Inter- and intra-provenances variations in seed size and seedling characteristics of Khaya senegalensis A. Juss in Burkina Faso

Article *in* Agroforestry Systems · April 2014

Impact Factor: 1.22 · DOI: 10.1007/s10457-014-9684-7

4 authors:


Catherine Ky-Dembele
Consultative Group on International A…


Mulualem Tigabu
Swedish University of Agricultural Scie…


Jules Bayala
Consultative Group on International A…


Per Christer Oden
Swedish University of Agricultural Scie…

Agroforest Syst (2014) 88:311–320
DOI 10.1007/s10457-014-9684-7

Inter- and intra-provenances variations in seed size and seedling characteristics of *Khaya senegalensis* A. Juss in Burkina Faso

Catherine Ky-Dembele · Mulualem Tigabu · Jules Bayala · Per Christer Odén

Received: 11 March 2013 / Accepted: 12 March 2014 / Published online: 27 March 2014

Abstract Within- and between-provenance variations in seed and seedling traits of *Khaya senegalensis* A. Juss were studied at INERA in Burkina Faso. Nursery grown seedlings from four provenances in Burkina Faso were used for the study. The studies revealed significant variability in all traits evaluated. Seed length and weight significantly varied among provenances and families within provenances, where Bopiel and Koyenga had the highest mean values. Height and root collar diameter of 1 year old seedlings significantly varied among families within provenances. Except leaf biomass ratio and carbon isotope ratio which varied significantly among provenances but not among families within provenances, all other seedling biomass traits—total plant biomass, stem biomass ratio, leaf biomass ratio, root biomass ratio, root shoot ratio, specific leaf area, and leaf area ratio were significantly affected by provenances and families within provenances. The magnitude of variation due to family effect ranged from 65 to 93 % for seed size traits, and from 4.5 to 17.8 % for seedling characters. Estimates of family heritability were moderate to high (0.67–0.95) for seed traits, but low to moderate (0.19–0.59) for seedling characters, indicating that much of the total variation in seed traits is due to the genetic effect. The two most prominent provenances, Koyenga and Bopiel, with higher seed size and greater seedling growth could be considered for an eventual *K. senegalensis* improvement program in Burkina Faso.

Keywords Genetic variation · Seedling growth characters · Senegal mahogany

C. Ky-Dembele (✉) · J. Bayala
World Agroforestry Centre, West Africa and Central Regional Office - Sahel Node, BP E5118 Bamako, Mali
e-mail: C.Dembele@cgiar.org

M. Tigabu · P. C. Odén
Southern Swedish Forest Research Centre, Swedish University of Agricultural Sciences, Box 49, 230 53 Alnarp, Sweden

Introduction

Khaya senegalensis A. Juss or Senegal mahogany (Meliaceae) is a timber species indigenous to sub-Saharan Africa. It is the most commercially important and widely distributed timber species in the Sudanian and Sahelian Africa. The distribution of the species ranges from eastern Mauritania to northern Uganda, within the rainfall range of 650–1,300 mm (Nikiema and Pasternak 2008). In Burkina Faso, it occurs in various habitat types, such as on river banks, fields, fallows and protected woodlands, and its population density increases from North to South (Lompo 2007). The climate in which this species occurs naturally in Burkina Faso is characterized by a long dry season of 6–8 months, one short rainy season of 4–6 months and a decreasing aridity from the north to the south. Two main agro-ecological zones (Sahelian and Sudanian) can be found based on the isohyets and the length of the dry season that shape the vegetation types. The Sahelian domain with less than 600 mm annual rainfall is characterized by shrub savannas and grasslands, while the Sudanian zone covers less arid area with more tree savannas in the southern part of the country (Fontès and Guinko 1995; Anonymous 1988).

Khaya senegalensis is mostly exploited for its high value timber used for carpentry, joinery, furniture, ship building. The bark has medicinal properties and is used for traditional treatment of ailments such as malaria, diarrhea, dysentery, and anemia. The leaves of *K. senegalensis* constitute a good source of fodder for cattle, because of its high dry matter content (Ouedraogo-Kone et al. 2008). Currently, *K. senegalensis* is classified as vulnerable (IUCN 2013) because of overexploitation for timber, fodder and medicine, and as a result of habitat loss and degradation (Nikiema and Pasternak 2008). Efforts to regenerate the species are constrained by several factors. Natural regeneration of *K. senegalensis* is poor (Nikiema and Pasternak 2008) as its seeds lose viability quickly under natural conditions (Danthu et al. 1999; Gamene and Eriksen 2005; Opuni-Frimpong et al. 2008). In addition, attacks by mahogany shoot borer, *Hypsipyla robusta* (Moore), prevent the successful establishment of plantations within its native area in West Africa (Newton et al. 1993; Nikiema and Pasternak 2008). The mahogany shoot borer kills the main stem of young trees, causing excessive branching and contributing to mortality and poor quality timber production (Danthu et al. 2003).

Cloning resistant individuals to *H. robusta* has been sought as a solution for enhancing the success of plantation establishment and productivity (Danthu et al. 2003; Nikiema and Pasternak 2008). Accordingly, methods for vegetative propagation using leafy stem cuttings and micro-cuttings has been successfully developed that allow screening from seedling populations and multiplication of eventual resistant genotypes by cuttings (Danthu et al. 2003; Ky-Dembele et al. 2011). Moreover, our previous study has shown that seedlings and stecklings (individuals obtained from cuttings) of *K. senegalensis* have comparable growth patterns, but water stress appears to be a major growth limiting factor (Ky-Dembele et al. 2010). These previous studies highlight the need for selecting not only borer resistant but also drought resistant genotypes for successful establishment of *K. senegalensis* plantation.

At present, little information is known about the extent of genetic variation within and between provenances for this species. Conservation and sustainable use of genetic resources require an understanding of the extent and pattern of inter- and intra-specific variation. Generally, patterns of genetic variation in plant populations are determined by various factors involving complex interactions between plant attributes, such as life form, floral architecture, modes of reproduction, mating system, and ecological and environmental factors that may influence pollination events, population size and isolation (Hamrick et al. 1992; Prober and Brown 1994; Coates and Byrne 2005). Knowledge of genetic variation within and between provenances is, thus, essential to exploit their improvement potential and is considered to be a substantial determinant of adaptive abilities of populations (Callaghan 1964; Zobel and Talbert 1984; Nanson 2004). The significance of provenance or seed source variation studies in tree improvement is well recognized (Callaghan 1964; Nikles 1970), as such studies allow screening the available genetic variations, and subsequent utilization of the best material for obtaining maximum productivity for further breeding work and in identifying characters that have great importance in tree improvement program as well as conserving these variations for future use. The effectiveness of tree improvement program depends upon the nature and magnitude of existing genetic variability and also on the degree of transmission of traits or heritability because genetic variation is a basic requirement for long-term stability of forest ecosystem and maintenance of diversity (Zobel and Talbert 1984; Nanson 2004; Eriksson et al. 2006).

As *K. senegalensis* has wide distributional ranges with varying geographic, climatic and edaphic conditions, it is legitimate to expect large variations within and among provenances, which may be reflected in the genetic constitution of its diverse provenances as observed for other species in the region (Lamien et al. 2007; Ouedraogo et al. 2012). Therefore, the present investigation was undertaken to quantify the extent of variations in seed size, seedling growth characteristics and rooting ability of *K. senegalensis* in Burkina Faso. The study will provide baseline information for early selection criteria of some prominent traits in nursery

Table 1 Geographic location, mean annual rainfall (1999–2008), mean temperature (1999–2008) and number of *Khaya senegalensis* family from which seeds were collected in Burkina Faso

Provenances	Latitude	Longitude	Altitude (m)	Rainfall (mm)	Mean temperature °C		Number of families
					Minimum	Maximum	
Balla	11°35 N	04°09 W	432	985.8	22.2	33.8	15
Bisso	12°41 N	03°44 W	280	668.0	22.4	36.0	8
Bopiel	09°51 N	02°01 W	298	1,019.4	21.5	34.3	15
Koyenga	12°39 N	02°01E	214	778.2	22.5	35.3	15

Data were obtained from meteorological service in Burkina Faso

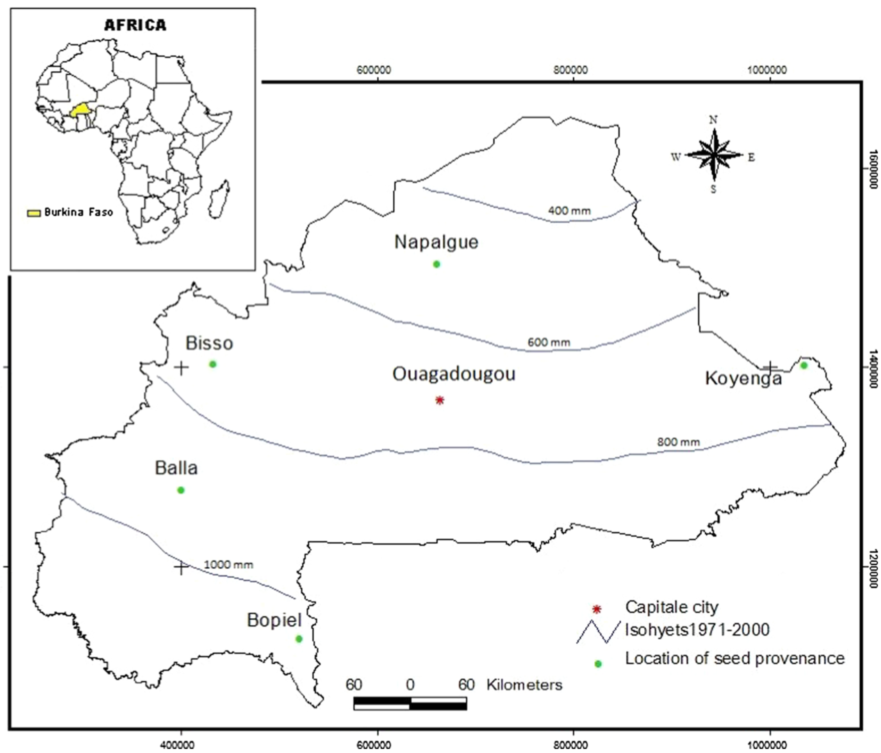

Fig. 1 Location of *Khaya senegalensis* seed origins investigated, Burkina Faso. *Source* BNDT (IGB)

that could be used for future *K. senegalensis* improvement program.

Materials and methods

Seed collection

For this study, four provenances were selected based on the natural distribution and existing populations of *K. senegalensis* in Burkina Faso (Lompo 2007). The geographic locations and climatic conditions of the chosen provenances, Balla, Bisso, Bopiel, and Koyenga, are presented in Table 1 and Fig. 1. These four original geographic areas are hereafter denoted as provenances. Rainfall data are that of the nearest cities, Bobo Dioulasso for Balla, Nouna for Bisso, Batié for Bopiel, and Botou for Koyenga while temperature data were obtained from Bobo Dioulasso (Balla), Dédougou (Bisso), Fada (Koyenga), and Gaoua (Bopiel). A total of 15 naturally regenerated and open pollinated tree families of *K. senegalensis* were selected within each provenance of Koyenga, Balla and Bopiel and eight families in Bisso (Table 1), as the number of fruit bearing trees at the time of seed collection was few in Bisso. The selected families were located at least 60 m apart. Seeds were collected between March and May 2009, brought to the Department of Forest Productions, Institute of Environmental and Agricultural Research (INERA) in Ouagadougou, Burkina Faso. Seeds from each family were kept separately and air-dried for 1 week in the laboratory before processing and characterization.

Assessment of seed size traits

To examine the variability in seed size traits, seed length, seed width, and seed weight were determined. Four set of 25 undamaged seeds were randomly drawn from each of the 53 seed lots collected from 53 tree families. Seed length and width were recorded using an electronic caliper. Seed weight of 100 seeds was recorded in g using 4 replications of 25 undamaged seeds randomly taken from each seed lot.

Progeny performance test

To evaluate the variability in seedling growth traits, seeds from each of the 53 families were sown in black perforated polythene bags (20 cm diameter × 30 cm height) filled with a mixture of sand, arable soil and manure (2:2:1 v/v/v), in the nursery on July 1–2, 2009. Since *K. senegalensis* is a light-demanding species (Djodjouwin et al. 2012), 60 seedlings were grown from the seed lot of each family in full sunlight, and watered every 2 days as per the standard nursery practice at the forestry department in Burkina Faso. After 20 weeks of growth (18–20 November 2009), 20 seedlings per family were moved and re-arranged in a completely randomized design with a single tree plot as experimental unit for growth performance evaluation. Seedling height and root collar diameter were measured every 2 months from November 2009 to July 2010.

The remaining 10 seedlings per family were harvested for biomass measurement. Harvested plants were separated into leaves, stems and roots. The root systems were gently washed with tap water. The total leaf area of fresh leaves was measured with a laser area meter (CI-202, CID Inc., USA). The dry mass of the stems, leaves and roots was determined after oven-drying at 70 °C for 48 h. The total dry mass (TPB) of the plant was calculated by summing the stem, root and leaf dry masses. The dry mass is henceforward referred to biomass. Specific leaf area (leaf area per unit of leaf biomass, SLA), leaf area ratio (leaf area per unit of plant biomass, LAR), leaf biomass ratio (leaf biomass per unit of plant biomass, LBR), stem biomass ratio (stem biomass per unit of plant biomass, SBR), root biomass ratio (root biomass per unit of plant biomass, RBR), and root shoot ratio (root biomass per unit shoot biomass, RSR), were calculated.

In addition, carbon isotope ratio was determined using a mass spectrometer (Finnigan Delta + XL; Thermofinnigan, Bremen, Germany) in the Radio Carbon Dating Laboratory at the University of Helsinki, Finland. As this analysis is expensive, foliar samples of seedlings from 3 provenances (6 families from Bala, 14 from Bopiel and 14 from Koyenga), resulting from seedling growth evaluation, were analyzed. The carbon isotope ratio ($\delta^{13}C$) of the sample ($\delta^{13}C_{sample}$) was expressed as;

$$\delta^{13}C_{sample}\ (‰) = [(R_{sample}/R_{PDB}) - 1] \times 1000$$

R_{sample} is the carbon isotope molar abundance ratio $^{13}C/^{12}C$ of the sample and R_{PDB} is the Pee Dee Belemnite standard for carbon, the usual standard to which all measurements are referred (Lajtha and Michener 1994; Raddad and Luukkanen 2006).

Rooting ability of stem cuttings

In order to examine the rooting ability of stem cuttings, 10 cm-long cuttings were collected from 11-week old seedlings of 52 families (15 families from Bala, Bopiel and Koyenga and 7 from Bisso) in September 21–26, 2009. The stem cuttings experiment was arranged in a completely randomized block design with 3 replicates of 6-cutting experimental unit. Leafy stem cuttings were prepared between 6:00 and 7:00, dipped in water to prevent drying. Two leaves which were also trimmed to 2–3 cm were left on each cutting. Cuttings were soaked in a fungicide solution of Ivory (80 % Mancozeb) for 10 min before planting to avoid fungal attack; then planted at a depth of 2–3 cm in a rooting medium consisted of a mixture of sterile sand and perlite (1:1 v/v) without any growth regulator. The cuttings were regularly watered manually as extra cautious measure to avoid desiccation damage. The experiments were carried out for 8 weeks in a greenhouse fitted with mist system with 22 °C (night) to 37 °C (day) temperature range, 70–100 % relative humidity and a mean light intensity of 450 μmol m^{-2} s^{-2} during daytime. After 8 weeks, the root systems of all cuttings were gently washed and the number of roots counted on each cutting, the length of the longest root measured and the number of secondary roots from the longest root (>1 mm long) counted. The percentage of rooted cuttings was calculated as the proportion of rooted cuttings to that of planted cuttings in each experimental unit.

Data analysis

All the collected data were first checked for normality before subjecting them to analysis of variance (ANOVA). Johnson transformed data obtained from Minitab 16 (Minitab Inc., State College, PA, USA) were used for the following variables that did not fulfill the assumption of normal distribution: seed length, seedling height, root collar diameter, LBR, RBR, RSB, SLA, LAR, TPB, δ^{13}C, length and number of root per rooted cutting. The general linear model (GLM) procedure of Minitab was employed for analysis of variance for all the variables regarding seed size traits, seedling biomass measurement and rooting ability of stem cuttings including the percentage of rooted cutting which could not be successfully transformed. The repeated measurement data of seedling height and collar diameter from September 2009 to July 2010 were analysed using proc mixed procedure (repeated/subject) of Statistical Analysis System (SAS Institute Inc., 2002–2008). The following ANOVA models were used for analysis of seed size traits, biomass components, height and root collar diameter of one year old seedlings (1), for rooting ability of cuttings with a randomized block design (2), and MIXED procedure based on the general linear mixed model for seedling height and collar diameter (3).

$$y_{ijk} = \mu + P_i + F(P)_{j(i)} + \varepsilon_{(ij)k} \quad (1)$$

$$y_{ijkl} = \mu + P_i + F(P)_{j(i)} + B_k + \varepsilon_{(ijk)l} \quad (2)$$

$$Y = X\beta + ZU + e \quad (3)$$

μ = the overall mean, P_i = the effect of the ith provenance (random), $F(P)_{j(i)}$ = the effect of the jth family within the ith provenance (random), B_k = the effect of the kth block and $\varepsilon_{(ij)k}$ and $\varepsilon_{(ijk)l}$ = the residual terms; Y is a vector of observations, the vector β contains the fixed effect parameters (the overall mean μ and the fixed effect of time T_k), the vector U contains the random effects of provenance (P_i), family within provenance $F/P_{j(i)}$, and the interaction provenance and time, P_iT_k, e contains the residual error $\varepsilon_{(ijk)l}$. X and Z are matrices of regressors relating the observations Y to β and μ, respectively. Means that exhibited significant differences ($p < 0.05$) were compared using Tukey's HSD.

To quantify the magnitude of between- and within-provenance variations, variance components were estimated for each source of variation based on the expected mean squares. For traits that exhibited significant differences among families within provenances, family heritability (h_f^2) was estimated as follows:

$$h_f^2 = \sigma_{f/p}^2 / \left(\sigma_p^2 + \sigma_{f/p}^2 + \left[\sigma_e^2/r\right]\right)$$

$\sigma_{f/p}^2$, σ_p^2, σ_e^2 and r stands for family within provenance variance, provenance variance, error variance and number of replications, respectively. r = 4 for seed traits analysis and r = 20 for seedlings characteristics.

Results

Variations in seed size traits

Analysis of variance showed significant differences among provenances and families within provenances for seed length and weight, while seed width varied significantly among families within provenances only. Estimates of variance components revealed that the magnitude of family effects was higher than the provenance effect for all seed size traits. The family effect was relatively higher for seed width than seed length and seed weight. The mean values for seed size traits exhibited a wider range at intra-provenance level than inter-provenance level for which there was significant differences in seed length and seed weight (Table 2). Maximum mean values for seed length (30 mm) were observed in Bopiel and for 100-seed weight (24.6 g) in Koyenga (Table 3). Ranking of provenances based on mean seed length and seed weight showed consistently lower values for Bala and Bisso. The rankings in ascending order of magnitude were as follows:

Seed length: Bisso/Bala < Koyenga < Bopiel
Seed weight: Bisso/Bala < Bopiel < Koyenga

Estimates of family heritability indicated that the genetic component accounted for more than 65 % of the total phenotypic variation in seed size traits (Table 3). Among them, heritability was relatively

Table 2 Estimates of variance components, expressed as percentage of the total variation, and family within provenance heritability (h_f^2) for seed size traits of four *Khaya senegalensis* provenances in Burkina Faso

Variables	Sources of variation			
	Provenance	Family/provenance	Residuals	h_f^2
Seed length	10.74**	82.23**	7.03	0.87
Seed width	3.91	92.71**	3.38	0.95
Seed weight	31.00**	65.00**	4.00	0.67

* $p < 0.05$; ** $p < 0.01$

higher for seed width and seed length than seed weight.

Variations in seedling growth, biomass production and stem cutting rooting ability

Root collar diameter of 1 year old seedlings varied significantly between and within provenances, while seedling height significantly varied only among families within provenances. The magnitude of variations in seedling growth due to family effects was relatively higher than the provenance effect (Table 4). The mean minimum and maximum seedling height ranged from 10.0 to 118.4 cm and that of root collar diameter was 6.2–19.8 mm. For root collar diameter, the lowest value was recorded for Bala (Table 5). The repeated measures ANOVA revealed significant variation in seedling height among provenances ($F_{(3, 931)} = 20.36$; $p < 0.0001$), families within provenance ($F_{(45, 931)} = 5.30$; $p < 0.0001$), time ($F_{(4, 931)} = 1850.71$; $p < 0.0001$), and the interaction of provenance and time ($F_{(12, 931)} = 1.87$; $p = 0.0338$). Root collar diameter of seedlings also varied significantly among provenances ($F_{(3, 931)} = 7.69$; $p < 0.0001$), families within provenance ($F_{(45, 931)} = 3.99$; $p < 0.0001$), time ($F_{(4, 931)} = 1695.53$; $p < 0.0001$), and the interaction of provenance and time ($F_{(12, 931)} = 2.31$; $p = 0.0065$). Shoot height growth was greater for Koyenga and Bopiel than Bala and Bisso while the highest collar diameter growth was observed for Koyenga and the lowest for Bala (Fig. 2).

Leaf biomass ratio and carbon isotope ratio varied significantly among provenances but not among families within provenances while other biomass production characters, namely total plant biomass, stem biomass ratio, root biomass ratio, root shoot ratio, leaf biomass ratio, specific leaf area, and leaf area ratio varied significantly among provenances and families within provenances (Table 4). Ranking of provenances based on mean values (Table 5) did not show a consistent trend for all biomass components. The rankings in ascending order of magnitude were as follows:

Total plant biomass: Bala < Bopiel ≤ Bisso ≤ Koyenga
Leaf biomass ratio: Bisso/Koyenga < Bala/Bopiel
Stem biomass ratio: Bala/Bisso < Bopiel/Koyenga
Root biomass ratio: Bopiel < Bala/Koyenga < Bisso
Root shoot ratio: Bopiel < Koyenga < Bala < Bisso
Specific leaf area: Koyenga ≤ Bisso ≤ Bala < Bopiel
Leaf area ratio: Bisso/Koyenga < Bala < Bopiel

Regarding carbon isotope ratio, Koyenga exhibited the highest value followed by Bala and then Bopiel (Table 5). Family heritability estimates for seedling

Table 3 Range, mean ± SE of seed length, width and weight of four *Khaya senegalensis* provenances in Burkina Faso

Seed size traits	Statistics	Provenances			
		Bala	Bisso	Bopiel	Koyenga
Seed length (mm)	Mean	27.9 ± 0.3c	27.8 ± 0.4c	30.0 ± 0.3a	29.4 ± 0.4b
	Range	22.4–34.5	25.0–31.5	26.1–38.1	24.0–36.7
Seed width (mm)	Mean	17.6 ± 0.2a	17.6 ± 0.2a	18.0 ± 0.2a	18.2 ± 0.3a
	Range	15.5–20.2	15.4–19.4	15.3–20.9	13.5–21.8
Seed weight (g)	Mean	19.8 ± 0.5c	19.3 ± 0.6c	23.9 ± 0.4b	24.6 ± 0.5a
	Range	12.0–27.2	13.6–27.2	18.0–29.6	16.4–31.6

Mean ± SE followed by the same letter are not significantly different at the 5 % level according to Tukey's multiple comparison test

Table 4 Estimates of variance components, expressed as percentage of the total variation, and family within provenance heritability (h_f^2) for seedling growth and biomass traits of four *Khaya senegalensis* provenances in Burkina Faso

Variables	Sources of variation			
	Provenance	Family/provenance	Residual	h_f^2
Diameter at age 1 year	1.90*	7.23**	90.87	0.53
Height at age 1 year	1.21	4.54**	94.25	0.43
Total plant biomass	8.54**	17.85**	73.61	0.59
Leaf biomass ratio	8.65**	0.52	90.83	nc
Stem biomass ratio	11.20**	11.20**	77.6	0.43
Root biomass ratio	16.86**	8.76**	74.38	0.30
Root: shoot ratio	18.54**	14.39**	67.06	0.40
Specific leaf area	19.02**	8.07**	72.91	0.26
Leaf area ratio	19.92**	5.70**	74.38	0.19
Carbon isotope ratio (‰)	13.91**	2.16	83.93	nc

nc Heritability not computed due to insignificant variation among families

* $p < 0.05$; ** $p < 0.01$

traits were <60 %. It was low for leaf area ratio, specific leaf area, root biomass ratio, stem biomass ratio and seedling height while moderate for root collar diameter and total plant biomass (Table 4).

There was no significant variation among provenances and families within provenances for the percentage of rooted cuttings, mean length of rooted cuttings, mean number of secondary roots per rooted cutting (Table 6). The mean number of roots per rooted cutting varied significantly only among families within provenances.

Discussion

With the intensification of forest farming, tree improvement programs have become an integral part of forest management. As a result of which, seed stands or seed production areas have been recommended as an interim measures for immediate gain (Sivakuma et al. 2011). Usually, progeny and provenance trials are used to predict the genetic worth of families or provenances. Based on these, superior individuals/stands are selected, used for seedling or clonal seed orchard establishment or managed as seed stands (Zobel and Talbert 1984; Quijada 1985; Willan 1994; Sharma et al. 2001; Nanson 2004). In the present

Table 5 Mean ± SE of seedling growth parameters and biomass components of four *Khaya senegalensis* provenances in Burkina Faso

Variables	Provenances			
	Bala	Bisso	Bopiel	Koyenga
Diameter at age 1 year (mm)	12.3 ± 0.1b	12.9 ± 0.2a	12.8 ± 0.1a	13.0 ± 0.1a
Height at age 1 year (cm)	73.3 ± 0.9a	69.7 ± 1.4a	75.5 ± 0.8a	74.3 ± 0.8a
Total plant biomass (g)	9.2 ± 0.3c	11.6 ± 0.5ab	10.8 ± 0.4b	12.1 ± 0.4a
Leaf biomass ratio	0.47 ± 0.004a	0.43 ± 0.008b	0.47 ± 0.004a	0.45 ± 0.004b
Stem biomass ratio	0.24 ± 0.003b	0.24 ± 0.005b	0.27 ± 0.002a	0.26 ± 0.003a
Root biomass ratio	0.29 ± 0.004b	0.33 ± 0.0.01a	0.26 ± 0.004c	0.29 ± 0.004b
Root: shoot ratio	1.24 ± 0.02b	1.43 ± 0.1a	1.00 ± 0.02d	1.13 ± 0.03c
Specific leaf area ($cm^2\ g^{-1}$)	126.1 ± 1.3b	123.9 ± 1.5bc	139.3 ± 2.0a	120.2 ± 1.4c
Leaf area ratio (cm2 g^{-1})	58.7 ± 0.9b	53.0 ± 1.3c	65.9 ± 1.1a	54.1 ± 0.9c
Carbon isotope ratio (‰)	−28.4 ± 0.2b	na	−28.6 ± 0.1b	−27.9 ± 0.1a

Mean ± SE followed by the same letter are not significantly different at the 5 % level according to Tukey's multiple comparison test

na, data not available for this provenance as it was not included during the analysis

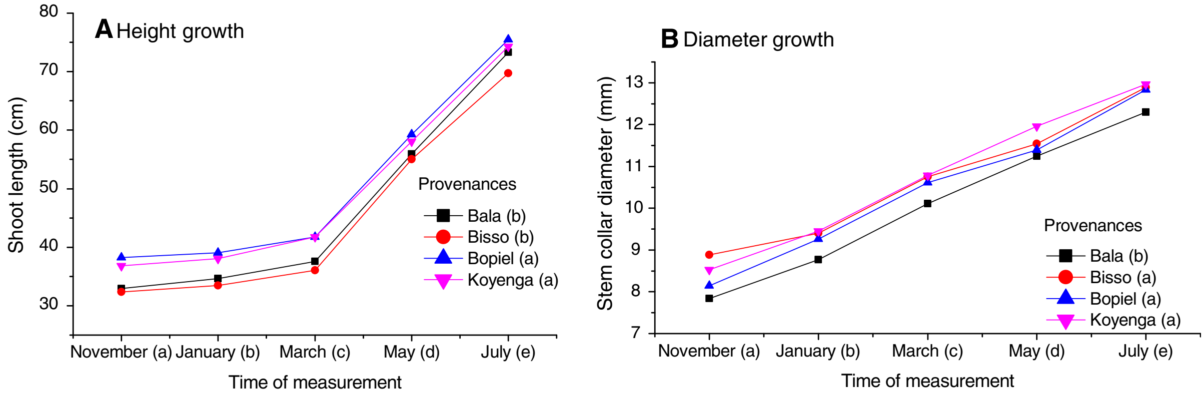

Fig. 2 Shoot height (**a**) and collar diameter (**b**) growth curves of *Khaya senegalensis* seedlings grown in nursery from seeds collected at Bala, Bisso, Bopiel and Koyenga in Burkina Faso from November 2009 to July 2010. Different letters indicate significant differences between provenances and between times of measurement at the 5 % level according to Least Squares Means adjusted with Tukey–Kramer for multiple comparisons

Table 6 Rooting ability (percentage of rooted cuttings, number of roots per rooted cutting, length of cutting longest root and number of secondary roots) of seedlings cuttings of four *Khaya senegalensis* provenances in Burkina Faso

Provenances	Rooting percentage	No. roots/rooted cutting	Longest root length (cm)	No. secondary roots
Bala	70 ± 4a	2.7 ± 0.2a	6.28 ± 0.41a	9.7 ± 1.0a
Bisso	82 ± 5a	3.4 ± 0.3a	6.50 ± 0.53a	12.5 ± 1.8a
Bopiel	78 ± 3a	3.0 ± 0.2a	6.71 ± 0.46a	10.1 ± 0.7a
Koyenga	77 ± 3a	3.0 ± 0.2a	6.28 ± 0.39a	9.4 ± 0.8a

Mean ± SE followed by the same letter are not significantly different at the 5 % level according to Tukey's multiple comparison test

study, clear differences were observed among the four *K. senegalensis* provenances, Bala, Bisso, Bopiel and Koyenga, in Burkina Faso in terms of seed length and weight. Since seed width did not differ among provenances, greater seed weight in Bopiel and Koyenga was probably due the larger length of these seeds. Seeds collected from Koyenga and Bopiel showed larger seed length, greeter seed weight (Table 3) and faster seedling growth (Fig. 2). The greater seed weight of Bopiel and Koyenga families probably result in faster initial seedling growth. Seed germination and initial seedling growth parameters are known to be interdependent and governed by genetic make-up, environmental influences and seed traits (Dunlap and Barnett 1983). The superior performance of Koyenga and Bopiel in seed size and seedling growth suggests that conservation and management of these provenances as seed sources could improve *K. senegalensis* in Burkina Faso. Much of the total variation in seed traits can be considered due to genetic effect as evidence from high heritability estimates (>65 %). Similar genetic variation in seed traits has been reported for several tree species (Liu et al. 2011; Loha et al. 2006; Mamo et al. 2006; Loha et al. 2008, 2009; Rawat and Bakshi 2011).

The present study also revealed the existence of considerable amount of variation among provenances and among families within provenances for all seedling growth and biomass characters studied. Similar results have been reported for *Faidherbia albida* (Ibrahim et al. 1997; Rouspard et al. 1998), *Cordia africana* (Loha et al. 2006) *Milletia ferruginea* (Lha et al. 2008) in contrast to the results obtained for *K. anthotheca* and *K. ivorensis* with no significant variation in growth among provenances but within provenances (Ofori et al. 2007). In contrast to seed traits, seedling traits had higher residual variations (Table 4); indicating that the growing environment had greater effect on those characters. Since high genetic coefficient of variation along with high heritability and genetic advance provide better information than other parameters alone (Nanson 2004), on the basis of the present study where seedling characters did not show such parameter, more studies are required in order to determine the most important seedling characters to be taken into consideration in addition to seed weight for effective selection in *K. senegalensis*. According to the relationship found between carbon isotope ratio ($\delta^{13}C$) and water use efficiency (Hall et al. 1994; Handley et al. 1994), the more negative values for Bisso and Bopiel would suggest that seedlings from these provenances would grow better in drought condition. However, according to O'Leary et al. (1992), leaf $\delta^{13}C$ differences less than 1 ‰ are biologically uninterpretable. Therefore, the range of 0.5–0.7 ‰ is not sufficient to draw an accurate conclusion (Handley et al. 1994).

As provenances did not significantly affect the rooting ability of cuttings, namely percentage of rooted cuttings, length of rooted cuttings, number of roots and number of secondary roots per rooted cutting, considering the origin of seed source is not an obvious criterion for genetic selection in relation to the rooting ability at seedling stage. Similar result was obtained in *Gnetum* spp. in Cameroon (Bongjoh et al. 2010).

Conclusion

The results from this study indicate that genetic differences exist among families within provenances and provenances in seed traits of *K. senegalensis* in Burkina Faso. Based on observed seed and seedling characteristics, the most prominent provenances are Koyenga and Bopiel. Seeds collected from these two provenances are longer, heavier and engender faster seedling growth; thus these two provenances might be considered for an eventual *K. senegalensis* improvement program to assure the supply of good quality seeds that enhance productivity in reforestation or afforestation in Burkina Faso. However, more studies are required in order to determine the most important seedling characters to be taken into consideration in addition to seed weight for effective selection in *K. senegalensis* as well as conducting genotype × site testing.

Acknowledgments Funding for this study was provided by the Swedish International Development Cooperation Agency (Sida). Special thanks are due to Do Etienne Traore, Augustin Waneweogo, T.A. Rosalie Dembele, and Abou Sanou for assistance in the field and nursery, to Apollinaire Samne for driving the team to the field. The anonymous reviewers are greatly appreciated for their constructive comments on the manuscript.

References

Anonymous (1988) *Khaya senegalensis* (Desr.) A. Juss. Bois Forets des Trop 218:43–56

Bongjoh CA, Ngame BK, Tchatat M (2010) Assessing certain root characteristics among provenances of *Gnetum spp*. in South West Cameroon: relevance for domestication and conservation. Sci Res Essays 5:3378–3383

Callaghan RZ (1964) Provenance research: investigation of genetic diversity associated with geography. Unasylva 18(2–3). www.fao.org/docrep/03650e/03650e05.htm

Coates DJ, Byrne M (2005) Genetic variation in plant populations: assessing cause and pattern. In: Henry RJ (ed) Plant divers. Evol. genotypic phenotypic Var. High. plants. CABI Publishing, Wallingford, pp 139–164

Danthu P, Gaye A, Sarr A (1999) Long term storage of *Khaya senegalensis* seeds. Int Tree Crop J 10:93–100

Danthu P, Diaite-Sanogo D, Sagna M, Sagna P, Dia-and Gassama YK (2003) Micropropagation of *Khaya senegalensis*, an African mahogany from dry tropical zones. J Trop For Sci 15:164–175

Djodjouwin L, Kakai RG, Sinsin RB (2012) Effets des sols et du taux de recouvrement sur la morphologie des espèces introduites dans les galeries forestières en zone soudano–guinéenne au Bénin. Agron Afr 24:101–115

Dunlap JR, Barnett JP (1983) Influence of seed size on germination and early development of loblolly pine (*Pinus taeda* L.) germinants. Can J For Res 13:40–44

Eriksson G, Ekberg I, Clapham D (2006) An introduction to forest genetics. SLU, Sweden, p 185

Fontès J, Guinko S (1995) Carte de la végétation et de l'occupation du sol du Burkina Faso. Ministère de la coopération française, Paris

Gamene CS, Eriksen EN (2005) Storage behaviour of *Khaya senegalensis* seeds from Burkina Faso. In: Sacande M, Joker D, Dulloo ME, Thomsen KA (eds) Comparative storage biology of tropical tree seeds. International Plant Genetic Resources Institute (IPGRI), Rome, pp 9–15

Hall AE, Richards RA, Condon AG, Wright GC, Farquhar GD (1994) Carbon isotope discrimination and plant breeding. Plant Breed Rev 12:81–113

Hamrick JL, Godt MJ, Sherman-Broyles SL (1992) Factors influencing levels of genetic diversity in woody plant species. New For 6:92–124

Handley LL, Odee D, Sryscrimgeour CM (1994) Delta-N-15 and Delta-C-13 Patterns in savanna vegetation—dependence on water availability and disturbance. Funct Ecol 8:306–314

Ibrahim AM, Fagg CW, Harris SA (1997) Seed and seedling variation amongst provenances in *Faidherbia albida*. For Ecol Manag 97:197–205

IUCN (2013) IUCN Red list of threatened species. Version 2013.2. <www.iucnredlist.org>

Ky-Dembele C, Bayala J, Savadogo P, Tigabu M, Odén PC, Boussim IJ (2010) Comparison of growth responses of *Khaya senegalensis* seedlings and stecklings to four irrigation regimes. Silva Fenn 44:787–798

Ky-Dembele C, Tigabu M, Bayala J, Savadogo P, Boussim IJ, and Odén PC (2011) Clonal propagation of *Khaya senegalensis*: the effects of stem length, leaf area, auxins, smoke solution, and stockplant age. Int J For Res 2011, p 10

Lajtha K, Michener RH (1994) Stable isotopes in ecology and environmental science. Blackwell, Oxford, UK, p 316

Lamien N, Tigabu M, Guinko S, Oden PC (2007) Variations in dendrometric and fruiting characters of *Vitellaria paradoxa* populations and multivariate models for estimation of fruit yield. Agrofor Syst 69:1–11

Liu JL, Wang YG, Yang XH, Wang BF (2011) Genetic variation in seed and seedling traits of six Haloxylon ammodendron shrub provenances in desert areas of China. Agrofor Syst 81:135–146

Loha A, Tigabu M, Teketay D, Lundkvist K, Fries A (2006) Provenance variation in seed morphometric traits, germination, and seedling growth of *Cordia africana* Lam. New For 32:71–86

Loha A, Tigabu M, Teketay D (2008) Variability in seed- and seedling-related traits of *Millettia ferruginea*, a potential agroforestry species. New For 36:67–78

Loha A, Tigabu M, Fries A (2009) Genetic variation among and within populations of *Cordia africana* in seed size and germination responses to constant temperatures. Euphytica 165:189–196

Mamo N, Mihretu M, Fekadu M (2006) Variation in seed and germination characteristics among *Juniperus procera* populations in Ethiopia. For Ecol Manage 225:320–327

Lompo D (2007) Contribution à la mise œuvre d′un programme de conservation et d′amélioration génétique de *Khaya senegalensis* (Desr.) A. Juss. au Burkina Faso. Université de Liège - Gembloux, Faculté Universitaire des Sciences Agronomiques, Belgique, Master thesis, p 94

Nanson A (2004) Génétique et amélioration des arbres forestiers. Les Presses Agronomiques de Gembloux, Belgique, p 712

Newton AC, Baker P, Ramnarine S, Mesen JF, Leakey RRB (1993) The mahogany shoot borer—prospects for control. For Ecol Manage 57:301–328

Nikiema A, Pasternak D (2008) *Khaya senegalensis* (Desr.) A. Juss. In: Louppe D, Oteng-Amoako AA, Brink M (eds) Plant resources of tropical Africa. PROTA Foundation, vol 7. Wageningen, pp 339–344

Nikles DG (1970) Breeding for growth and yield. Unasylva 24(2–3). www.fao.org/docrep/a2173e/a2173e03.htm

O'Leary MH, Madhavan S, Paneth P (1992) Physical and chemical basis of carbon isotope fractionation in plants. Plant Cell Environ 15:1099–1104

Ofori DA, Opuni-Frimpong E, Cobbinah JR (2007) Provenance variation in *Khaya species* for growth and resistance to shoot borer *Hypsipyla robusta*. For Ecol Manag 242:438–443

Opuni-Frimpong E, Karnosky DF, Storer AJ, Cobbinah JR (2008) Key roles of leaves, stockplant age, and auxin concentration in vegetative propagation of two African mahoganies: *Khaya anthotheca* Welw. and *Khaya ivorensis* A. Chev. New For 36:115–123

Ouedraogo M, Ræbild A, Nikiema A, Kjær E (2012) Evidence for important genetic differentiation between provenances of *Parkia biglobosa* from the Sudano-Sahelian zone of West Africa. Agrofor Syst 85:489–503

Ouedraogo-Kone S, Kabore-Zoungrana CY, Ledin I (2008) Intake and digestibility in sheep and chemical composition during different seasons of some West African browse species. Trop Anim Health Prod 40:155–164

Prober SM, Brown AHD (1994) Conservation of the grassy white box woodlands: population genetics and fragmentation of *Eucalyptus albens*. Conserv Biol 8:1003–1013

Quijada M (1985) Seed stands. In: FAO Forestry Paper no. 20 (ed) Forest tree improvement. FAO, Rome, pp 112–115

Raddad EAY, Luukkanen O (2006) Adaptive genetic variation in water-use efficiency and gum yield in *Acacia senegal* provenances grown on clay soil in the Blue Nile region, Sudan. For Ecol Manage 226:219–229

Rawat K, Bakshi M (2011) Provenance variation in cone, seed and seedling characteristics in natural populations of *Pinus wallichiana* A.B. Jacks (Blue Pine) om India. Ann For Res 54:39–55

Rouspard O, Joly HI, Dreyer E (1998) Variabily of initial growth, water-use efficiency and carbon isotope discrimination in seedlings of *Faidherbia albida* (Del.) A. Chev., a multipurpose tree of semi-arid Africa. Provenance and drought effects. Ann For Sci 55:329–348

Sharma CM, Ghildiyal SK, Nautiyal DP (2001) Plus tree selection and their tree germination in *Pinus roxburghii from* Garhwal Himalaya. Indones J For 24:48–52

Sivakuma V, Singh BG, Anandalakshmi R, Warrier RR, Sekaran S, Tigabu M, Odén PC (2011) Culling phenotypically inferior trees in seed production area enhances seed and seedling quality of *Acacia auriculiformis*. J For Res 22:21–26

Willan RL (1994) Economic returns from tree improvement in tropical and sub-tropical conditions. Technical Note 36, p 36

Zobel B, Talbert J (1984) Applied forest tree improvement. Wiley, New York, p 505