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Status of Tree Improvement in the North Western Himalayan Region of India

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ABSTRACT

The North western Himalayan Region (NWHR) comprises of three states of the Indian Republic *viz.*, Jammu & Kashmir, Himachal Pradesh and Uttarakhand. Geographically, it spread between 28^0 43'-37^0 05 ' N latitude and 72^0 40'-81^0 02' E longitude covering an approximate area of 33 million ha contributing about 10 per cent of total geographical area of the country. Climate varies considerably from sub-tropical in the foothills to temperate towards alpine region in the southern flanks, however crossing Himalayan ranges towards north, it is cold arid zone with hardly any rainfall (Dar and Ahmed 2016; Sharma et al. 2017). There is great diversity in floristic pattern due to altitudinal variation, coupled with rainfall factor which becomes lesser and lesser from East to West. Large number of species from wild edible fruit plants, medicinal and aromatic plants, ornamental plants, orchids, bamboos, fodder tree species to timber species are found (Hazra and Rao 1990). Tree improvement has immense potential and provides the basic building block to improve the tree species growing in North West Himalaya. To develop genetically improved quality of planting material, it is essential to exploit the existing genetic variation in trees for various end uses *e.g.*, to increase the productivity along with tolerance to abiotic and biotic stresses.

Key Words:

broadleaved, conifers, genetic resources, Himalayas, variation

INTRODUCTION

The genetic improvement of any species is done either through recurrent selection or development of hybrids. Unlike field crops, the aim of tree breeding is not to develop new varieties/ clones but gradual advancement in population through recurrent selection. Though varieties/strains/clones have been

developed in number of tree species but this trend is mainly confined to short rotation species where maintaining broad genetic base may not be a big issue. In the first path, tree breeding basically starts with selection of plus trees from best provenance, raising of seed orchards, conducing progeny tests. Based on progeny tests, selected trees are inter mated with each other and next generation is advanced with outbred multi-parental populations (Scott et al. 2020) hence become the base population of a second generation. With each advancing generation, genetic gains are increased but genetic variability is eroded resulting in narrowing of genetic base. In order to minimize this risk, a breeding population is established to increase genetic variability. Inter mating may rely on infusions from external populations. Species like *Pinus radiata* (Jayawickrama and Carson 2000), *Pinus ellotii* (White and Byram 2004), *Psuedostuga menzsii* (Silen and Wheat 1979) are being improved following this strategy. In number of species, inter and intra specific hybrids have been developed by exploiting the heterosis in F_1. The F_1 hybrids are successful only in those species where vegetative propagation is possible. In this way, a number of hybrids have been developed in *Populus*, *Eucalyptus* (Venketesh and Sharma 1980), *Salix* (Thakur et al. 2014). In both the methods, improvement starts with selection in the unimproved populations.

In India tree improvement is still in infancy as compared to developed countries. Nevertheless, efforts have been made by both government organisation and private industry to increase productivity of our native species through genetic improvement. Clones/varieties have been developed in short rotation species like Poplar, Eucalyptus (Varghese and Hegde 2001), Casuarina (Rao et al. 1999) *etc*. Still much needed to be done. This paper reviews the improvement work done in the north west Himalayas.

The species wise work is given in table 1 and detailed below:

BROADLEAVED SPECIES

1. *Populus* species

The native species that are used as nurse crop for the silver-fir regeneration, stabilization of hill slips and as a main source of timber in temperate arid dry zone found only passing references till the improvement programmes began on these species, particularly the Himalayan poplar (*Populus ciliata*) and white poplar (*P. alba*) which was initiated by the Dr. Y.S. Parmar University of Horticulture and Forestry, Solan (Fotidar 1983; Ramesh and Khurana 2003, 2006, 2007). The reproductive biology of *P. ciliata* was studied over a long period of time to look at its behavior with respect to environment and stability of sex only one case of switching of sex was observed when a female tree turned monoecious (Khurana 1985). In *P. ciliata* flushing differences of one week with every 600 m elevation has also been found (Khurana and Mohanty 2000). Pollination in the *Populus* species was studied by Khurana (2000). The natural genetic variation in two indigenous species, *P. ciliata* and *P. alba* has been studied. *P. ciliate* was found to have a 3: 2 male female sex ratio (Khosla et al. 1979), female trees had better growth rate (Khosla et al. 1980). Edaphic conditions and water availability affected the overall growth of the trees and provenance variation with respect to growth, rust resistance (Sharma and Sharma 2000), and infestation of the branches and leaves with galls was more (Chauhan and Khurana 1992; Chaukiyal et al. 1995; Uniyal and Todaria 2006). *P. ciliata* with introduced *P. monilifera*, and *P. generosa* were tried and proved useful in regenerating fir and spruce in Kullu district but could not be replicated on a large scale. However, the productivity levels of clones of these various species vary according to site conditions and type of rooting ability and rooting behaviour. Clones have been categorized into five categories depending upon the plunging and anchor root behaviour, and thus dividing them into

plantation categories (Khurana 1994; Bhrot and Khurana 2001).

The productivity levels of Australian clones of *Populus deltoides* like G48 in Punjab and Haryana are reported to be much higher at 25 to 40 m^{-3} ha^{-1} yr^{-1} with some farmers reporting productivity levels of about 60 $m^{-3}ha^{-1}yr^{-1}$ with intensive farming and supplementation of macro- and micro-nutrients under rigorous silvicultural practices (Dhanda and Verma 1995; Kumar et al. 2004; Dhiman 2008). In foothills, rotation age of eastern cottonwood (*P. deltoides*) is 7-9 yrs. At higher elevations in Kullu Valley and Nauni (Solan) it ranged from 9-15 yrs. The rotation cycle with *P. ciliata* and its hybrids was even higher at 15-25 yrs, again dependant on site, soil, moisture level and the clone planted. Looking at the diverse plantation requirements and the species involved, different short and long-term strategies for their breeding and improvement were adopted.

Chaturvedi and Rawat (1994), Khurana and Thakur (1995) and Jha and Kumar (2000) raised inter-specific hybrids in different cultivars of *P. deltoides, P. ciliata, P. yunnanensis* and *P. x euramericana* 'Robusta', including reciprocals and backcross. Khurana and Bhanwara (1982) were able to show that only one way cross was possible between them. Embryo rescue by Khosla and Thakur (1991) was adopted to get the hybrid seedlings. Hybrid seedlings of *P. deltoides* 'G-48' x *P. euphratica* have also been produced to combine the rapid growth of *P. deltoides* and stress tolerance of *P. euphratica* (Singh et al. 2002).

Dr YS Parmar University of Horticulture and Forestry, Nauni, Himachal Pradesh in 1990 introduced open-pollinated seeds from 103 trees of *P. deltoides* from Texas and Davenport, USA. FRI, Dehradun got selected 104 plus trees of *P. deltoides* in 44 natural stands spread in 11 states in South-Eastern USA were surveyed during June 1997 and 104 plus trees were selected (Khurana and Narkhede 1995; Singh et al.1999). All India Co-ordinated Research Project (AICRP) on Poplar Improvement was started with head quarter at FRI, Dehradun and 27 coordinating centers (State Agricultural Universities, State Forest Departments and ICFRE Research Institutes) are working on poplar improvement programme (Kumar et al. 1999, Singh et al. 1999 and 2001). Uttar Pradesh state department developed new clones by open pollination between clones (4 ♂ clones - G-3, S_7C_1, S_7C_{15}, S_7C_{20} and 3 ♀ clones G-48, D-121 and S_7C_8) and the seedling progenies were raised, the clone name given as "L" series by UP State Forest Department. WIMCO Seedling Ltd. has got registered 6 new clones- WSL-22, WSL-27, WSL-32, WSL-39, WSL-A26 and WSL-A49 with the International Poplar Commission, Italy during 2000. Some clones have also been developed by controlled breeding by FRI, Dehra Dun, Uttar Pradesh State Forest Department, Haldwani, WIMCO seedlings Limited, Rudarpur (Sharma et al. 2014; Dhiman and Gandhi 2015) and UHF, Solan.

Multilocation trials have been conducted to evaluate growth performance and wood traits of poplar planted at various agroclimatic regions of the country (Singh et al. 2008; Ramesh and Khurana 2008; Pande 2011; Pande and Dhiman 2011; Gangoo et al. 2011; Kumar 2011; Lone and Tewari 2008). Site-specific poplar clones recommendation for future commercial cultivation in different agroclimatic zones of India has been reported by Mathur and Sharma (1983), Khurana et al. (1992) and Kumar et al. (1999). On the basis of age-age correlation studies, Kumar and Singh (2001) reported that early selection of *P. deltoides* clones for rotation age of 6 years in India can be done effectively at age four. Chauhan and Singh (2008) suggested use of induced mutation for creating genetic variability and somatic mutation in *P. deltoides*.

The few clones of *P. deltoides* were selected out of recently developed by UHF Nauni and FRI, Dehradun and screened for nursery parameters (Sharma and Khurana 2011; Sharma et al. 2014). New hybrids were made from the superior clones collected from many institutes at UHF Nauni in Line x tester design (Sharma et al.

2019) and various crosses were studied for morphological characters (Dobhal et al. 2019). Nursery growth performance of 33 (Thakur et al. 2019a) and 49 (Thakur et al. 2019b) international clones of *P. deltoides* were evaluated.

Genetic evaluation of 24 of these interspecific hybrids along with the two mother trees (P. ciliata), and five male-parent (*P. maximowiczii*) genotypes was carried out using the AFLP marker assay confirming paternity of the hybrids (Chauhan et al. 2004) and change in protein bands in pollen of *P. ciliata* was studied (Dhir et al. 1982). Thakur et al. (2005) carried out plant regeneration and genetic transformation studies in petiole tissue of *P. ciliata* and obtained high percentage root regeneration in *in vitro* developed shoots. Aggarwal et al. (2012) developed an efficient plant regeneration protocol through micropropagation for *P. ciliata* using leaf explants and thidiazuron. Petiole explants were also successfully cultured to regenerate *P. ciliata* (Aggarwal et al. 2015). Grewal et al. (2014) and Thakur (2017) studied genetic diversity in *P. deltoides* clones using SSR markers.

2. *Salix* species

Salix is a multifarious species having wide habits. Andleeb et al. (2013) considered willows for potential bioenergy crop species for Kashmir. Over the years two hundred clones/ strains/ species were procured from twenty different countries covering five continents namely Europe, North America, South America, Asia and Africa. These clones were subjected to repeated nursery screening for growth (Singh et al. 2012; Sharma et al. 2014; Huse et al. 2018), physiological (Huse et al. 2015) and wood traits (Singh et al. 2014c; Gupta et al. 2014) followed by field testing (Sharma et al. 2011and 2015).On the basis of five years field performance clones J-799, J-194, 131/25, PN-731, SI-63-007 have been recommended for plantation in mid hill region of Himachal Pradesh (Sharma et al. 2011).

The eighteen clones were tested for Genotype × Environment interactions. Based on stability parameters the clones J-799, SI-63-007 and NZ-1002 for volume index and SI-63-007 for diameter at breast height were found most adaptive to overall environments. Suitable clones for poor environment was J-194, while for average environments were V-99, NZ- 1040 and NZ-1179, respectively for diameter at breast height. Clones suitable for rich environment are PN731 for diameter at breast height and NZ-1140 and 131/25 for volume index (Singh et al. 2014a).

The Crossability pattern and genetic variation among controlled pollinated progenies of tree willows (*Salix* spp.) was studied during 2008-2010. The investigations included the study on reproductive biology of different *Salix* species, pollen collection, storage, germination and pollen viability of different species/clones (Chaudhary and Singh, 2013) carried out. Assessment of crossability relationship among selected species by controlled hybridization were assessed and revealing molecular genetic variation among selected species/clones that also included the parents involved in hybridization (Choudhary et al. 2011 & 2013).The best clones after nursery (Singh et al. 2015; Chaudhary et al. 2016) and field screening were selected for control crossing using line × tester design and hybrid progenies were evaluated for the morphometric and genetic traits (Thakur et al. 2014 and 2018).The hybrids were further subjected to nursery (Sharma et al. 2015) and field testing (Sharma et al. 2017a and 2017b).

Genetic characterization of introduced clones was done with RAPD (Singh et al. 2014b) and SSR (Singh et al.2013) markers. Paternity of willow hybrids were confirmed with molecular markers (Choudhary et al. 2013). The study of genetic diversity and population structure of Indian willow (*S. tetrasperma*) with ISSR and SSR markers has been studied using GenAlex and Structure software (Sharma 2019) alongwith genetic analysis of morphological parameters under

common garden test (Sharma et al. 2019 a&b).

3. *Melia azedarach*

Variation studies for growth and biomass characters of open pollinated progenies was carried out at UHF, Nauni. Seeds were collected from selected mother trees one each at 27 locations and progenies were raised to study the extent and pattern of variation among growth (Thakur and Thakur 2015) and biomass characters (Thakur and Thakur 2014) of *Melia azedarach*. The study revealed that, maximum weightage should be given to fresh shoot weight (0.916) due to its maximum variable loading for the initial selection of progenies followed by dry shoot weight (0.911) for the biomass improvement of the species (Thakur and Thakur 2015).

4. *Morus* species

Morus species of Himalayan region produces a minor fruit that has medicinal properties (Singh 2010) for the treatment of jaundice and hepatitis (Mahmood and Kadam 2012). An extensive survey and exploration was conducted by Tikedar (2011) in northwestern India who collected 261 genotypes from Uttar Pradesh, Jammu and Kashmir, New Delhi, Haryana and Punjab during the flowering season (Feb-April and Sept-November) following a random sampling and biased procedure. He reported variability in all species (*M. laevigata*, *M. indica*, *M. alba* and *M. multicaulis*) during survey as well after establishment at an *ex-situ* field gene bank. Tikader and Dandin (2005) surveyed and collected 54 samples of *M. serrata* from three states *i.e*. Uttaranchal (45), Himachal Pradesh (07) and Jammu and Kashmir (02) and studied morphological variability, habitat viz., natural abode of plant and other related data. The collected materials were established in the *ex-situ* field gene bank of Central Sericultural Germplasm Resources Centre (CSGRC) for further study. They found variation for morphological, anatomical, reproductive and growth traits. Rooting behaviour of some indigenous mulberry genotypes was studied (Thakur et al. 2009; Mir et al. 2011) in open and polyhouse conditions and recorded more rooting in polyhouse conditions. High phenotypic variation in *M. alba* trees representing three natural populations from the trans-Himalayan Ladakh region for 10 quantitative morphological characters (leaf length, leaf width, petiole length, leaf area, inter-nodal distance, number of nodes, bud length, fruit length, fruit width and fruit weight) were observed by (Bajpai et al. 2015) and found phenotypic variation in mulberry along an altitudinal gradient. Variation in growth parameters (Thakur 2016; Suman et al. 2018a) and mineral nutrients and proximate principles of leaves (Thakur 2010; Suman et al. 2018b) of different clones of *M. alba* was studied in different durations and genetic parameters was calculated for growth (Thakur and Chauhan 2008; Thakur 2018).Genome scan was done with 439 dominant marker loci to identify outlier loci in three populations of *M. alba* from the trans-Himalayan region (Nubra, Suru and Indus). Sequence-related amplified polymorphism markers were used to assess the genetic structure with SRAP markers in three natural populations of *M. alba* from 14 collection sites in trans-Himalaya by Bajpai et al. (2014).

5. *Grewia* species

A study was conducted to evaluate the best population of *Grewia optiva* in Himachal Pradesh, India on the basis of seed characteristics. Morphological and genetic variation in seed characters among provenances of *G. optiva* and *G. oppositifolia* and *G. optiva* were studied (Tyagi et al. 1999; Uniyal 2002). Studies on germination (Uniyal et al. 2000) of *G. oppositifolia* and *G. optiva* (Thakur et al. 2002, Tewari et al. 2008) seeds were performed. Studies were carried out by Pant et al. (1997 and 2000) on the breeding system of *G. optiva* in a plantation and 2 natural forests in Himachal Pradesh. Observations are reported on flower morphology, flowering,

anthesis, pollination (including experimental studies) and fruiting. Compatibilities were inferred on the basis of difference in fruit-set between self- and cross-pollinated flowers together with the examination of pollen on the stigmas. The floral biology and breeding system of 60 genotypes of *G. optiva* which have been collected from different districts of Himachal Pradesh were studied by Verma (2012). In *G. optiva* application of IBA, pre-severance treatment and IBA x pre-severance interaction effects were significantly related to rooting percent, number of roots per cutting and survival percentage (Bhardwaj et al. 2006). The fodder quality parameters of *G. laevigata* Vahl. (Sankhyan et al. 2009) and open pollinated seedling seed orchard of *G. optiva* (Bhagta et al. 2015; Bhagta and Sankhyan (2016) were studied and found families KA-3 (Varal), SO-6 (Amberkhothi), CH-2 (Shahu), SO-10 (Jaunaji), HA-1 (Bharari) and genotype I of family KA-3 (Varal), genotype I, II, III of family HA-2 (Patta Bhalaker) best for proximate principles.

A seedling seed orchard containing 60 families and three replications in a 2x2 meter distance was planted in UHF in the year 2000. The study on morphological (Bhatt et al. 2012a, Bhagta and Sankhyan 2016) genetic parameters (Bhat et al. 2018) and the genetic divergence (Bhatt and Ahmad 2012; Bhatt et al. 2012b) on the basis of seed and seedling characters of progeny of the families. The effect of seed collection time on seed germination percentage and found optimum time of seed collection between first fortnight, second fortnight of December and first fortnight of January (Sankhyan et al. 2014). The families were gain evaluated for variability in seedling growth, biomass and fodder characters (Bhagta et al. 2019b) and their correlation and principal component analysis (Bhagta et al. 2019a).The genotypes in seedling seed orchard were studied for molecular characterization that exhibited a very high level of molecular diversity and DNA polymorphism with RAPD and ISSR markers (Verma et al. 2015). Saresh (2013) crossed 6 female (SO-1, SO-2, SO-4, SO-8, CH-2 and SI-15) and 4 male (SO-3, SI-6, BI-4 and HA-4) genotypes selected from seedling seed orchard using Line X Tester (6X4 factorial) mating design and studied heterosis effect for nursery morphological traits of these families (Saresh et al. 2020).

6. *Toona ciliata*

Gupta and Sehgal (1999) recorded wide range of genetic variabilities for seed traits of *Toona ciliata* in Himachal Pradesh among the altitudinal provenances and zones. Gupta et al. (2006) conducted study in Himachal Pradesh, India to estimate the variability for the juvenile growth and biochemical parameters of *T. ciliata* among the altitudinal provenances, zones and seed sources. Sehgal et al. (2006) observed significant variation between and within seed source was for various seed traits and germination parameters in open pollinated seeds of *T. ciliata* were collected from 50 trees from ten seed sources in Himachal Pradesh. Sharma and Thakur (2001) and Sharma et al. (2002) studied germination and seedling characters of *T. ciliata*. Shamet and Sharma (2004) tested cuttings of red cedar (*T. ciliata*) for their rooting response under nursery condition and found that the girdled cuttings of seedling origin material exhibited significantly higher sprouting and rooting performance. Rana et al. (2009) evaluated progenies of 25 seed sources (plus trees) of *T. ciliata* of Himachal Pradesh, India, under nursery and field conditions and recorded significant variation for seedling height, collar diameter and number of leaves under nursery conditions. Uppal and Singh (2010) recorded progenies of Dhelu, Solan, Darang, and Gagal based on seed polymorphism and average growth as ideal seed sources for healthier seedling production. Progenies of 25 seed sources (plus trees) of *T. ciliata* (Toon) collected from different seed zones of Himachal Pradesh were evaluated under nursery and field conditions and found significant variation in morphological characters as well as high heritability (broad sense) coupled with high genetic advance for seedling height and

collar diameter (Rana et al. 2009). Morphological variability and genetic estimates for number of flower and inflorescence length and correlation were conducted by Singh et al. (2018).

7. *Bauhinia variegata*

Anand et al. (2004) collected seeds from 48 plus trees of *Bauhinia variegata* (Kachnar) were selected from different parts of Himachal Pradesh and recorded genetic parameters of these progenies. Anand and Diwedi (2014) observed that collar diameter, plant height and leaf area are the common causal factor that influences biomass productivity of *B. variegata* genotypes. Maximum variation was observed for leaf area and minimum for collar diameter. Yadav and Khare (2003) have given comparative study on the reliability of tetrazolium and indigo carmine staining for in testing the viability of *B. variegata* seeds.

Khantwal et al. (2008) observed presowing treatment of soaking seed in cold water under normal temperature up to 24 h to get highest germination for *B. variegata* along with other multipurpose broad leaved tree species. While, Sinhababu et al. (2007) observed best pretreated of seeds is with hot water. Enhanced germination and seedlings had better vigour when seed before sowing is given a fire treatment than the untreated seedlings (Singh and Raizada 2010). Wani and Chauhan (2008) studied floral biology and stigma receptivity of *Bauhinia variegata* during 2003-2004.Thirty-two half sib progenies of Kachnar (*B. variegata* L.) belonging to different geographic regions of Himachal Pradesh, Haryana, and Jammu & Kashmir were sown in glasshouse and field condition by Wani and Chauhan (2007) and genetic diversity expressed by using non-hierarchical Euclidean cluster analysis that grouped genotypes into ten and eight clusters in glasshouse and field atmosphere, respectively. They found that seedling height contributed maximum to the total divergence and played a predominant role in creating the genetic diversity. Wani and Chauhan (2008) found the high significant correlations between shoot dry weight with root dry weight and seedling biomass under both environments. Path analysis revealed that seedling biomass, root dry weight and shoot/root ratio showed the highest direct effect on shoot dry weight under both the environments. Genetic parameters studied by Wani et al. (2009) under both the environments depicted that PCV were higher than the corresponding GCV for all the morphological and biomass traits.

Thakur et al. (2009) collected seeds were collected from phenotypically superior trees of *B. variegata* at 35 geographical locations from the natural distribution area in Himachal Pradesh during March-April and studied phenotypic and genotypic variability in seedling growth, biomass, and mineral nutrients and proximate principles (Poonam et al. 2012 & 2014, Thakur 2018). Anand and Huse (2013)studied the magnitude of genetic divergence in *B. variegata* by collecting seed from 48 open pollinated (plus trees) families and grouped all the families in to the eight clusters. Different clones were evaluated for morphometric characters in a clonal seed orchard (Thakur 2017).The combining ability and genetic variance for growth traits and biomass traits in *Bauhinia variegata* by developing progeny using line x tester (Tesfaye and Thakur 2019) and Diallel mating design (Thakur 2019) and selected good combiners and paternity of hybrids was confirmed with RAPD molecular markers (Thakur 2019).

8. *Acacia catechu*

Gera and Gera (2006) marked CPTs of khair (*Acacia catechu*) from different geographic locations of Jammu region, India. The variation in pod, seed germination and nursery performance along with genetic parameters were studied in populations collected from Jammu and Kashmir (Gera and Gera 2006), Himachal Pradesh (Selven and Guleria 2012) and Garhwal Himalaya and Siwaliks (Todaria et al. 2004). While, Kumar et al. (2004) observed significant variation in seed traits

among different seed sources of *A. catechu* from Haryana, Punjab, Uttaranchal and Jammu and Kashmir, India. Chauhan and Mohapatra (1998) studied morphological variation of 1-yr-old nursery seedlings raised from 40 seed sources of *A. catechu* through Metroglyph analysis and recorded 10 groups on the basis of seedling height and dry weight of seedling (the most variable seedling characteristics). Mahapatra et al. (2001) studied seedling characters of 40 seed sources and grouped nine seedling traits of *A. catechu* into 15 clusters, with the largest cluster containing 13 seed sources. The pattern of distribution of seed sources in different clusters indicated that genetic divergence was not related to geographical differentiation. While, Gupta et al. (2012) grouped seedling characters into three clusters. Gupta et al. (2010) selected twenty best performing provenances were to investigate the variability in physico-chemical properties of sapwood and heartwood of *A. catechu*. Selvan et al. (2003) standardize the technique of micropropagation for *A. catechu*.

9. *Albizia* species

The populations of *Albizia chinensis* distributed in Himachal Pradesh and Uttarakhand (Dhanai et al. 2003a and Thakur et al. 2002) and *A. lebbeck* (Todaria et al. 2003) from Garhwal Himalaya and Siwaliks, Uttaranchal, Uttar Pradesh were observed for pod and seed morphology and studied their genetic characters. Seedling characters of *Albizia chinensis* (Osbeck) (Dhanai et al. 2003b) and *A. lebbeck* (Bahar 2008) were studied. Bahar (2008) recorded non-clinal pattern of variation in studying seedling of sources of *A. lebbeck*. On average, the population of Dehra Dun (Uttarakhand), Kathua (Jammu & Kashmir) and Tirunelveli (Tamil Nadu) were found to be the best on the basis of weight, germination per cent and vigour index of seed as an important criterion for delineating the superior seed source. Singh and Todaria (2006) observed differences in nutritive value in terms of soluble protein, soluble sugar, potassium, phosphorus and calcium contents of *A. chinensis*, while there was significant variation in seed characters (Thakur et al. 2014) and seedling character biomass, nitrogen, phosphorus, potassium, calcium, magnesium and crude protein (Thakur and Dhuppe 2015) of *A. lebbeck* progenies of provenances from Himachal Pradesh. Uppal and Singh (2010) significant variation for seedlings height, collar diameter and number of leaves in progenies of 25 seed sources (plus trees) of *A. chinensis* collected from different seed zones of Himachal Pradesh and evaluated under nursery. Seedling height and collar diameter after 120 days of sowing, exhibited high heritability (broad sense) coupled with high genetic advance. Borthakur et al. (2011) studied amenability of apical buds from in vitro seedlings for direct shoot regeneration, *A. chinensis*.

10. *Terminalia* species

The vegetative propagation of Behra (*Terminalia bellirica*) was standardized (Sharma and Thakur 2002) and germination behavior of *Terminalia* species in Garhwal Himalaya was studied (Chauhan et al. 2002). Fruit from 30 seed sources was studied for variation in different fruit and seed characters. There was large variation in fruit shape and colour within as well as between populations. The fruit shapes varied from obovate to ovoid, obovoid, elliptical and ovate while fruit colours noticed were dark green, light green, light yellow, pale yellow, pale green, light yellow (Thakur and Badiyala, 2000; Thakur et al. 2008a). There were significant differences in all the fruit and stone characteristics among five natural population of *T. chebula* (Sharma et al. 2016). Wide variation was found in fruit pulp from different sources for biochemical characters like tannins, carbohydrates, proteins etc. (Thakur et al. 2008b).

The studies on reproductive biology of Harar reveal that It is highly cross pollinated (Bhatia et al. 2011; Sankanur et al. 2015). Pollination is affected by insect pollinators. Out of six orders recorded to

visit the Harar bloom, Lepidoptera was represented by maximum number of 15 species followed by Hymenoptera (11 species), Diptera (10 species), Coleoptera (5 species). Thirty one random RAPD primers were used to study genetic diversity in 31 genotypes of *T. chebula* (Sood 2007). Six selected accessions of *T. chebula* were used for molecular characterization to know genetic diversity using two marker systems viz., Random amplified polymorphic DNA (RAPD) and Inter simple sequence repeat (ISSR) markers in which, 25 RAPD and 12 ISSR primers were effective in revealing polymorphisms among different accessions of *T. chebula* (Sankunar et al. 2017).

Table1. Improvement work in different tree species.

Sr	species	Type of work	Reference
1	*Acacia catechu*	Selection	Kumar et al. (2004), Gera and Gera (2006)
2	*Albizia chinensis*	Selection	Dhanai et al. (2003 a&b)
3	*Albizia lebbeck*	Selection	Nawa Bahar (2008), Thakur and Dhuppe(2015)
4	*Anogeissus latifolia*	Selection	Sankhyan et al. (2013a&b), Sankhyan and Singh (2014)
5	*Bauhinia variegata*	Selection	Anand et al. (2004), Poonam et al. (2012), Thakur et al. (2020b)
		Rep. Bio.	Wani and Chauhan (2008)
6	*Cedrus deodara*	Selection	Mughal and Thapliyal (2012),Sankhyan et al. (2013)
7	*Celtis australis*	Selection	Singh et al. (2006),Singh et al. (2010), Kumar et al. (2018)
8	*Grewia laevigata*	Selection	Sankhyan et al. (2009)
9	*Grewia optiva*	Breeding	Saresh et al. (2020)
		Selection	Tyagi et al. (1999)
		Rep. Bio.	Pant et al. (1997 & 2000),Sankhyan et al. (2014)
10	*Hippophae species*	Selection	Singh et al. (2006), Yadav et al. (2006), Kairon et al. (2017 & 2018)
11	*Melia azedarach*	Selection	Thakur and Thakur (2014 & 2015)
12	*Morus alba*	Selection	Bajpai et al. (2014 & 2015),Thakur (2018)
13	*Pinus gerardiana*	Selection	Singh (1992 & 1993)
14	*Pinus roxburghii*	Selection	Sinha et al. (2013), Bhat et al. (2016 a&b)
15	*Pinus wallichiana*	Selection	Thapliyal et al.(1985), Sehgal et al. (1994),Singh et al. (2012)
16	*Poplar deltoides*	Selection	Chauhan and Khurana (1992), Khurana et al. (1992), Jha and Kumar (2000), Kumar and Singh (2001), Chauhan et al.(2004), Pande and Dhiman (2011)
		Breeding	Jha and Kumar (2000), Singh et al. (2002), Dobhal et al. (2019)
		Variety release	Dhiman and Gandhi(2015)
17	*Populus alba*	Selection	Ramesh and Khurana (2003)
18	*Populus ciliata*	Rep. Bio.	Khurana and Bhanwara (1982), Khurana (1985 & 2000)
		Selection	Chaukiyal et al. (1995)
20	*Populus nigra*	Selection	Gangoo et al. (2011)
21	*Punica granatum*	Selection	Pant (2006), Singh and Gupta (2019),
22	*Quercus leuchotrichophora*	Selection	Devi et al.(2018)

23	*Salix species*	Selection	Choudhary et al. (2016), Sharma (2019), Sharma et al. (2019a&b)
		Breeding	Choudhary et al. (2011),Choudhary et al. (2013),Thakur et al. (2014), Sharma et al.(2017), Thakur et al. (2018)
		Rep. Bio.	Choudhary and Singh (2013)
24	*Sapindusmukorossi*	Selection	Bahar and Singh (2007), Kairon et al. (2016 & 2017)
25	*Terminalia chebula*	Selection	Thakur and Badiyala (2000), Sharma et al. (2016), Sankanur et al. (2017)
		Rep. Bio.	Sharma et al (2012), Sankanur et al. (2015)
26	*Toona ciliata*	Selection	Gupta and Sehgal (1999), Gupta et al. (2006), Rana et al. (2009), Uppal and Singh (2010)

Rep. Bio. = Reproductive Biology

11. *Celtis australis*

Singh et al. (2004) found that seed source and the temperature affect the germination of *Celtis australis*. Significant variation was observed for seed traits among provenances in seeds of *C. australis* collected from different sources in Central Himalaya Singh et al. (2006). Comparative study of nutrient composition between juvenile foliage and adult foliage along with altitudinal variation in provenances has been studied (Singh et al. 2010). Kumar et al. (2018) evaluated seed morphological parameters of *C. australis* L. provenances collected from North India and postulated that provenance selection and testing have great potential to improve different characteristics of *C. australis* for higher growth and productivity.

12. *Anogeissus latifolia*

Variation studies in tree morphological parameters in *Anogeissus latifolia* Wall in Himachal Pradesh was carried out (Sankhyan et al. 2013a) and evaluated for genetic variability wr.t. leaf characteristics (Sankhyan et al. 2013b) and fodder quality traits (Sankhyan et al. 2014).

13. *Hippophae* species

Number of studies have been conducted in different regions to assess the morphological and biochemical variations in natural growing populations of seabuckthorn in Spiti Valley Himachal Pradesh and Ladakh region of Jammu and Kashmir (Singh 1994; Singh and Dogra 1995; Singh and Singh 2004; Sankhyan et al. 2004; Dwivedi 2009) and Uttarakhand (Yadav et al. 2006). A survey was conducted in cold desert of Spiti Valley, Himachal Pradesh to assess morphometric andchemical seed oil traits diversity of *Hippophae rhamnoides* population. Nine major gene pool areas and three growing conditions within major gene pool areas selected for the study showed wide variation was obtained among gene pool areas of *H. rhamnoides* population in cold desert of Spiti valley, Himachal Pradesh for morphological, biochemical and leaf proximate compositions traits (Sankhyan et al.2012; Kairon et al. 2017 and 2018). Morphological descriptors for registration of *Hippophae* genotypes were developed (Sankhyan et al. 2018). Molecular diversity was studied with RAPD (Singh et al. 2006, Sharma et al. 2014), ISSR (Tian et al. 2004) and SSR markers. Sharma et al. (2010) studied sex identification with RAPD markers and identifies sex linked peroxidase enzyme system and five random decamer primers. Jain et al. (2010) developed EST-based SSR markers by screening a collection of 1584 clustered ESTs of seabuckthorn (*H. rhamnoides*) from Leh.

14. *Ulmus villosa*

The study on *Ulmus villosa* was carried out in Himachal Pradesh to know the progeny performance and estimate

genetic variability for biomass traits of progenies at nursery stage (Thakur et al. 2013; Thakur and Thakur 2016). The genetic diversity in progenies of selected genotypes of *Ulmus villosa* Brandis was estimated by using RAPD markers (Thakur et al. 2014).

15. *Sapindus mukorossi*

The significant variation was observed in fruit diameter, fruit weight, seed diameter and seed weight (Bahar and Singh 2007; Kairon et al. 2015; Kairon and Sankhyan 2017) and seed oil content (Kairon et al. 2016) among various seed sources of *Sapindus mukorossi* from various localities of Himachal Pradesh, India. The effect of seed size and pre sowing treatments on the germination and initial seedling growth of soapnut (Attri et al. 2017). The diversity of genotypes collected from Western India was evaluated with ISSR molecular markers (Mahar et al. 2012).

16. *Quercus leuchotrichophora*

The *Quercus lecuchotrichophora* provenances of Himachal Pradesh and Uttarakhand was evaluated for seed and seedling morphological characters and found that altitude had significant positive relationship with seed weight, seed length and germination per cent (Saklani et al. 2012; Devi et al. 2018). The progeny of Himachal Pradesh were evaluated for oil content, physico-chemical characteristics of fatty oil and nutritional value of deoiled cake (Devi 2016).

17. *Punica granatum*

The *Punica granatum* provenances were collected from geographically isolated and climatically different locations of five districts in Himachal Pradesh and evaluated for seed and seedling variation studies (Pant 1995). The phenotypic characters of the trees were studied surrounding the University area (Singh et al. 2018a) and used to raise hybrid progeny in line x tester mating design (Singh et al. 2018b). The progeny was evaluated for seed and seedling morphological and paternity was confirmed with molecular markers (Singh et al. 2019).

CONIFEROUS SPECIES

18. Pinus roxburghii

Ghildiyal et al. (2009) studied the environmental variation in seed characters and to explore the efficacy of hydrogen peroxide treatment on the germination and seedling traits of sixteen provenances of *Pinus roxburghii* from Uttarakhand Himalaya. Variation among individual trees of *P. roxburghii* for cone and seed characteristics has been reported by Sagwal (1984), Sharma et al. (1999) and Kumar et al. (2007).Genetic variability of *P. roxburghii* from geographically distinct population were studied by RAPD markers (Ginwal et al. 2010, Sinha et al. 2013). A set of 19 SSR (Simple Sequence Repeats), 9 ISSR (Inter-Simple Sequence Repeats) and 5 AFLP (Amplified Fragment Length Polymorphism) primer combinations were used to evaluate the variability among 53 genotypes of *P. roxburghii* selected based on resin yield from the natural zone of occurrence of this species in Uttarakhand, India (Rawat et al. 2014). Positive and significant correlation of oleoresin yield with diameter and height of different provenances of *P. roxburghii* was observed by Singhal (1996). She also found that all the needle colours except yellow green gave higher resin yield in association with crooked bole form than of straight bole form. However, yellow green colour needles observed higher resin yield in combination with straight bole form. Diameter, bark thickness, needle colour and needle length were found having significant variation with oleoresin yield (Nimkar et al. 2007). The maximum value of diameter, needle length and needle thickness was recorded in high resin yielders 9 and minimum in check trees. He observed maximum bark percentage in check trees and minimum in Ghandir-3. On studying the variation in resin yield with season and diameter class was studied in *P. roxburghii*, it was found that as the diameter increased from 20 to 30 cm, the resin yield increased significantly (Brahmi et al. 1998).Variability

studies for needle, wood (Bhat et al. 2016a) and growth (Bhat et al. 2016b) traits of different half sib progenies of *P. roxburghii* in a 25 years old plantation was undertaken.

19. Pinus wallichaiana

Singh and Thapliyal (2012) analyzed 17 seed sources (seed stands) of *Pinus wallichiana* for variations present in cone and seed characters, scattered over natural distribution in north-west Himalayan states (Uttarakhand and Himachal Pradesh) of India and found significant variations were observed in cone weight, cone length, cone width, seed length, seed width, seed weight, seed germination, radicle length, and plumule length among different seed sources of the species. The study revealed seed source variation in the degree of dormancy at low temperature of incubation (Thapliyal et al.1985). Reddy (1985) observed that resin yield increased significantly with increase in diameter in *P. wallichiana*. Sharma (1987) reported that oleoresin yield increased with the increase in diameter at breast height, which ranged from 35 to 45 cm and above in *P. wallichiana*. Similarly, Kaushal and Sharma (1988) also reported significant increase in resin yield with diameter at breast height in chir pine and blue pine. Similar results were reported by Sharma and Kaushal (1990) and Sehgal et al. (1994).

20. Pinus gerardiana

The improvement work on Chilgoza pine was initiated in the year 1992 with the selection of plus trees from different places of Kinnaur in Himachal Pradesh, standardized clonal propagation (Singh 1992), its progeny evaluation and studying genetic parameters (Singh and Chaudhary, 1993). Natural regeneration of *P. gerardiana* is in critical stage and found that the species is facing higher risk of extinction and needs to be considered as 'Critically Endangered' in Indian Himalayan Region (Malik et al. 2009, Aziz et al. 2017). The germination and biochemical changes in the seeds of chilgoza pine (*P. gerardiana* Wall.) was studied (Malik and Shamet 2008; Malik et al. 2009). The impact of growing media and seed size on germination and seedling characters have been studied (Kumar et al. 2016). Genetic diversity of *P. gerardiana* genotypes from District Kinnour of Himachal Pradesh was studied with RAPD primers and found that it can be attributed to highly cross-pollinating nature of the species and small distributional range in the area (Kant et al. 2006 and Srivastava et al. 2012).

21. Cedrus deodara

Variability studies carried in different seed sources of *Cedrus deodara* of Jammu and Kashmir (India) (Mughal and Thapliyal 2012) and Himachal Pradesh (Sankhyan et al. 2013)with respect to cone, seed and seedling traits that revealed significant variation in different cone and seed characteristics.While, Sofi et al. (2016) studied the seed storage conditions. Chand et al. (2018) studied the variation in field growth of families collected from different populations belonging to Himachal Pradesh.

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