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Seed source variation affects the growth, biomass, carbon stock, and climate resilience potential: A case study of *Celtis australis* in Indian Himalayas

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ABSTRACT

Climate change has adversely affected the tree species growth throughout the globe. In Indian Himalayas, *Celtis australis* is an important agroforestry tree species which is highly exploited for domestic use (fuel wood, fodder, and small timber), and thus the growth and biomass production linked to the species bears importance. However, growth, biomass, and carbon stock of *C. australis* can be improved if genetically superior planting material is used under agroforestry programmes. Therefore, seed source (SS) variation studies in *C. australis* were initiated to identify potential germplasm for improving the species productivity and climate resilience. Experimental results showed that genotypic variation for height, collar diameter, and total biomass were found higher than corresponding environmental variance after four years. In the field environment, highest plant growth was recorded in Tehri SS (Height: 4.88 m; Diameter: 9.69 cm) and Solan SS (Height: 4.81 m; Diameter: 8.64 cm), compared to rest of the seed sources. In contrast, least plant growth (Height: 3.46 m; Diameter 5.19 cm) was observed in Dehradun SS. Likewise, biomass production was assessed maximum (207 t ha^{-1}) in Tehri SS and it was minimum (44 t ha^{-1}) in Dehradun SS. In different seed sources, the estimated carbon stock and carbon sequestration was ranged between 33 103 t ha^{-1} and 99–381 t ha^{-1}, respectively. Overall, growth, biomass, carbon stock, and carbon sequestration confirmed the superiority of Tehri SS over rest of the SS, after four years of field experiment. Moreover, Tehri SS showed better mitigation and adaptation potential for changing climate compared to rest of the SS, because of its superiority in term of the growth performance, biomass production, carbon stock, and carbon sequestration. The results indicated that SS induced genetic variation has the tremendous potential to improve the productivity and climate change mitigation and adaptation in *C. australis*. Therefore, selection of genetically diverse seed sources and evaluation of their potential (adaptive and mitigate) could be one of the futuristic strategies for climate change related fine-tuning of agroforestry practices.

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1. Introduction

Climate change is the greatest challenge to plant productivity, adaptation, and biological conservation in the 21st century (Rosenzweig et al., 2008; Hooper et al., 2012). In Indian Himalayas, annual temperature increased at a rate of about 0.1 °C per decade during 1901–2014, and future climate projections under various scenarios suggest warming in the region in the range of 2.6–4.6 °C by the end of the twenty-first century (Sabin et al., 2020). Several plant species are being subjected to climate change and anthropogenic pressure, which has reduced their productivity, and consequently they are on the brink of extinction in Himalayas and elsewhere (Kumar, 2016; Fortini and Dye, 2017). High temperature fluctuations, extreme rainfall events, and drought, coupled with high biotic pressure, such as indiscriminate felling, unscientific lopping and pruning, etc. severely affect tree species. Consequently a decline has been noted in growth and development (Thomas et al., 2004; Walther et al., 2002; Kumar et al., 2014), carbon stock (Kumar, 2016), biological diversity (Kulkarni and Laender, 2017), and genetic make-up (Helm et al., 2009; Oliveira et al., 2015) of plant species. However, superior planting material developed through selection and improvement programmes has the potential to sustain and enhance plant growth, stock more carbon, and sequester higher CO_2 thereby contributing to the climate change adaptation and mitigation (Whittet et al., 2017).

Several techniques such as conventional breeding (selection, hybridization and mutation, etc.), biotechnology, and vegetative propagation (cloning) has been tested and successfully adopted to improve the growth and characteristics in many important tree species such as, *Eucalyptus, Populus and Pinus* etc. (Assis and Resende, 2011). However, quality seed source identification and superior tree selection is considered as the best strategy to improve tree structure and functions under the climate change scenario (O'brien et al., 2007). For example, Havens et al. (2015) suggested the identification of tree and seed sources as one of the tools for climate change mitigation and adaptation. Superior planting material can be better in any of the characteristics such as, growth, productivity, yield, and quality parameters or it can be any specific trait important for the end-users. Identifying, screening, and testing genetically diverse seed source provide greater opportunity to improve the tree growth, biomass, carbon stock, and resilience against climate change (Mátyás, 1994; Prober et al., 2015; Horváith, 2016).

Foresters and researchers can manage genetic adaptation to climate change by using diverse seed source and selection at multiple sites (Gray et al., 2016a). Seed source/ provenance research is considered as an important contribution to the tree biological sciences (Matyas, 1996). Genetic variation in provenances of tree species evolves either through local adaptation or genetic drift (Hamrick 1990), which provides evolutionary flexibility and enables a response to environmental change (Booth and Grime 2003). The natural variations in climate, ecology, and environment in different geographical regions induce genetic differences in morphology, physiology, and biochemistry of plant species (Jones et al., 2001). As a consequence a plant species may respond differently in a new ecological region, compared to the original geographical location (Bower et al., 2014). Indeed, a particular genotype may exhibit superior plant characteristics and adapt to changing climate, as seed source variations are genetically controlled (Zhao et al., 2020). Moreover, genetic improvement based reforestation strategies are urgently required in the era of global climate change (Whittet et al., 2016). Another important strategy can be to select best performing sibling/progenies from stands that had successfully withstood climate change impacts previously. In general, genetic based tree improvement through seed source variation, testing, and breeding approaches has great potential to meet the growing afforestation needs, this can provide greater climatic and economic benefits such as, soil improvement, erosion control, climate change mitigation, carbon stock enhancement, and provision of various tree products and services (Oliveira et al., 2015).

Celtis australis L. is mostly found in the sub-tropical to temperate regions of America, Europe, Asia and Africa, and the species is categorized as least concern in the IUCN Red List. Large variability has been reported for the growth and morphological traits in India (Singh et al., 2006a,b; Kumar et al., 2018), and abroad (Ammari et al., 2016). In Indian Western Himalaya, this species grows naturally in the states of Uttarakhand, Himachal Pradesh, and Jammu & Kashmir. Due to fast-growing nature and multipurpose use, the species is grown specifically in different agri-silviculture and silvipasture based agroforestry systems, for meeting the requirements of fodder, fuel, fruit, and timber (Yadav and Bisht, 2015). For Indian Himalayas, there have been predictions that climate change in general may severely affect the distribution, productivity, carbon stock, and genetic diversity of many tree species. The predicted increased temperature in Himalaya due to climate change may adversely affect the species productivity and their even distribution by shifting their ecological niches to higher elevations (He et al., 2019). For example, decline in apple productivity due to increased temperature and shift in cultivation zone to higher altitude has already been reported in Himalaya (Rana et al., 2011). In agroforestry systems, *C. australis* sequester atmospheric carbon in biomass and soils, and enhance annuals resilience to changing climatic conditions. Species also improves the local microclimate, and influences regional climatic conditions, thereby contributing to the climate change mitigation and adaptation in Himalaya (Goswami et al., 2014; Kumar et al., 2018).

Previous studies have examined the effect of seed source variation on growth pattern and biomass production of *Celtis australis* seedlings under nursery conditions (Singh et al., 2006a,b), and on a large number of tree species globally (O'brien et al., 2007; McLane, 2011; Gray et al., 2016a). The studies are completely lacking on the role of seed source variations in enhancing the carbon sequestration and climate resilience, particularly in tree species (Gray and Hamann, 2016a; McLane et al., 2011; Kapeller et al., 2012; Gray et al., 2016b). Identification and selection of germplasm and climate resilient trees for improving the growth, biomass production, carbon stock, and carbon sequestration is lacking globally for tree species in general and *C. australis* in particular. Moreover, operational tree breeding for climate change mitigation and adaptation in Himalayan agroforestry species is still years away. Hence, it is of utmost important to improve the growth, biomass, carbon stock, and climate change adaptation of *C. australis* through identification of germplasm by testing genetically diverse seed sources in the field environment. We hypothesized that genetic variation present in seed sources of *C. australis* may result in differential response in term of growth, biomass production, carbon stock, and consequently to climate in a new and different environment compared to their indigenous habitat. Therefore, we investigated the effects of seed source variation on growth, biomass, carbon stock, and climate resilience in *C. australis*.

2. Material and methods

Identification of seed source: The *C. australis* seeds (fifteen trees at each site) of total 150 trees were collected from climatically diverse ecosystems of ten locations in Jammu & Kashmir, Himachal Pradesh and Uttarakhand states of India during October-November, 2012, with the aim to cover a wide range of geographical environments to exploit greater genetic variability (Fig. 1). These seed sources were considered due to endemic nature of species in those localities. Moreover, *C. australis* regional seed sources also displayed genetic variability (Singh et al., 2006a,b). The latitude, longitude and altitude of the seed source were ranged from 29°21′ 11″ to 32°45′44″ N, 75°51′09″ to 79°38′35″ E and 1040 −2322 m, respectively (Table 1). The weather data was obtained from climate-data.org model, which contains data between year 1982 and 2012 (https://en.climate-data.org/). The mean annual rainfall and average temperature of different locations ranged between 1413-2493 mm and 19.1−24.2 °C, respectively.

Selection of trees: Uniform aged stands were identified for selecting trees at a location where tree mortality (5−10%) was observed due to climatic variability, particularly previous occurrence of drought or low seasonal rainfall etc. Any insect pest and disease incidence causing tree mortality was not observed during the seed collection. Phenotypic variation was observed in tree species as few trees were performing better compared to rest due to the influence of climatic factors. The fifteen phenotypically superior and climate resilient trees (plus trees) were selected from each location to represent an SS for seed collection, spaced 100 m apart to avoid collection from closely related individuals. Among the existing populations, climate resilient superior trees were considered based on height and diameter growth using the comparison tree method. The seeds were collected from superior trees to establish a provenance testing trial.

Experimental site: The experiment was conducted during 2013−2017 at the ICAR-Indian institute of soil and water conservation, Research Farm, located at Selaqui, Dehradun, India (30°21′ N and 75°52′ E'). The area is situated at 525 m amsl, and characterized by winters from November to March and summers from April to October. We obtained daily minimum temperature, maximum temperature, and rainfall during four years from the meteorological observatory located at the research farm. The average daily maximum and minimum air temperatures ranged between 31.7 and 20.6 °C in June and 17.8 to 1.1 ^{O}C in January, respectively. The long-term mean annual precipitation is 1625 mm, with 80% falling during the rainy season (June−September).

Seed extraction and germination: From each provenance approximately 2 kg drupe was collected during October−November (2012), brought to laboratory for further analysis and processing. The *C. australis* ripened drupe was dried under the sun for 24 h. The seed of each source was stored in the refrigerator during winter (Nov−Jan), and subsequently it was sown in the nursery during the first week of February 2013. The *C. australis* seeds were soaked in water for 24 h before sowing in the nursery to hasten the germination process. Hundred seeds of each seed-source were sown in polybag to grow seedling in the nursery.

Plantation management. In December (2013), six-month-old nursery grown saplings of *C. australis* were planted in 3 m × 3 m geometry to identify the most suitable *C. australis* genotypes for greater growth, biomass, carbon stock, and climate change adaptation. During the experimental period, all the standard tree management practices were followed to maintain growth and productivity of *C. australis*. To overcome the edge effects, a single guard row was planted around the experiment.

Measurement of tree growth: To evaluate growth and productivity of *C. australis*, nine trees of each genotype were measured every year during 2014, 2015, 2016 and 2017. For productivity analysis, plant saplings were also planted outside experimental area for destructive sampling to estimate biomass and carbon stock. The collar diameter, total tree height, and stem volume was determined in sampled trees using procedure described by (West, 2009). The diameter (>2.5 cm) of all the branches close to main stem was recorded for each tree.

Biomass and Carbon stock estimation: To find out seed source variation in biomass and carbon stock of *Celtis*, twenty-five branches of varying diameter from trees grown outside experimental area were harvested during December 2017. The each harvested branch (leaves + wood) were oven-dried (60 °C) to compute the dry biomass. The relationship between branch diameter and dry biomass (branch wood + leaves) established (Branch (s) biomass (g) = 20.964e0.078x; x = branch diameter (cm); e = Exponential base) and the biomass of each branch estimated using the derived relationship. The biomass of all the branches in each sampled tree was computed by summing the estimated biomass of individual branch. The specific gravity of *Celtis* wood was measured to be 0.716, and the root: shoot ratio (root biomass/shoot biomass) of the nursery grown seedling was 0.71. The stem biomass was computed by multiplying the specific gravity with the stem volume. The above ground biomass was estimated by summing up the stem biomass and branch (s) biomass. The below ground biomass was derived by multiplying the above ground biomass with the root: shoot ratio. The total tree biomass was computed by summing the above and below ground biomass. Carbon stock (CS), and CO_2 sequestration were estimated according to Petersson et al. (2012). Carbon stock of each tree was calculated from the total tree biomass (biomass x 0.50) and carbon sequestration was determined from the tree carbon stock (carbon stock x 3.67). Furthermore, the total biomass, carbon stock, and carbon sequestration for each seed source were determined on the hectare basis.

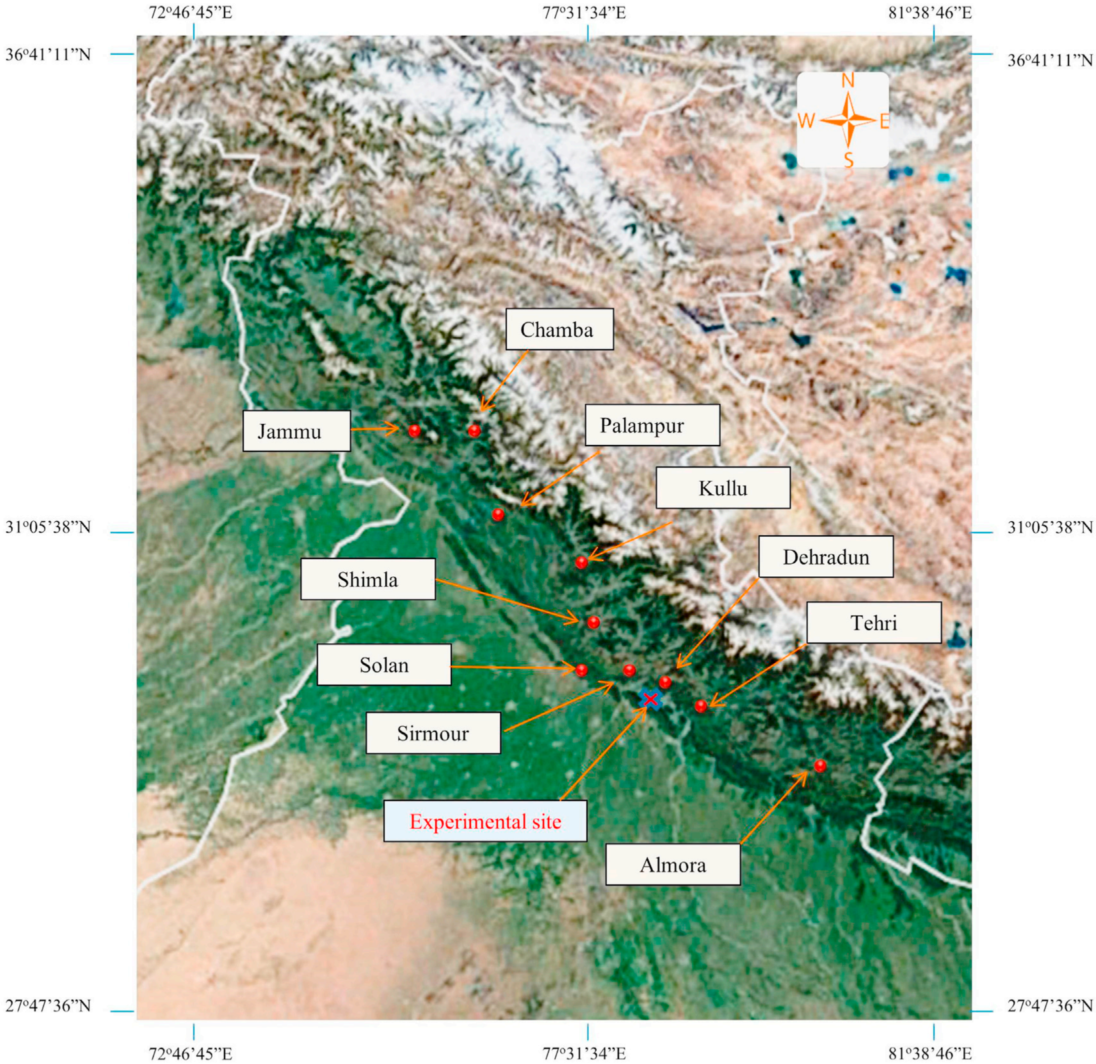

Fig. 1. Map depicting the sites considered for collection of seed sources of *Celtis australis* in North -West Himalaya.

Table 1
Geographical features and climatic conditions of ten provenances considered for the study.

Ecological features		Latitude (N)	Longitude (E)	Altitude (m)	Average Rainfall (mm)	Average annual temperature (°C)
Ecological Regions	Genotypes					
HP	I.C. Chamba	32°45′44″	76°03′52″	2154	2213	20.7
J&K	I.C. Jammu	32°42′10″	75°51′09″	1615	1238	24.2
HP	I. C. Kullu	31°38′00″	77°21′00″	1691	1972	15.1
HP	I. C. Shimla	31°07′46″	77°13′38″	2322	1480	14.2
HP	I.C. Solan	30°51′12″	77°10′51″	1161	1413	17.4
UK	I.C. Dehradun	30°55′56″	77°47′08″	1040	1896	21.8
UK	I.C. Tehri	30°28′17″	78°00′21″	1356	1934	15.3
UK	I.C. Almora	29°38′39″	79°38′02″	1216	1575	14.4
HP	I.C. Palampur	32°08′24″	76°33′16″	1327	2493	19.1
HP	I.C. Sirmour	30°40′15″	76°33′35″	1405	2174	21.0

(HP-Himachal Pradesh, J&K-Jammu and Kashmir, UK-Uttarakhand state); I.C = indigenous collection.

Experimental design and data analysis: The experiment was laid out in completely randomized block design (CRBD), and whole experimental area was divided into three uniform blocks with the aim to reduce the site heterogeneity. Three sapling of each seed source was planted in each block, and the total 90 saplings planted in the experiment area. Repeated measure analysis was performed to detect differences in seedling height, collar diameter, biomass, and carbon stock during four years of growth period. In this experiment, the growth rate and other parameters were measured over time to determine the interaction effects and rate of change from one time period to another between different seed sources. Therefore, the common approach was applied to combine the data from all stages to obtain a single analysis of variance. In this analysis, time of observation was considered as an additional factor in the experiments, treating it as subplot. The, pooled analysis of variance for measurements over time was estimated according to Gomez and Gomez (1984). The data were statistically analyzed using the STAR software version 2.0.1 (2014). Tukey's honestly significant difference (HSD) test was used to compare means within and among seed sources at the 5 and 10% level of significance (Table 2). The Tukey's HSD test was applied for multiple comparisons in different seed sources. In HSD test, error rate can be controlled through minimum significant difference (MSD) which increases with increase in number of treatments, whereas LSD does not depend on the number of treatments (Clewer and Scarisbrick, 2001).

Biometrical approaches

Growth and biomass production in tree species is complex, quantitatively inherited character, and it is highly influenced by the environmental fluctuations. Effectiveness of seed source selection depends on the existence of sufficient genetic variability. The expected improvement in such characters primarily depends on the nature and magnitude of heritable variations. Therefore, to capture genetic variation in seed sources different biometrical approaches (such as phenotypic and genotypic variation, heritability, and genetic advance) were applied.

$$\text{Genotypic variance } \left(\sigma_g{}^2\right) = \frac{MSS - MS(s \times t)}{rt} \tag{i}$$

$$\text{Phenotypic Variance } (\sigma_p{}^2) = (\sigma_g{}^2 + \sigma_e{}^2) \tag{ii}$$

$$\text{Environmental variance } (\sigma_e{}^2) = \text{MSe} \tag{iii}$$

where.

MSS = Mean square for seed sources
MS (s x t) = Mean square for year x seed source interaction
r = number of replications
s = number of seed sources
t = number of years

Phenotypic, genotypic and environmental coefficients of variation were obtained as the ratio of respective standard deviation to the general mean of the characters and expressed in percentage following Burton (1952).

$$\text{Phenotypic Coefficient of Variation (PCV \%)} = \frac{\sigma_{Pi}}{X_i} \times 100 \tag{iv}$$

Where,
σ_{Pi} = Phenotypic Standard Deviation of character 'i'
X_i = General Mean of character 'i'

Table 2
Pooled Analysis of variance for height, Collar Diameter (cm), biomass, and carbon stock overtime.

Source	df	Mean square			
		Height (m)	Collar diameter (cm)	Total Biomass (t/ha)	Carbon stock (t/ha)
Replication	2	3.3***	0.96**	8393.5***	2098.2***
Seed sources (S)	9	2.2***	23.03***	29552.9***	7388.1***
Error (a)	18	0.05	0.17	406.3	101.5
Time of observation (T)	3	36.8***	284.7***	310582.3***	77646.3***
S × T	27	0.14*	1.66***	6570.8***	1642.6***
Error (b)	60	0.09	0.36	657.3	164.3
Total	119				

*, **, *** significant differences at $P < 0.10$, 0.01 and 0.001, respectively.

$$\text{Genotypic Coefficient of Variation (GCV \%)} = \frac{\sigma_{gi}}{X_i} \times 100 \qquad \text{(v)}$$

where, σ_{gi} = Genotypic Standard Deviation of character ‘i’

$$\text{Environmental Coefficient of Variation (ECV \%)} = \frac{\sigma_{ei}}{X_i} \times 100 \qquad \text{(vi)}$$

where, σ_{ei} = Environmental Standard Deviation of character ‘i’.

Heritability in broad sense was calculated for each character by following Allard (1960).

$$h^2_{(b)} = \frac{\sigma^2_{gi}}{\sigma^2_{Pi}} \qquad \text{(vii)}$$

where, $h^2_{(b)}$ = Heritability in broad sense.

σ^2_{gi} = Genotypic Variance of character ‘i’
σ^2_{Pi} = Phenotypic variance of character ‘i’

The expected genetic advance under selection for different characters was estimated as suggested by Allard (1960).

$$G.A.(s) = h^2_{(b)} \times \sigma_{Pi} \times K \qquad \text{(viiv)}$$

where.

G. A. (s) = expected genetic advance under selection
$h^2_{(b)}$ = heritability in broad sense
σ_{Pi} = Phenotypic standard deviation of character ‘i’
K = constant for which the value is given as 2.06 which is the expectation in case of 5% selection intensity as given by Lush (1949).

Genetic advance as percent of mean for each character was calculated as suggested by Johnson, Robinson and Comstock (1955).

$$\text{G.A. as \% of mean} = \frac{\text{G.A.}}{\text{General Mean}} \times 100 \qquad \text{(ix)}$$

3. Results

Performance of *C. australis* germplasms under experimental trials in terms of growth, biomass, carbon stock and climate change adaptation is influenced by the seed source variation (SS) and regional climatic conditions, and same has been explained in the following sections:

3.1. Climatic data of experimental site

During the study period (2014–17), maximum monthly rainfall ranged between 376 and 682 mm was recorded during july month of each year, although less than 200 mm rainfall was also recorded during January to April (Fig. 2). Annual rainfall was recorded minimum of 1400 mm (2014) and maximum of 1593 mm (2015), while long term average rainfall was 1681 mm. Likewise, mean monthly minimum and maximum temperature recorded was 4.62 and 23.85 °C during December and May month, respectively.

3.2. Variance and coefficient of variability

The variance and coefficient of variability (CV) estimates of different *C. australis* genotypes are shown in Table 3. The genotypic variance ranged from 2.88 (Height) to 23419.1 (biomass). With respect to variability, the, phenotypic (141) and genotypic (143) CVs were the highest for the total biomass. Minimum phenotypic (39.7), genotypic (40.4) CVs were recorded for the plant height. Genotypic variance and genotypic CVs for height, collar diameter, and total biomass were found to be higher than corresponding environmental variance and environmental CVs. These results indicate that the genotypic component was the major contributor to the total variance for these characteristics. Estimates of broad sense heritability ranged from 96.7 (height.) to 98.3 (total biomass and diameter). Genetic gain ranged between 8056 and 28679, with mean of height giving the lowest value and that of total biomass the highest value (Table 3). The higher heritability and genetic gain for a particular character demonstrates their potential to express superiority in field conditions.

3.3. Height and diameter growth

The significant effect of time of observation followed by replications (siblings) and genotypes ($P < 0.001$) was observed in *C. australis* for plant height and collar diameter growth (Table 2). Maximum variability was observed due to time of observation followed by replications (siblings) and seed sources. Significant variation due to replication indicated that all the plant of same SS were genetically different due to species cross pollination nature and that provide the selection opportunity within genotypes. Accordingly, significant variation due to genotypes explains the diverse nature of seed collection that may provide better selection opportunity with the genotypes. Significant differences in growth pattern were observed from first year (2014) to fourth year (2017), even after possessing uniform size during field transplanting. Selection for growth pattern (plant height) would be more desirable after first year of experiment. The significant ($P < 0.10$) effect of SS variation was observed on tree height over time (Table 4). Results showed that average tree height ranged between 3.49 and 4.88 m, and the fastest tree growth was observed in Solan followed by Tehri SS, compared to rest of SS. In terms of height, the growth in Tehri and Solan SS was recorded as 25% and 26% higher, respectively, compared to Dehradun SS, which recorded slowest rate of height growth. For collar diameter trait, maximum variability was observed due to time of observation followed by genotype and replications (siblings). Average collar diameter ranged between 5.19 and 9.69 cm, and higher collar diameter growth was observed in Tehri followed by Solan SS, compared to rest of the SS (Table 5). Maximum variation for collar diameter within the genotypes was observed in Tehri SS, as it showed maximum standard error compared to other SS. Likewise, diameter growth was also recorded higher in Tehri (66%) and Solan (87%) SS compared to Dehradun SS. Interestingly, Dehradun SS which is a local seed source performed least compared to rest of the SS. In general, these both characters i. e height and diameter growth performance affected the biomass production in tree species.

3.4. Tree biomass

In this study, total biomass (TB) trends differed significantly in all the seed sources. Significant effect ($P < 0.001$) of time of observation, replication (siblings), seed source and interaction of time of observation and SS was observed for total biomass production during experimental period (Table 4). Non-significant estimates for total biomass (TB) production in one-year (2014) old plant saplings showed the production of uniform biomass in the species (Table 6). Although after four year of experiment, significant trends of TB were in the order of Dehradun < Chamba < Kullu < Sirmour < Shimla < Palampur < Almora < Jammu < Solan < Tehri, respectively. Highest estimated total average biomass production i.e. 208 and 168 ton/ha was observed in Tehri and Solan SS, respectively, which were 4.7 and 3.77 times more, respectively, compared to Dehradun SS which recorded the least total biomass production. In precise terms, Tehri and Solan SS contributed more total biomass production compared to other SS.

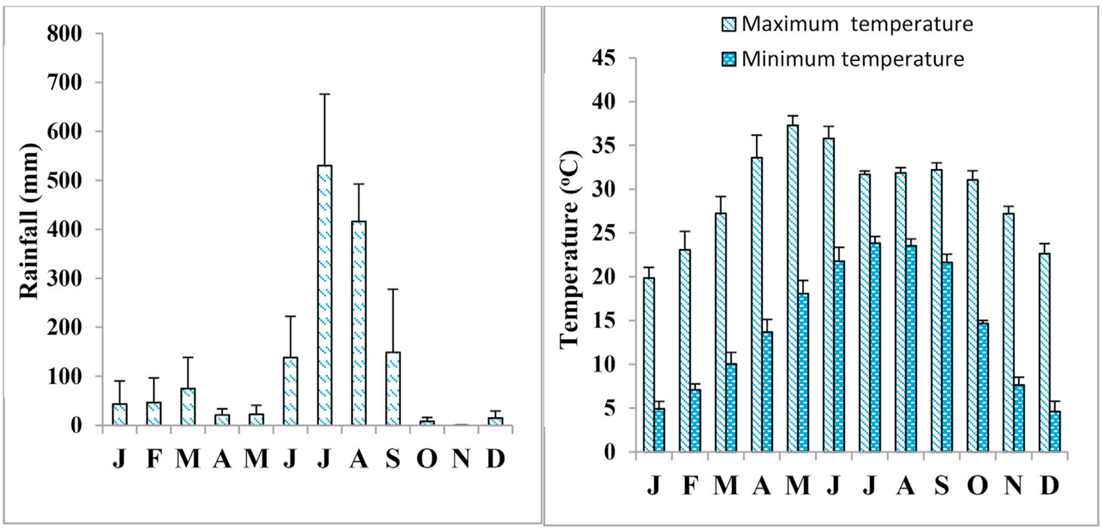

Fig. 2. Trends in the monthly total rainfall, maximum and minimum temperatures temperatures recorded during the study period (2014–2017) at the experiment site (mean = 4).

Table 3
Variances and coefficient of variability estimates.

Parameters	Ve	Vg	Vp	ECV	GCV	PCV	h^2b	GA	GA (%)
Height	0.10	2.88	2.98	10.51	39.77	40.44	96.71	344.02	8056.7
Collar diameter	0.37	21.81	22.17	2.73	65.13	65.67	98.35	954.0	13305.7
Total Biomass	657.3	23419.1	24076.4	0.11	141.1	143.1	97.27	31091.5	28679.5

Note: Vp, phenotypic variance; Vg, genotypic variance; Ve, environment variance; GCV, genotypic coefficient of variance; PCV, phenotypic coefficient of variance; ECV, environment coefficient of variance; h^2B, broad sense heritability; GA; Genetic advance.

Table 4
Measurement of trees height (m) over time in different genotypes of *C. australis* L.

Ecological features						
Ecological Regions	Seed source	2014	2015	2016	2017	Average trees height
UK	I.C. Almora	3.30 ± 0.30^{a}	3.71 ± 0.25^{cd}	4.75 ± 0.13^{ab}	5.75 ± 0.18^{abc}	4.38 ± 0.30^{bc}
HP	I.C. Chamba	2.64 ± 0.05^{ab}	3.23 ± 0.50^{de}	4.48 ± 0.42^{bc}	5.08 ± 0.05^{cd}	3.86 ± 0.32^{ef}
UK	I.C. Dehradun	2.43 ± 0.08^{b}	2.71 ± 0.27^{e}	3.79 ± 0.60^{c}	5.02 ± 0.07^{d}	3.49 ± 0.34^{f}
J&K	I.C. Jammu	3.19 ± 0.06^{a}	4.53 ± 0.12^{ab}	4.76 ± 0.30^{ab}	5.70 ± 0.13^{abcd}	4.54 ± 0.28^{ab}
HP	I.C. Palampur	2.93 ± 0.02^{ab}	3.77 ± 0.23^{cd}	4.77 ± 0.31^{ab}	5.69 ± 0.25^{abcd}	4.29 ± 0.33^{bcd}
HP	I.C. Shimla	3.05 ± 0.08^{ab}	3.94 ± 0.35^{bcd}	4.41 ± 0.28^{bc}	5.22 ± 0.10^{cd}	4.16 ± 0.26^{cde}
HP	I.C. Sirmour	3.14 ± 0.02^{ab}	3.95 ± 0.32^{bcd}	5.02 ± 0.20^{ab}	5.40 ± 0.16^{bcd}	4.38 ± 0.28^{bc}
HP	I.C. Solan	3.31 ± 0.02^{a}	4.18 ± 0.42^{abc}	5.37 ± 0.22^{a}	6.39 ± 0.14^{a}	4.81 ± 0.37^{a}
UK	I.C. Tehri	3.33 ± 0.05^{a}	4.72 ± 0.16^{a}	5.39 ± 0.37^{a}	6.07 ± 0.16^{ab}	4.88 ± 0.32^{a}
HP	I.C. Kullu	2.64 ± 0.05^{ab}	3.38 ± 0.17^{de}	4.46 ± 0.09^{bc}	5.23 ± 0.10^{cd}	3.93 ± 0.30^{de}

HP-Himachal Pradesh, J&K-Jammu and Kashmir, UK-Uttarakhand.
Note: Data are summarized as the mean ± standard error. Any two means within a column having common alphabet notation (a, b, c, d and e) are not significantly different at the 10% level of significance, analyzed through Tukey's Honestly Significant Difference (HSD) Test.

3.5. Carbon stock (CS) and CO_2 sequestration (COS)

CS and COS was estimated in different ecotypes collected from different sites and evaluated for four years in perpetuity. Analysis of data showed that there was significant difference between different SS for CS and COS. Average CS and COS was ranged between 33-103 t ha^{-1}, and 121–359 t ha^{-1}, respectively, in different SS (Table 7). CS and COS showed largest increase in Tehri and Solan SS compared to Dehradun SS (Fig. 3). In absolute terms, CS in Tehri and Solan SS was recorded 81 t ha^{-1} and 62 t ha^{-1} higher, respectively, compared to Dehradun SS. Likewise, average COS found to increase significantly in Tehri (238 t ha^{-1}) and Solan SS (232 t ha^{-1}), compared to Dehradun SS.

4. Discussion

Growth, biomass production, and carbon stock of tree species are affected by the environmental factors, anthropogenic activities, and genotypic responses (Kumar et al., 2016; Hovrath, 2016). The climatic data of the region for past few decades has indicated an increase in the extreme rain events (Goswami et al., 2006). In general, the region is characterized by high

Table 5
Collar diameter (cm) over time in different seed sources of *C. australis* L.

Ecological feature		Collar Diameter (cm)				
Ecological Regions	Seed source	2014	2015	2016	2017	Average Collar Diameter
UK	I.C. Almora	3.98 ± 0.05^{abc}	5.70 ± 0.12^{bcd}	8.50 ± 0.12^{cd}	11.37 ± 0.42^{bc}	7.39 ± 0.85^{c}
HP	I.C. Chamba	2.74 ± 0.02^{c}	4.32 ± 0.05^{de}	6.47 ± 0.21^{e}	8.21 ± 0.58^{ef}	5.43 ± 0.64^{d}
UK	I.C. Dehradun	2.65 ± 0.07^{c}	4.14 ± 0.20^{e}	6.39 ± 0.39^{e}	7.58 ± 0.45^{f}	5.19 ± 0.59^{d}
J&K	I.C. Jammu	3.75 ± 0.05^{abc}	4.72 ± 0.17^{cde}	7.68 ± 0.25^{de}	12.14 ± 0.48^{b}	7.07 ± 0.99^{c}
HP	I.C. Palampur	3.75 ± 0.06^{abc}	6.13 ± 0.10^{abc}	8.23 ± 0.41^{cd}	11.33 ± 0.41^{bc}	7.36 ± 0.85^{c}
HP	I.C. Shimla	4.45 ± 0.14^{ab}	6.33 ± 0.21^{ab}	9.66 ± 0.26^{bc}	10.43 ± 0.63^{cd}	7.72 ± 0.75^{bc}
HP	I.C. Sirmour	3.79 ± 0.11^{abc}	6.29 ± 0.05^{ab}	8.51 ± 0.09^{cd}	10.57 ± 0.50^{cd}	7.29 ± 0.77^{c}
HP	I.C. Solan	4.38 ± 0.05^{ab}	7.08 ± 0.07^{ab}	10.32 ± 0.20^{ab}	12.77 ± 0.95^{b}	8.64 ± 0.98^{b}
UK	I.C. Tehri	5.20 ± 0.23^{a}	7.40 ± 0.12^{a}	11.75 ± 0.14^{a}	14.40 ± 0.40^{a}	9.69 ± 1.09^{a}
HP	I.C. Kullu	3.14 ± 0.05^{bc}	4.76 ± 0.35^{cde}	6.70 ± 0.31^{e}	9.28 ± 0.79^{de}	5.97 ± 0.72^{d}

HP-Himachal Pradesh, J&K-Jammu and Kashmir, UK-Uttarakhand.
Note: Data are summarized as the mean ± standard error. Any two means within a column having common alphabet notation (a, b, c, d and e) are not significantly different at the 10% level of significance, analyzed through Tukey's Honestly Significant Difference (HSD) Test.

Table 6
Estimates of total biomass (tons/ha) over time in different seed sources of *C. australis* L.

Ecological features		Total biomass (tons/ha)				
Ecological Regions	Genotypes	2014	2015	2016	2017	Average biomass
UK	I.C. Almora	18.39 ± 1.44[a]	42.37 ± 2.21[ab]	121.06 ± 4.63[cd]	263.80 ± 27.36[cd]	111.41 ± 29.50[bc]
HP	I.C. Chamba	6.98 ± 0.06[a]	21.14 ± 3.00[b]	67.01 ± 9.80[de]	122.35 ± 18.04[f]	54.37 ± 14.30[cd]
UK	I.C. Dehradun	5.99 ± 0.14[a]	16.18 ± 0.45[b]	53.28 ± 5.31[e]	102.62 ± 12.55[f]	44.52 ± 11.79[d]
J&K	I.C. Jammu	15.80 ± 0.73[a]	35.85 ± 3.50[ab]	98.61 ± 4.07[cde]	296.92 ± 21.88[c]	111.80 ± 33.86[bc]
HP	I.C. Palampur	14.56 ± 0.41[a]	49.86 ± 1.55[ab]	113.83 ± 10.31[cde]	259.37 ± 25.22[cd]	109.41 ± 28.82[bc]
HP	I.C. Shimla	21.25 ± 0.78[a]	56.27 ± 7.68[ab]	144.37 ± 3.64[bc]	203.00 ± 28.90[de]	106.22 ± 22.54[c]
HP	I.C. Sirmour	15.94 ± 0.79[a]	54.98 ± 3.87[ab]	128.10 ± 2.36[cd]	214.80 ± 26.38[de]	103.46 ± 23.57[cd]
HP	I.C. Solan	22.44 ± 0.49[a]	74.12 ± 9.11[ab]	202.28 ± 13.83[cb]	373.34 ± 60.47[b]	168.05 ± 42.96[ab]
UK	I.C. Tehri	31.97 ± 3.03[a]	91.37 ± 5.96[a]	261.99 ± 15.68[a]	445.39 ± 34.05[a]	207.68 ± 49.26[a]
HP	I.C. Kullu	9.20 ± 0.36[a]	27.01 ± 2.70[ab]	70.95 ± 7.26[de]	161.53 ± 29.62[ef]	67.17 ± 18.93[cd]

HP-Himachal Pradesh, J&K-Jammu and Kashmir, UK-Uttarakhand.
Note: Data are summarized as the mean ± standard error. Any two means within a column having common alphabet notation (a, b, c, d and e) are not significantly different at the 10% level of significance, analyzed through Tukey's Honestly Significant Difference (HSD) Test.

event in monsoon, and extreme summer and winter temperatures. These conditions have deterministic influence on plant growth and development. Likewise, (Kumar et al., 2020) also observed that erratic and uneven distribution of precipitation considerably affects the tree plant growth and biomass productions. For a tree species, seed source of a specific origin/provenance grows, evolves, and adapts to a particular set of climatic conditions, which contributes to the genotypic and phenotypic variability, and succession in that particular seed source. In general, climate affects the genotypic response, and phenotypic and environment variability in a particular plant species, and over-time their seed sources adapts to the contrasting climate conditions.

In present study, the phenotypic assessment indicated towards high genetic variability within and among the seed source of *C. australis* across their geographic range in the Indian Himalayas. In most tree species, seedling growth and other characteristics are strongly controlled by the genotype than the environmental factors (Asaro et al., 2016), indicating a good potential for selection and further improvement in the tree species. In our study, both genotypic variation and genetic gain were found higher for height, collar diameter, and total biomass, which suggests that immense improvement, could be achieved for these characters through simple selection.

Genotypes selection from diverse environments can help in improving the several useful characteristics in tree species. As explained in results, the seed source (SS) variability significantly influenced the *C. australis* growth, and Solan SS and Tehri SS outperformed all others, particularly the seed source which was native (Dehradun) to the test site. Results further indicated that Solan SS and Tehri SS have strong potential to adapt to Dehradun environment (Fig. 4). Therefore, the performance assessment predicted that these SS would survive and better perform compared to the rest SS once exposed to extreme climate conditions because the seeds were collected from the climate resilient trees at each location. In general, better performing SS will be least affected under the changing climate scenarios (Alfaro et al., 2014). In addition, improvement in growth characteristics as a consequence of SS variation will contribute to increased vegetative biomass production which can be exploited for enhancing land productivity, particularly of the degraded lands. (Whittet et al., 2016).

For biomass production, Tehri SS and Solan SS outperformed all other SS and there was large variation among the SS. Presence of variability among genotypes has been noticed to contribute to the differences in the species biomass production (Singh and Pokhrial, 2000). It is also established that geography and ecosystem contribute to the species genetic constitution that results in the biomass production differences within the same spp. (FAO, 1985). Moreover, particular SS may exhibit high

Table 7
Estimates of Total Carbon stocks (tons/ha) over time in different seed sources of *C. australis* L.

Ecotype features		Total Carbon stocks (tons/ha)				
Ecological Regions	Seed sources	2014	2015	2016	2017	Average carbon stocks
UK	I.C. Almora	9.19 ± 0.72[a]	21.19 ± 1.10[ab]	60.53 ± 2.32[cd]	131.90 ± 13.68[cd]	55.70 ± 14.75[bc]
HP	I.C. Chamba	3.49 ± 0.03[a]	10.57 ± 1.50[b]	33.51 ± 4.90[de]	61.17 ± 9.02[f]	27.19 ± 7.15[cd]
UK	I.C. Dehradun	3.00 ± 0.07[a]	8.09 ± 0.23[b]	26.64 ± 2.66[e]	51.31 ± 6.28[f]	22.26 ± 5.89[d]
J&K	I.C. Jammu	7.90 ± 0.36[a]	17.93 ± 1.75[ab]	49.31 ± 2.03[cde]	148.46 ± 10.94[c]	55.90 ± 16.93[bc]
HP	I.C. Palampur	7.28 ± 0.20[a]	24.93 ± 0.78[ab]	56.92 ± 5.16[cde]	129.69 ± 12.61[cd]	54.70 ± 14.41[bc]
HP	I.C. Shimla	10.63 ± 0.40[a]	28.13 ± 3.84[ab]	72.18 ± 1.82[bc]	101.50 ± 14.45[de]	53.11 ± 11.27[c]
HP	I.C. Sirmour	7.97 ± 0.40[a]	27.49 ± 1.93[ab]	64.05 ± 1.19[cd]	107.40 ± 13.19[de]	51.73 ± 11.79[cd]
HP	I.C. Solan	11.22 ± 0.25[a]	37.06 ± 4.55[ab]	101.14 ± 6.91[ab]	186.67 ± 30.23[b]	84.02 ± 21.48[ab]
UK	I.C. Tehri	15.98 ± 1.51[a]	45.69 ± 2.98[a]	130.99 ± 7.84[a]	222.69 ± 17.02[a]	103.84 ± 24.63[a]
HP	I.C.Kullu	4.60 ± 0.18[a]	13.50 ± 1.35[ab]	35.48 ± 3.63[de]	80.76 ± 14.81[ef]	33.59 ± 9.46[cd]

HP-Himachal Pradesh, J&K-Jammu and Kashmir, UK-Uttarakhand.
Note: Data are summarized as the mean ± standard error. Any two means within a column having common alphabet notation (a, b, c, d and e) are not significantly different at the 5% level of significance, analyzed through Tukey's Honestly Significant Difference (HSD) Test.

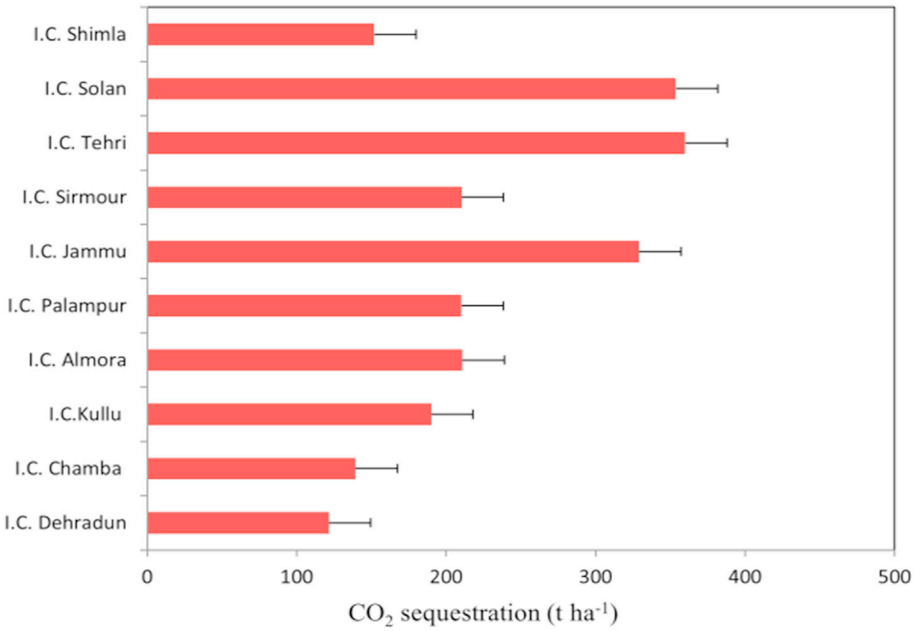

Fig. 3. CO_2 sequestration in different seed sources of *Celtis australis*.

Fig. 4. Growth of *Celtis australis* under field conditions after four years.

biomass production in the changing climatic scenario compared to others because of frequent previous exposures and adaptation to such conditions. In general, assessment and adaptation of SS variation can play significant role in improving biomass production of agroforestry trees during extreme weather condition anticipated under different climate change scenarios (Briceno et al., 2015).

Currently, researchers throughout the globe are working tirelessly on developing different approaches, which can rapidly sequester more and more carbon for mitigating the global warming impacts (Rweyongeza, 2010; Gray et al., 2016a). For example, Joseph et al. (2013) suggested that transgenic trees with multiple genes for resistance to abiotic stress help them to cope with future climate change. Recently, seed source (SS) identification has emerged a new tool to improve carbon assimilation in the tree species (Gray et al., 2016b). Accordingly, our results suggested that SS wise variation exists for carbon stock and CO_2 sequestration in *C. australis,* and Tehri SS and Solan SS demonstrated strong potential for these characteristics. Similarly, these studies also indicated that seed source variation has strong potential to improve ecosystem level carbon stocks that contributes to greater atmospheric CO_2 sequestration and climate change mitigation (Lal, 2001). Higher CO_2 sequestration in plants contributes to the climate change mitigation by maintaining the global C balance (Franzluebbers and Doraiswamy, 2007). Therefore, extensive genotype and seed source testing can be adopted as one of the strategies for climate change mitigation, regionally as well as globally. Identifying genotype of tree species based on SS variation for climate change mitigation can reduce vulnerability of regional and global ecosystems to climate change.

Inducing adaptation to climate extremes is one of the major challenges currently faced by the researchers and policy planners, worldwide. Improvement and selection for multiple stresses is one of the important strategies for enhancing plant species adaptation to climate change**.** Genotype selection through seed source testing is considered as economical, rapid, and highly effective technique in trees species (Jones et al., 2001). Selecting tree seeds or planting materials from agro-ecosystems that are continuously exposed to extreme climatic events may lead to the higher survival and adaptation in agroforestry plantations under the extreme climatic events. Future research should also focus on recording long-term climatic data and establishing its relationship with the tree growth at sites considered for seed/germplasm selection. The varied plant growth as a consequence of genotypic variation may result in the differential response to changing climate in a particular region. In this study, we identified superior seed sources of *Celtis* germplasm that would greatly contribute in biomass production, carbon stocking and sequestering the atmospheric carbon. This will help in enhancement of agroforestry systems productivity as well provision of climate change mitigation and adaptation in Himalayan ecosystem. Moreover, these practices can contribute in improving the ecological and economic benefits of the regional population in Himalaya. Continuous selection and testing efforts may lead to higher productivity as well as better species adaptation to climate change. In general, at global scale, tree species genotype testing and exchange programme should be initiated for conserving species diversity, improving plant productivity, restoring degraded lands and enhancing forest's capacity to climate change adaptation. Species selection and testing programme should be run continuously over long time spans, as part of a global research framework on tree improvement with the cooperation of international developmental agencies.

5. Conclusion

Our finding explained that significant variation between and among the *Celtis australis* seed sources (SS) can provide an opportunity for selecting superior planting materials to improve species productivity and climate resilience. Selection of superior germplasm could successfully increase growth and biomass productions of trees species like *Celtis australis* under a preferred condition. For Western Indian Himalayas, Tehri and Solan SS performed significantly better compare to Jammu, Almora, Sirmour, Palampur, Kullu, Shimla, Chamba, and Dehradun seed sources. These two genotypes can be adopted in improvement projects worldwide under the conditions similar to Himalayan foothills. The studies point out that SS is an effective tool for improving afforestation success in climatically vulnerable regions. Seed source based selection can help in improving biomass yields, carbon sequestration and plant survival in extreme events, thus helping both adaptation and mitigation goals for climate change. Therefore, in future, SS selection and testing of other commercially important agroforestry tree species should be initiated for further enhancing the species productivity under climate change scenario.

Author contribution statement

RK, HM, RK conceptualized and designed the experiment, recorded data and wrote the first version of manuscript. AK and AKB analyzed data and improved the revised manuscript. SD, AKG, RB, MK, SK, and KM contributed in writing the manuscript.

Conflicts of interest

None of the authors has any conflict of interest to declare.

Author agreement

All authors have seen and approved the final version of the manuscript being submitted. They warrant that the article is the authors' original work, hasn't received prior publication and isn't under consideration for publication elsewhere.

Declaration of interest

There's no financial/personal interest or belief that could affect their objectivity, or if there is, stating the source and nature of that potential conflict.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Alfaro, R.I., Fady, B., Vendramin, G.G., Dawson, I.K., Fleming, R.A., Saenz-Romero, C., Lindig-Cisneros, R.A., Murdock, T., Vinceti, B., Navarro, C.M., Skroppa, T., Baldinelli, G., El-Kassaby, Y.A., Loo, J., 2014. The role of forest genetic resources in responding to biotic and abiotic factors in the context of anthropogenic climate change. For. Ecol. Manag. 333, 76–87.
Allard, R.W., 1960. Principals of Plant Breeding. John Wiley and Sons Inc, New York, pp. 185–p.
Ammari, Y., Zouaoui, R., Abbasi, M., Jebali, S., Hamdi, S., 2016. Study of dendrometric and morphological variability of *Celtis australis* located in northern Tunisia. Int. J. Agric. Innov. Res. 5, 301–309.
Asaro, A., Ziegler, G., Ziyomo, C., Hoekenga, O.A., Dilkes, B.P., Baxter, I., 2016. The interaction of genotype and environment determines variation in the maize kernel ionome. G3 (Bethesda, Md.) 6 (12), 4175–4183. https://doi.org/10.1534/g3.116.034827.
Assis, T.F., Resende, M.D.V., 2011. Genetic improvement of forest tree species. Crop Breed. Appl. Biotechnol. S1, 44–49.
Booth, R.E., Grime, J.P., 2003. Effects of genetic impoverishment on plant community diversity. J. Ecol. 91, 721–730.
Bower, A.D., St Clair, J.B., Erickson, V., 2014. Generalized provisional seed zones for native plants. Ecol. Appl. 24, 913–919. https://doi.org/10.1890/13-0285.1.
Briceao, V.F., Hoyle, G.L., Nicotra, A.B., 2015. Seeds at risk: how will a changing alpine climate affect regeneration from seeds in alpine areas? Alpine Bot. 125 (2), 59–68.
Burton, G.W., 1952. Quantitative inheritance of grass. Int. Grassland Cong. Held at Pennsylvania State Coll.. Pa. US. 1, 7483. Proc. 6th.
Clewer, A.G., Scarisbrick, D.H., 2001. Practical Statistics and Experimental Design for Plant and Crop Science. John Wiley, Chichester.
FAO, 1985. A Guide of Forest Seed Handling: with Special Reference to Tropics. FAO, Rome, Italy, p. 379. FAO Forestry paper No 22/2.
Fortini, L.B., Dye, K., 2017. At a global scale, do climate change threatened species also face a greater number of non-climatic threats? Glob. Ecolo. Conserv. 11, 207–212. https://doi.org/10.1016/j.gecco.2017.06.006.
Franzluebbers, A.J., Doraiswamy, P.C., 2007. Carbon Sequestration and Land Degradation. In: Sivakumar, M.V.K., Ndiangui, N. (Eds.), Climate and Land Degradation. Environmental Science and Engineering (Environmental Science). Springer, Berlin, Heidelberg.
Gomez, K.A., Gomez, A.A., 1984. Statistical Procedures for Agricultural Research, 2 ed. John wiley and sons, NewYork, p. 680p.
Goswami, S., Verma, K.S., Kaushal, R., 2014. Biomass and carbon sequestration in different agroforestry systems of a Western Himalayan watershed. Biol. Agric. Hortic. 30 (2), 88–96. https://doi.org/10.1080/01448765.2013.855990.
Goswami, B.N., Venugopal, V., Sengupta, D., Madhusoodanan, M.S., Xavier, P.K., 2006. Increasing trend of extreme rain events over India in a warming environment. Science 1442–1445, 01 dec 2006.
Gray, L.K., Hamann, A., John, S., Rweyongeza, D., Barnhardt, L., Thomas, B.R., 2016a. Climate change risk management in tree improvement programs: selection and movement of genotypes. Tree Genet. Genomes 12, 1e12.
Gray, L.K., Rweyongeza, D., Hamann, A., John, S., Thomas, B.R., 2016b. Developing management strategies for tree improvement programs under climate change: insights gained from long-term field trials with lodgepole pine. For. Ecol. Manag. 377, 128–138.
Hamrick, J.L., 1990. Isozymes and the Analysis of Genetic Structure in Plant Populations. Isozymes in Plant Biology. In: Soltis, D.E., Soltis, P.S. (Eds.). Chapman & Hall, London, UK, pp. 87–105.
Havens, K., Vitt, P., Still, S., Kramer, T.A., Fant, J.B., Schatz, K., 2015. Seed sourcing for restoration in an era of climate change. Nat. Area J. 35 (1), 122–133. https://doi.org/10.3375/043.035.0116.
He, X., Burgess, K.S., Yang, X.F., Ahrends, A., Gao, L.M., Li, D.Z., 2019. Upward elevation and northwest range shifts for alpine Meconopsis species in the Himalaya-Hengduan Mountains region. Ecol. Evol. 9, 4055–4064. https://doi.org/10.1002/ece3.5034.
Helm, A., Tatjana, O., Liina, S., Krista, T., Tiina, T., Meelis, P., 2009. Human influence lowers plant genetic diversity in communities with extinction debt. J. Ecol. 97 (6), 1329–1336.
Hooper, D.U., Adair, E.C., Cardinale, B.J., Byrnes, J.E.K., et al., 2012. A global synthesis reveals biodiversity loss as a major driver of ecosystem change. Nature 486, 105–108. https://doi.org/10.1038/nature11118.
Horvaith, A.K., 2016. Beech Adaptation to Climate Change According to Provenance Trials in Europe. Theses of Doctoral (PhD) Dissertation. University of West Hungary. Faculty of Forestry.
Johnson, H.W., Robinson, H.F., Comstock, R.F., 1955. Estimates of genetic and environmental variability in soybean. Agron J 47, 314318.
Jones, A.T., Hayes, M.J., Sackville, H.N.R., 2001. The effect of provenance on the performance of *Crataegus monogyna* in hedges. J. Appl. Ecol. 38, 952–962.
Joseph, G.D., Timothy, J.S., Armin, W., 2013. Potential transgenic routes to increase tree biomass. Plant Sci. 212, 72–101.
Kapeller, S., Lexer, M.J., Geburek, T., Hiebl, J., Schueler, S., 2012. Intraspecific variation in climate response of Norway spruce in the eastern Alpine range: selecting appropriate provenances for future climate. For. Ecol. Manag. 271, 46–57.
Kulkarni, D., De Laender, F., 2017. The combined effects of biotic and abiotic stress on species richness and connectance. PloS One 12 (3). https://doi.org/10.1371/journal.pone.0172828 e0172828.
Kumar, R., Bhatnagar, P.R., Kakade, V., Dobhal, S., 2020. Tree plantation and soil water conservation enhances climate resilience and carbon sequestration of agro ecosystem in semi-arid degraded ravine lands. Agricultural and Forest Meteorology 282-283, 107857.

Kumar, R., Mehta, H., Kaushal, R., Banyal, R., Kumar, M., 2018. Influence of provenance variation on seedling characteristics of *Celtis australis* in nursery environment. Indian J. Ecol. 45 (4), 797–801.
Kumar, R., Shamet, G.S., Alam, N.M., Jana, C., 2016. Influence of growing medium and seed size on germination and seedling growth of *Pinus gerardiana*. Compost Sci. Util. 24 (2), 94–104.
Kumar, R., Shamet, G.S., Mehta, H., Alam, M., Tomar, J.M.S., Chaturvedi, O.P., Khajuria, N., 2014. Influence of gibberellic acid and temperature on seed germination in Chilgoza pine (*Pinus gerardiana* Wall.). Indian Journal of Plant Physiology 19 (4), 363–367.
Lal, R., 2001. Potential of desertification control to sequester carbon and mitigate the greenhouse effect. Climatic Change 51, 35–72. https://doi.org/10.1023/A: 1017529816140.
Lush, J.L., 1949. Animal Breeding Plans. Collegiate Press, Iowa.
Matyas, C., 1994. Modeling climate change effects with provenance test data. Tree Physiol. 14, 797–804.
Matyas, C., 1996. Climatic adaptation of trees: rediscovering provenance tests. Euphytica 92, 45. https://doi.org/10.1007/BF00022827.
McLane, S.C., Daniels, L.D., Aitken, S.N., 2011. Climate impacts on lodgepole pine (*Pinus contorta*) radial growth in a provenance experiment. For. Ecol. Manag. 262, 115–123.
O'brien, E.K., Mazanec, R.A., Krauss, S.L., 2007. Provenance variation of ecologically important traits of forest trees: implications for restoration. J. Appl. Ecol. 44, 583–593.
Oliveira, S.P.D., Lacerda, N.B.D., Blum, S.C., Escobar, M.E.O., Oliveira, T.S.D., 2015. Organic carbon and nitrogen stocks in soils of northeastern Brazil converted to irrigated agriculture. Land Degrad. Dev. 26, 9–21.
Petersson, H., Holm, S., Stahl, G., Alger, D., Fridman, J., Lehtonen, A., Lundstrom, A., Makipaa, R., 2012. Individual tree biomass equations or biomass expansion factors for assessment of carbon stock changes in living biomass - A comparative study. For. Ecol. Manag. 270, 78–84. https://doi.org/10.1016/j.foreco.2012.01.004.
Prober, S.M., Byrne, M., McLean, E.H., Steane, D.A., Potts, B.M., Vaillancourt, R.E., Stock, W.D., 2015. Climate-adjusted provenance: a strategy for climate-resilient ecological restoration. Front. Ecol. Evol. 3, 65. https://doi.org/10.3389/fevo.2015.00065.
Rana, R.S., Bhagat, R.M., Kali, V., 2011. Impact of climate change on apple crop in Himachal Pradesh. J. Agrometeorol. 13 (2), 97–103.
Rosenzweig, et al., 2008. Attributing physical and biological impacts to anthropogenic climate change. Nature 453, 353–357.
Rweyongeza, D., Barnhardt, L., Dhir, N., Hansen, C., 2010. Population differentiation and climatic adaptation for growth potential of white spruce (*Picea glauca*) in Alberta, Canada. Silvae Genet. 59, 158.
Sabin, T.P., Krishnan, R., Vellore, R., Priya, P., Borgaonkar, H.P., Singh, B.B., Sagar, A., 2020. Climate change over the Himalayas. In: Krishnan, R., Sanjay, J., Gnanaseelan, C., Mujumdar, M., Kulkarni, A., Chakraborty, S. (Eds.), Assessment of Climate Change over the Indian Region. https://doi.org/10.1007/978-981-15-4327-2_11. Springer, Singapore.
Singh, B., Bhatt, B.P., Prasad, P., 2006a. Variation in seed and seedling traits of *Celtis australis*, a multipurpose tree, in Central Himalaya, India. Agrofor. Syst. 67, 115–122.
Singh, B., Uniyal, A.K., Bhatt, B.P., Prasad, P., 2006b. Altitudinal variation in seed characteristics of *Celtis australis* L. For. Trees Livelihoods 16, 289–293. https://doi.org/10.1080/14728028.2006.9752566.
Singh, N., Pokhriyal, T.C., 2000. Biomass distribution pattern in relation to seed source variation in *Dalbergia sissoo* seedlings. Ann. For. 8, 238–249.
Thomas, C.D., Cameron, A., Green, R.E., Bakkenes, M., 2004. Extinction risk from climate change. Nature 427, 145–148.
Walther, G.R., Post, E., Convey, P., Menzel, A., 2002. Ecological responses to recent climate change. Nature 416, 389–395.
West, W.P., 2009. *Tree and forest*, measurement.2nd ed. Springer, Berlin,192p.
Whittet, R., Cavers, S., Cottrell, J., Ennos, R., 2017. Seed sourcing for woodland creation in an era of uncertainty: an analysis of the options for Great Britain. Forestry: Int. J. Financ. Res. 90 (2), 163–173. https://doi.org/10.1093/forestry/cpw037.
Whittet, R., Stephen, C., Joan, C., Richard, E., 2016. Seed sourcing for woodland creation in an era of uncertainty: an analysis of the options for Great Britain. Forestry 90, 163–173.
Yadav, R.P., Bisht, J.K., 2015. *Celtis australis* Linn: a multipurpose tree species in North west Himalaya. Int. J. Life Sci. Sci. Res. 1, 66–70.
Zhao, Y., Li, M., Wang, X., Deng, J., Zhang, Z., Wang, B., 2020. Influence of habitat on the phylogenetic structure of *Robinia pseudoacacia* forests in the eastern Loess Plateau, China. Glob. Ecolo. Conserv. 24 https://doi.org/10.1016/j.gecco.2020 .e01199, 2020, e01199.