Provenance research in *Gmelina arborea* Linn., Roxb. A summary of results from three decades of research and a discussion of how to use them

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SUMMARY

More than 60 *Gmelina arborea* provenance trials were established in the mid-seventies as a joint effort between 20 countries, mainly outside the natural distribution areas of gmelina. Results from 27 of these trials are presented in this article focusing on differences between seed sources in growth rate, bole quality and wood density. The results allow identification of provenances that in general perform well on a number of sites. More detailed results are found on Danida Forest Seed Centre's web-site (www.dfsc.dk), which show performance of provenances in specific trials and include information on more characters. An interesting observation is that plants originating from plantations often perform very well compared to those originating from natural forests. This can be due to (i) a positive selection during thinning in the plantations, (ii) a result of lower inbreeding in the plantations, or (iii) a positive response to adaptation to local conditions (because the plantings often represent local 'landraces'). The presented results cannot clarify the relative importance of these factors, but all three factors suggest that important gains can be obtained by tree improvement programmes in gmelina. The second potential factor (release of inbreeding) suggests that such programmes should incorporate a broad genetic base. They may include hybrids of well-performing provenances, and maintain genetic diversity through advanced generations.

Keywords: genetic resources, G*melina arborea,* landraces, provenances, seed sources.

INTRODUCTION

Earlier Experience of Success and Problems

In 1969, the FAO Panel of Experts on Forest Genetic Resources assigned top priority for improved utilisation and conservation to *Gmelina arborea* Linn. Roxb. (FAO 1969). This reflected the fact that many tree planters considered gmelina to be a very promising species due to ease and cheapness of establishment, rapid early growth, expectations of early returns and promising wood characteristics, including high durability and good yield and quality of pulp.

Other tree planters have had a less encouraging experience with the species. They have found a rapid reduction in increment after the seventh year of growth, a tendency of trees to die at a young age, problems with uneven and slow drying of wood, in general poor stem and branching characteristics, and finally difficulties in selling the wood to pulp mills. In addition, attacks by various pests and diseases have prevented its planting on a large scale especially within its natural distribution area (Greaves 1981). Because of the encountered problems, an initial enthusiasm for planting the species in the 1960's, 1970's, and 1980's has been replaced by a lapse in interest in some areas where large-scale planting programmes had been initiated.

Still, interest in planting the species has been maintained in other areas. This includes agro-forestry or small-scale plantings where combination of good growth and high durability of the wood is important and makes gmelina an important alternative to eucalypts. A survey in the Philippines (Magcale & Rocamora 1997) showed that many farmers plant trees for their future housing or to pay for the education of their children, and in this context gmelina is important. Some 80% of the farmers had 100 to 500 gmelina trees on their land. Around 41% of farmers would like to increase the area, while 28% would maintain the current area with gmelina, and 29% preferred to plant *Eucalyptus deglupta* instead. In Central America there is also a renewed interest in the species (Hamilton *et al.* 1998).

Many problems of poor increment, and possibly of top-dying, have most probably been due to the choice of wrong planting sites (see also below in the section on health). There is therefore a need to be more cautious with the choice of planting sites for gmelina. There may be no easy answer to the problem of severe attacks of pests in areas of natural occurrence of the species. One possibility may be to plant gmelina in mixture with other species or in hedgerows.

Concerning the problem of uneven and slow drying of gmelina wood, the standard kiln drying schedules developed for species of the density class to which gmelina belongs do not apply. Sattar, Sarkar, & Taukdar (1991) applied an accelerated drying schedule with temperatures comparatively higher than for the standard schedule. They were able to lower moisture content from an initial approx. 160 % (dry weight basis) to ultimately 12 %, obtaining an acceptable and uniformly dried product with only minor distortions. Drying time was lowered from 16 to 14 days, and the cost per cubic meter wood was reduced by 15 % as compared to the standard method. However, the total drying time of 2-3 weeks for gmelina is still long compared to one week for other species of comparable density.

The uncertainties regarding yield and quality of pulp from gmelina are difficult to understand in view of reports on promising characteristics (Palmer 1973, Palmer *et al.* 1984). Further, newer processing technologies, *e.g.* addition of anthraquinone to the soda process, have increased the prospects of using gmelina for pulp (Palmer 1994, Goodwin 1994, and Akhtaruzzaman & Chowdhury 1991).

Genetic Aspects

In addition to the improvement that may be obtained by applying good measures of silviculture and wood processing, substantial gains in production and quality can be obtained by using the best possible plant material in respect of genetic quality, i.e. potential for good adaptation and growth for the given planting sites. The question of which plant material to select for planting programmes or as a basis for domestication programmes is thus important.

Several programmes for genetic improvement of gmelina have been initiated. Publications on plans and experiences are thus available from many programmes in many countries: India (review in Tewari 1995), Bangladesh (Jones & Das 1981), Nigeria (Oduwaiye 1983, and Akachuku 1984), Brazil (Woessner 1980 a), Solomon Islands (Chaplin *et al* 1988, and Sandiford 1990), Colombia (Konig & Venegas Tovar 1981), Malaysia (Afzal & Muhammad 1987, Ibrahim & Ong 1982, Sim Boon Liang & Jones 1984, and Wong & Jones 1986), and Costa Rica (Murillo 1992, Hamilton *et al.* 1998, and Mesén & Ñunez 1999). The overall experience is that gmelina is easy to breed owing to its fast growth, early flowering (short breeding generations), and good response to selection (large phenotypic variation combined with high heritability for important traits). In addition, it is easy to reap the benefits of breeding, because gmelina is very easy to mass propagate vegetatively (see for example Sim Boon Liang & Jones 1984).

The first question in any such improvement activity is how to select the base population from which the 1st generation parents can be selected. Would there be suitable plantings or natural populations available locally, or should new material be imported? If so, then from where should the new germplasm be imported? Choice of best provenance would be important in relation to this question.

Earlier gains could also be obtained by proper choice of the best provenances to meet immediate seed demand for planting. It is often the case that existing local seed sources are of unknown origin and relative performance, and it is therefore valuable to import new provenances to enrich the local genetic base.

Fortunately, there is much information on provenance variation of gmelina from many years of collaborative provenance research. The objective of the present article is to compile and present this information and to discuss how it can be applied.

THE INTERNATIONAL PROVENANCE RESEARCH PROJECT ON GMELINA

There have been several efforts to explore provenance variation in gmelina during the last 30-35 years. The most comprehensive work is an international project initiated on the recommendation of the FAO Panel of Experts on Forest Genetic Resources. This project was co-ordinated by Danida Forest Seed Centre, and implemented as a joint effort between a large number of countries (Lauridsen 1977, Lauridsen, Wellendorf & Keiding 1987, and Lauridsen, Kjaer & Nissen 1995). The objectives were to (i) determine the magnitude and pattern of variation among populations/provenances of gmelina, and (ii) identify provenances that would be superior in terms of important characteristics, and therefore would be the best sources of seed or other propagation material for plantation or improvement programmes.

Participating Countries

Seed for international distribution was contributed first of all by the state forest services of India supported by the Forest Research Institute & Colleges, Dehra Dun. Besides this, a number of seed samples for international distribution was provided by Thailand (Royal Forest Department), Ghana (Forest Products Research Institute), Tanzania (Forest Research Institute), Malawi (Forest Research Institute), Cote D'Ivoire (Centre Technique Forestier Tropical), and Brazil (Jari Florestal Company). In addition to the seed lots supplied, most participants included one or more seed lots of local plantations in their own trials.

Trials were established by research institutes or organisations in: Australia, Brazil, Cameroon, Central African Republic, Colombia, Costa Rica, Gambia, Ghana, India, Indonesia, Malawi, Malaysia, Mexico, Nigeria, Papua New Guinea, Philippines, Senegal, Solomon Islands, Thailand, and Vanuatu.

Individual reports have been published on the results from several trials: Forest Officer, Research, Solomon Islands 1980, Hamel, Malagnoux, & Vincenti, 1983, Husin 1977, Jamaluddin, Harsh, & Tiwari 1992, Kushalappa & Akbarsha 1978, Ladrach 1986, Luton & Skelton 1981, Mésen 1990, Suhaendi 1989a, Suhaendi 1989b, Tewari 1995, Trang Hoang Anh 1987, Valerio 1987, and Woessner 1980 b.

In addition, co-ordinated assessments were carried out during the years 1982-87 and again during the years 1991-95. The results of these two evaluations were published in two reports issued by Danida Forest Seed Centre (Lauridsen *et al.* 1987, and Lauridsen *et al.* 1995). Results from these two reports are summarised here.

Seed Samples, Provenances and Trials

Occurrence of Gmelina

The species **occurs** naturally over a range of latitudes of 5^o-30^o North and a range of longitudes of 70^o-110^o East, i.e. nearly 3,000 by 4,000 kilometres. Its altitudinal range is approximately 50-1300 metres. It is thus found from Pakistan in the west throughout India, Nepal, Bangladesh, Sri Lanka, Myanmar to Thailand, Laos, Cambodia, Vietnam and the southern provinces of China (Yunnan and Kwangsi Chuang) in the East. There are different opinions as to its origin in the Philippines and Malaysia, but possibly it is introduced there. Its ecological range is temperatures from near zero to 48?C and rainfalls from 800 to near 5000 mm (Lamb, 1970).

Trees of gmelina occur usually very scattered mostly in the mixed deciduous forests associated with Teak and is occasionally found in evergreen forests or in drier forest types (Troup, 1921).

Gmelina thrives best where the extremes of temperature range from 19?C to 35 ?C, where there is a distinct dry season, but where the relative humidity never drops below 40 per cent. Further, the optimum rainfall is from 1800 to 2300 mm per annum. Provenances at the extreme upper altitudinal limit of its range have some tolerance to frost. Gmelina growth best on deep, loamy, calcareous, and moist soils, and will check or fail on poorer soils (Lamb, 1970).

The species has been introduced widely to countries in the tropics, with the largest plantations having been formed in Africa, particularly West Africa, and in South and Central America. There were some 130,000 and 36,000 hectares respectively in the two countries by early 1990 (FAO/UNEP, 1981, FAO, 1993, Morel, 1984, Pandey, 1992, Hornick, Zerbe, & Whitmore, 1984). The largest plantations are found in: Nigeria, Brasil, Ghana, Ivory Coast, Cameroun, Colombia, Venezuela, Costa Rica, Malaysia, and Solomon Islands. Most plantations have been planned for paper-pulp production.

In Asia and the Pacific large plantations have been established in the Phillippines, and Malaysia, Fiji Islands, Solomon Islands, and Indonesia is planting an increasing area with the species. In all there is an estimated 50,000 hectares in Asia and the Pacific. Otherwise in Asia the rate of establishing plantations of gmelina in areas of its natural occurrence has been low due to severe attacks by variety of pests and diseases (browsing dear and cattle, Loranthus spp., or the larvae of a stem-borer).

Sampling of provenances

The international provenance series included a total of 88 seed samples collected from 60 provenances during the years 1976-1977 (Table 1); they were used in 62 trials, which were established in 20 countries during the years 1978-1980. Only 27 of these trials could be evaluated during the years 1982-83; the rest were either in a poor condition, were inaccessible, or had disappeared. Only 11 trials could be re-evaluated during the years 1991-92.

The provenances represent large variation in environmental conditions: altitudes from around 100 to around 1100 meters above sea level, and rainfall from less than 1000 to nearly 5000 mm per year are included. ‘Semi-evergreen’, ‘moist deciduous’, ‘semi-moist deciduous’, and ‘dry deciduous’ forest types from the natural range of occurrence are represented.

It is appropriate here to mention that three varieties[1] of gmelina have been defined in India (Haines 1910): *Gmelina a. canescens* Haines, *G. a. glaucescens* Roxb., which includes some of the

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[1] *G.a. canescens* (characterised by having the lower surface of leaves covered by stellate hairs) is found in West Bengal and Bihar. *G.a. glaucescens* (having glaucous leaves) is found in Assam and eastwards into Burma and in Tenasserim in Thailand. The holotype *G.a*. found in the rest of India has leaves that are glabrate above and stellately hairy beneath. It is not clear if the gmelina found in other parts of Thailand or in Laos and Vietnam is of the glaucescens variety or the holotype.

tallest and finest trees of gmelina, and the holotype *Gmelina arborea* Linn. In the present project, provenances belong to the holotype and the variety glaucescens only.

Most of the natural distribution of gmelina in India is represented in the scheme, except for areas in the dry zone, because of a generally poor seed production there. Thailand is represented by two provenances, covering only a small part of the total natural distribution. 35 provenances represent natural forests, and the rest plantations. The first evaluation (at about the age of 5) comprised 60 provenances, and the second evaluation (at about the age of 13) only 39 provenances.

The provenances representing plantations will be referred to as "landraces", although this is strictly correct for only those plantations, which are well adapted to the locality, where they are growing, or where seed from them are to be used. For example, a well performing provenance, Sao Miquel 72-14, SC4040, was a plantation established in 1972 in Brasil based on freshly imported seed from Africa (landraces) and from several provenances from natural forests (Palmer 1979). Land races from Cote D'Ivoire, Malawi and Brazil were distributed and tested at several locations. Otherwise, there was no attempt to systematically sample landraces. As mentioned above, most participating host countries have included one or a few local seed sources in their trials.

In order to cover a sufficient amount of the genetic variation for provenance testing, it was attempted to collect seed from a minimum of 25 well-dispersed trees in a population. This aim was achieved for only half the seed lots; 18 lots included from 4 to 24 seed trees, and there was no information on this aspect for 27 seed lots.

The two evaluations

Ideally, for the most comprehensive analysis and evaluation, each provenance should have been represented in each of the trials established. This has not been possible, primarily because the quantity of seed obtained from each of the provenances varied greatly. As it is, the first evaluation included 260 'observations' out of an ideal total of 1620 (60 provenances in 27 trials) i.e. 16%, and the second evaluation 120 observations of an ideal total of 429 (39 provenances in 11 trials) i.e. 28%. The consequence of this shortcoming has been that powerful methods for analysis of results could not be fully utilised.

The 27 trials evaluated covered a wide range of site conditions with altitudes from around 50 to nearly 1100 meters above sea level and rainfall from around 900 to nearly 5000 mm per year.

The joint evaluations were directed towards characteristics of importance for the wood products of gmelina: primarily structural wood for various uses in construction and furniture, and disintegrated wood for paper. Survival and health of the trees were also included.

The evaluation thus included three main groups of characteristics: a) ADAPTATION including survival and health, b) PRODUCTIVITY including DBH, height and wood density, and c) QUALITY including height and frequency of forking or crown development and stem straightness.

It was further in the first evaluation examined if the respective provenances could be grouped into *regions of provenance*. If such regions could be identified, seed collection operations could then be made with general reference to such provenance regions, or *seed procurement zones*, rather than to smaller, specific stands (cf. for example Westfall 1992; Haman *et al.* 2000). Also, it was examined if so-called *trial regions* could be established. Trial regions should serve as *seed deployment zones* for which provenance recommendations could be issued separately. Initially, three possible provenance regions and six possible trial regions were delineated based on broad geographical and ecological criteria. Combinations of provenance regions and trial regions were then evaluated in iterative tests until the combination was found, where ranking of provenance regions would change between trial regions and not inside trial regions. This exercise was based on survival and growth only, because these fitness traits were considered to be fundamental for choice of provenance. The regions defined in the first evaluation were maintained in the second evaluation, because of the reduced number of trials in the second evaluation.

SOME GENERAL RESULTS FROM THE INTERNATIONAL EVALUATIONS

Adaptation

Survival

The results of survival at the first evaluation showed a significant interaction of provenance region with trial regions. This lead to delineation of twelve[2] provenance regions (Table 1) and three trial regions.

Two of the trial regions, “VANUATU” and “GHANA-IVORY COAST”, are small compared to the region termed “REST OF THE WORLD”. The geographical boundaries or detailed ecological conditions of the regions are not well defined. For example, in Ghana, two of three trials are included in the small trial region and one in the large region, and in Ivory Coast there is one trial in each of the two trial regions. There is no obvious geographical or ecological pattern, however, which may help in deciding in which trial region any potential planting site may be located.

At age 5 (2-6) years, the mean survival of all provenances in the large trial region was high (92 %) with differences between provenances being non-significant. In contrast, survival of all provenances was slightly lower in Vanuatu (82 %, 1 trial) and Ghana/Ivory Coast (76 %, 5 trials), and differences between provenances were significant. Specifically for “VANUATU”, the survival of the local landraces was inferior to natural sources.

At the second evaluation, at age 11-15 years, survival had decreased for the two trial regions now left, to 66% for the large, and to 58% for the small region, Ghana(-Ivory Coast), and differences between provenances were significant, being a little smaller in the large, than in the small region.

The second evaluation has shown that the interaction found for survival in the first evaluation may not be of the practical importance envisaged at the first evaluation. However, provenance representation was rather poor in the second evaluation, and some caution should still be shown when choosing provenances for the small regions. For example, one provenance, Muag Lek, Thailand, which showed a much poorer survival in the small than in the large trial region in the first evaluation was not represented in the second evaluation.

Health

The trees in most of the trials have in general stayed healthy. Serious pests or diseases are of concern specifically in South and South-East Asia. In India, Thailand and Malaysia a borer, *Dihammus cervinus*, has been observed to kill or severely damage whole plantations. At the time of the first evaluation, one trial in Malaysia suffered slight attacks by this insect, but with no conspicuous provenance differences. Such attacks were not observed at the time of the second evaluation.

Jamaluddin *et al.* (1992) studied damage from a combined pest and fungus attack causing defoliation, drying of young shoots, canker and callus formation in twigs and stems, and finally mortality in two provenance trials in India. They identified significant differences in intensity of infestation between provenances with a local provenance (Madhya Pradesh) being mainly free of the disease. Otherwise, provenances with most healthy plants came from quite different provenance regions. At the time of the first evaluation, many trees in one trial in the Solomon Islands were attacked by root rot (*Noxius* sp.). Specific provenances from Central-North India, South-West India, and North India differed conspicuously from other provenances by being seriously affected by both fungi and insects. At the time of the second evaluation, there were no signs of this fungus, possibly because affected trees had been removed.

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[2] Two provenance regions were not included in the tests, because they were included in only one trial. These regions are thus empirical.

Productivity

Growth was used as one parameter in the process of identifying provenance and trial regions. However, the performance of provenance regions relative to each other did not significantly change with trial region. In other words, the best provenance regions for growth would perform best in all trial regions, and vice-versa.

Basal area together with average tree size are parameters of productivity, whereas wood density, bark thickness, and basal swelling sometimes may be regarded as parameters of productivity and sometimes of quality. Variation in performance for all these traits was studied.

Basal area

Basal area (m^2/ha) is a good indicator of total volume production, and it is within limits reasonably independent of tree spacing. The results of performance for this trait are presented in Table 1[3].

The land races grew – with very few exceptions - progressively faster than most natural sources. At the first evaluation, the overall average for all landraces was 18 m^2/ha against 17 m^2/ha for all natural sources. At the second evaluation, the corresponding figures were 61 m^2/ha against 53 m^2/ha. Among the natural sources, provenances from the region Thailand-Malaysia, North-East India, and North India had the highest increment and were – except for one provenance – consistently above average. The results from the first and second evaluation were quite consistent.

Basal swelling

This character may cause problems in determination of volume production. It is often seen on larger trees of gmelina that a proportionally wider diameter at the base extends above breast height. This is here termed basal swelling. Hence DBH may indicate a stem volume larger than the actual volume.

This feature was assessed only at the second evaluation. The height above ground level, where the swelling obviously disappeared, was measured, and this measure was used for analysis.

There were no significant differences between provenances for this character, but an adjustment for tree size was highly significant. This means that basal swelling is dependent on tree size, but not on provenance

Bark thickness

The bark may take up a considerable part of the volume of trees and is therefore an important economic parameter for both wood producer and buyer. It was measured at the second evaluation only using a standard bark gauge.

The average bark thickness was 11 mm for an average tree diameter of 25 cm (15 % of average basal area). Differences between provenance regions and between provenances within regions were found statistically significant, but differences were only of an order of one millimetre or less. Differences of this magnitude may not be considered important in relation to wood production under bark, or to handling and processing of the wood. It is not known, however, if the slight differences in bark thickness would affect resistance to fire or other physical damage.

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[3] Data in Table 1is based on an average of all evaluated trials, and shows the deviation of the so-called genetic estimate for each provenance from the overall mean. A genetic estimate is the observed differences weighted according to the level of significance in the trials. Trials with high level of significance thus contribute more to the average than trials with only random variation (cf. details in Lauridsen *et al.* 1995, p.22f).

Wood Density

Wood density, or rather wood specific gravity, is a very important property of wood, because it strongly influences the quality of structural wood as well as the yield and quality of pulp and paper. Wood density may be viewed as a parameter of productivity and yield or a parameter of quality depending on the product considered. Wood density of gmelina varies from 350 to 535 kg/m^3 (640 is quoted by Kasmudjo 1990), which puts it in the right weight category for very many uses. Hillis (1978) puts gmelina into the medium group of timbers, which are quite suitable for scantlings and general construction. Unlike pines, fast growth has not been thought to change the density of gmelina wood appreciably with the inference that the species is ideal for rapid production of large quantities of stable utility timber (but see following paragraph) (Hughes & Esan 1969).

An estimate of differences in wood density between provenances at the trial sites was obtained by measurements with a Pilodyn tester (Hansen 2000). The correlation between pilodyn reading and wood density was found to be high permitting the conversion of pilodyn readings to wood density. The main results are seen in Table 1 (note: on the scale of the pilodyn, 1 millimetre more, or less, corresponds to a change in wood density of around 30 kg/m^s., and a high reading (or deep penetration) corresponds to a low wood density, and vice-versa).

Major differences in wood density between natural sources and landraces were found in many of the provenance trials with natural sources generally having the highest wood density. Besides, there were clear differences between provenance regions of the natural distribution. In general, the fastest growing provenances had the lowest wood density. This result is in contrast to the earlier report of no correlation mentioned above. At an age of 11-15, the landraces were some 4 kg/ m^3 or 1 % below the overall average of 400 kg/ m^3. Specifically, the best volume producers among them were some 16 kg/ m^3 or 4 % below average, while the natural sources were nearly 2 kg or 0.5 % above the overall average of 400 kg/m^3. On the other hand, the very best volume producers among the natural sources were at an average 8 kg/ m^3 or 2 % below the average wood density. So, when good volume producing provenances are chosen, a slight loss of some 8-16 kg/ m^3 from an average of 400 kg/ m^3 should be expected. This corresponds to an observation by Sandiford (1989) that plus trees selected for good volume production had below average density.

Quality

Forking and branching

Gmelina trees tend to fork or branch frequently. It is further a characteristic for gmelina that one or more side branches may compete with the top shoot (primary axis), often to the extent where the top shoot loses dominance and even dies. As a result gmelina often has rather poor stem form. Zobel (1977) argues that ‘A major cause of variability in wood is differences in tree bole form and limb characteristics. … The chief cause of wood degrade is reaction wood, which normally is related to differences in tree form’.

To examine this aspect for gmelina, stem and branching characteristics were included in the assessments of the provenance trials and trees were assessed for 1) system of axis dominance, 2) axis persistence (level of forking and crown formation), 3) frequency of forking and branching, and 4) stem straightness. The first three measures were closely correlated, and the character, axis persistence, was chosen to represent forking behaviour or crown development. It was the parameter, which best discriminated for quality between provenances, and it gave consistent results at both evaluations. Axis persistence was defined as the height, relative to the tree height, of the unbroken main stem or axis. It was assessed by visually dividing the total tree height into nine equally sized sections and then determining the section, in which the axis broke. A score corresponding to the section was then given, so the higher the score, the longer the unbroken axis. The simple plot mean of nine classes is used for analysis and in presentation of results.

The average persistence for all provenances in all trials was at the first evaluation 4.9 classes, corresponding to a break of the axis at a height of half the tree height. Landraces performed overall slightly better than the natural sources (in average (5.1 classes vs. 4.8 classes), but some of the best natural sources were as good as the good landraces (see Table 1, Persistence). Among the landraces, notably the good volume producers from Oceania performed above average, whereas good volume-producing provenances from Latin-America in general exhibited below-average forking habit. Among sources from the natural distribution, some of the good volume producers also have good stem quality scores, specifically provenances from North-East, North, Central-North, and South-West India. However, the opposite is also true, i.e. some of the best volume producers have poor scores, *e.g.* Godamdabri-3 from North India and Khao Yai from Thailand.

Much the same picture is seen at the second evaluation. The average height of all trials at second evaluation was around 22 meters, and the average persistence class was 5.3. This would correspond to an average unbroken bole of around 11.7 meters, varying among provenances from 10.6 to 12.3 meters.

It is possible to identify provenances of good production with a reasonable possibility of some gain in stem quality.

Stem Form

Stem form, or Stem straightness, was defined using a scale of nine classes. Results are presented as the simple mean of nine classes. In the assessment of stem form much emphasis was given to the upper part of the stem and on the longer branches. This is because an evaluation of the lower part of the stem alone may give a false idea of any inherited tendency of a tree to grow straight, due to "filling-in" of any bends as the trees grow bigger.

This character varied much between provenances. Landraces have distinctly – with few exceptions - better stem form than the natural sources. At the first evaluation, 24 % of trees in the average landrace were classified as straight or almost straight, compared to only 16 % of the trees from the average natural population. The Latin-American provenances were generally among the poorest of the landraces. Among the natural sources, mainly provenances from Central-North India had many trees with good stem form. This result was found also at the second evaluation.

GENERAL RECOMMENDATIONS AND FURTHER INFORMATION

In the process of choosing provenances, good survival, health, and volume production are obviously needed. Good values for wood density and other quality characteristics are also preferable. Effort should be put into identifying provenances that perform well in many trials rather than only in one or a few.

? A general result from the provenance trial(s) is that progenies from **landraces perform well**. This indicates that gmelina responds strongly to domestication through plantation silviculture. For short-term seed supply, local and well performing landraces will therefore often be the first choice. However, the origin of the landraces is in most cases unknown, and may be based on a very narrow genetic basis. There is a risk of future pest and disease problems and loss of production due to inbreeding depression. This needs to be counteracted when initiating large-scale domestication programmes[4]. The mixing of provenances in seed stands has been the

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[4] In 1888 gmelina seed was imported to Nigeria and used for avenue planting in Lagos. The seed came from India, but the exact origin is unknown. Seed from the avenue plantings were used initially for making large plantations within Nigeria, and were later used also for extensive plantations outside Nigeria (Jones 1985). According to Sandiford (1989) most of the plantations in the Solomon Islands originates from plantations in Upkon Bende, Nigeria. A similar history can be found in the Philippines, Malaysia, Ghana, and Brazil (Jones 2001). Since gmelina was first spread from Nigeria, there

subject of much discussion. The concern is that progeny from stands composed of mixed provenances may suffer problems regarding general adaptation. In the gmelina provenance experiment, the general excellent performance in respect of vigour of landraces of provenance hybrid origin (see below) suggests that, for gmelina, different provenances may be mixed in seed stands.

? Progenies from **natural sources appear generally inferior to landraces**. However, comparing progenies from natural populations with progenies from planted stands may not be fully valid. Family structures in natural populations may be associated with light inbreeding depression, and this favours the progenies from plantations. However, the family structure in progenies from natural populations can easily be broken down when seed from natural populations are used for new seed production stands where out-crossing will occur. Progenies from these seed production stands will then show much better performance.

? The value of **introducing 'new blood'** into domestication and breeding programmes should not be underestimated. This may be from other natural sources or even from other landraces. For example, one of the very well performing landraces, Sao Miguel from Brazil, is known to come from a plantation of mixed origin (Palmer 1979). The value of mixing different origins in domestication activities therefore seems a promising possibility for gmelina.

? Among the natural populations, **provenances from Eastern Assam and Tripura in North-East India, and most provenances from North India would seem to be the best and safest choices** in respect of survival. In addition, since health in general may not be a problem, these provenances are best in respect of general adaptation. Especially the provenances, Baramura-1965, Shikaribari, Odah, and Longai, from North-East India, together with Godamdabri-3 and Sankosh-1, from West Bengal, North-India are promising choices. In respect of growth, these four provenances would at the age of 13 have produced some 2-10% more in basal area than the general average, but would also have somewhat lower wood density (2-4%). In respect of stem straightness and forking behaviour, these provenances are around average. A provenance Khao Yai, Muak Lek, from Thailand, has similar characteristics, except that is has shown a very poor adaptation in the trial region Ghana-Ivory Coast. Provenances with superior bole characteristics can be identified. For example, among the natural sources, the provenances Mahilong and Kundrukutu, both from Bihar State in Central North India, had good stem form. These provenances appear reasonably adaptable, but a loss in volume production of near 30% in relation to the best mentioned above may be expected.

? The landraces have done well in respect of adaptability and production, but they differ much in stem quality. They would have a generally lower wood density than most natural sources (2% below). Most have been tested only in the environment in which they have adapted hence the results are biased. Two landraces have been tested, however, in many trials world-wide, i.e. Bamoro, Ivory Coast, and Sao Miquel 72-14, Belem, Para, Brasil, (14 trials). These provenances have shown good (average) adaptability and a volume production of nearly 10% more than the general average. Wood density was at second evaluation average (400 kg/m^3) for both provenances. The provenance Bamoro is 4% better than the general average in persistence and stemform, while Sao Miquel 72-14 is average. Sao Miquel 72-14 is of mixed origin hence includes a broad genetic variation, but there is no information of Bamoro in this respect.

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have been efforts in many countries to obtain new and genetically more broadly based material from India or Myanmar. The situation on origin of plantations is now rather complex (Jones 2001).

? In the process of selecting the best material for future planting and tree improvement programmes, the following steps are suggested:

1. If local plantations are available, they should be checked for adaptation, vigour and quality (assuming that the sites are suitable for gmelina, and that the plantations have been well managed and protected). The origin of the plantations should be examined by studying information of seed acquisitions in the plantation files (see Sandiford, 1989, for example) in order to ensure that they are not based on seed collections from very few trees, or otherwise have an odd introductory history. Genetic markers could be used for a final check of the magnitude of the existing genetic variation, if the technology is locally available.
2. If local plantations appear vigorous, of acceptable quality, and their introductory history causes no concern, then these plantations are for a good basis for seed sources for future planting. Selection of the best among the local plantations for seed collection will still be recommendable. They may be converted to seed stands through strong selective thinning (cf. Lauridsen & Olesen, 1994).
3. If adaptation, vigour, or quality is inferior, then new material must be procured. Initially, consider obtaining seed or vegetative material from some of the provenances mentioned above as generally good performers (cf. also Table 1). Preference should be given to provenances tested at multiple sites. In this process, the detailed results regarding the performance of the various provenances at the various trial sites should be consulted[5].
4. The ICRAF tree seed suppliers directory provides information of seed suppliers (ICRAF 1997, and the internet site: www.icraf.org) where seed from provenances of interest might be obtained. In addition to commercial seed dealers, it may sometimes be useful to approach national forest institutions directly, including National tree seed programmes, which are existing in many counties. In order to facilitate procurement of seed from the right origins, detailed descriptions of the individual seed sources tested in the present investigation can be obtained from Danida Forest Seed Centre[5]. Not all provenances are easily accessible. Seed from the best natural sources in North-East India, for example, are located in remote and to some extend inaccessible areas.
5. If one or more trials of the international provenance experiment are existing locally, then this may be a good source of new material since gmelina is easy to propagate by cuttings or sprouts (cf. Zabala, 1977, or Zakaria *et al.*, 1982, for example). Also, existing provenance trials can be converted by leaving the best provenance(s) and use collected seed as input to domestication programs. Details on propagation as seed is found in Lauridsen (1986), DFSC (2002) amongst others.

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[5] This information is available from Danida Forest Seed Center's, either from the website www.dfsc.dk or in hard copy. See also Lauridsen *et al*. (1987 and 1995)

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