 40 accessions of 10 mango germplasms were collected across the country and maintained at RARS, Tarahara under NARC as *ex situ* gene bank. Some of the local landraces of mango such as Thulo, Kali, Sona and Sindhure had high commercial values (Budathoki *et al.*, 2004b).

Eight cvs. of banana, William Hybrid, FIA-1, FIA-23, Robusta, Harichhal, Chinia Champa, Dhurse and Local Malbhog were evaluated at HRS, Malepatan, Pokhara during 2004/05 and found that William Hybrid was the best cv. with respect to comb per plant and finger number but FIA 1 and FIA 23 showed the least winter damage (Bhusal *et al.*, 2009). Banana varieties 'Malbhog', 'William Hybrid' and 'G9' has been selected by participatory varietal selection approach and registered in 2019. The registered banana varieties in Nepal is given in Table 10.

Table 10. Registered banana varieties in Nepal, 2019

Name of Fruit	Name of variety	Year of registration	Yield potential (t/ha)	Recommendation domain
Banana	Malbhog	2019	25-30	Terai, inner terai and Mid hills
	William Hybrid	2019	50-60	Terai, inner terai and Mid hills
	G 9	2019	50-60	Terai, inner terai and Mid hills

Six papaya genotypes (Chinese Hybrid, Honey Dew, Red Lady, Farm Selection-1, Viuran Local and Pusa Dwarf) were evaluated and found that Pusa Dwarf and Farm Selection-1 were the most preferred genotypes due to excellent fruit bearing, dwarfness and yield while Red Lady was preferred due to its earliness, uniform ripening, good taste and hard skin in inner terai and tar area (Chaudhary *et al.*, 2012).

WAY FORWARD

Since we have only conventional approach of fruit breeding, the technological demand is very lagged behind the demand. Many exotic and local germplasms have high potentiality to increase fruit productivity. But exotic introduction is not utilized in varietal development properly. These fruit germplasms available in public institutions and private farms should be characterized, evaluated, multiplied and selected for wider geographical recommendation based on yield performance, export quality and market niche from the single door. To streamline the fruit breeding in the nation, a dedicated entity has to be identified by public sector research institution with clear mandate for national coordination and command. NARC, as a leading apex body for fruit research, should define lead centre for each commodity and focus on varietal development with the integration of conventional and molecular breeding approach. For this, NARC must improve and strengthen the human resources in terms of their number and academic qualifications. Germplasm collection, characterization, evaluation, selection and utilization in varietal development should be the priority program by public research organization.

RECOMMENDATIONS

In most of the fruits, exotic introduction is still not sufficient, and therefore it is essential to import exotic fruits of high economic importance such as emerging fruits such as dragon fruits, blue berry and nuts. A proper and timely collaboration and coordination should be exercised among the national and international centers. Fruit takes long gestation period to reach into bearing stage. It takes a highly dedication to develop a variety through conventional breeding. NARC needs to be restructured with special focus on fruit researches. There should be increased in infrastructure such as laboratory for molecular breeding, cryopreservation facility and sufficient land for field evaluation. Moreover, establishment of national fruit commodity programs along with establishment of Tropical Fruit Research Station at Province 2 and Temperate Fruit Research Station at Province 5 at national level can streamline NARC's fruit breeding and varietal development works.

ACKNOWLEDGEMENTS

Authors are indebted to National Citrus Research Program, Paripatle, Dhankuta, Agriculture Research Station, Pakhribas, Agriculture Research Station, Jumla, Horticulture Research Division, Khumaltar, Lalitpur, Fruit Development Directorate, Kritipur for providing information about fruit germplasms.

Authors' contribution

T.P. Gotame wrote the whole paper and I.P. Gautam and S.L. Shrestha collected some information from fields and extracted information from literatures. J. Shrestha and B.K. Joshi finalize the initial draft of this manuscript.

Conflict of interest

The authors declare that there is no conflict of interest regarding publication of this manuscript.

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