International Journal of Botany

ISSN: 1811-9700

science alert

ANSInet
an open access publisher
http://ansinet.com

International Journal of Botany 6 (2): 187-193, 2010
ISSN 1811-9700
© 2010 Asian Network for Scientific Information

Viable Options and Factors in Consideration for Low Cost Vegetative Propagation of Tropical Trees

Amri Ezekiel
Department of Science and Laboratory Technology,
Dar es Salaam Institute of Technology, P.O. Box 2958, Dar es Salaam, Tanzania

Abstract: Vegetative propagation techniques are increasingly being applied to the domestication of tropical tree species as a means of producing planting stock and capturing genetic variation. However, the level of knowledge of cost-effective for vegetative propagation is not common and has slowed down domestication many of tree species. The current scenario of rapid climate changes and increasing land degradation in many tropical countries, certain multi-purpose tree species are becoming rare and threatened with local extinction. Thus, knowledge and efforts to develop low-cost vegetative propagation technologies to the people are necessary. In this study viable alternatives and potential factors to simplify various operations and reduce the costs in vegetative propagation for both micropropagation and macropropagation are reviewed. Viable alternatives and potential factors should be opted to lower the cost of vegetative propagation without compromising the quality of the propagules and plants.

Key words: Vegetative propagation, micropropagation, macropropagation, low cost

INTRODUCTION

Vegetative propagation is asexual propagation which involves removing sections of stem, leaf or root tissue from the parent or donor plant, treating this tissue with plant growth regulators and then inducing adventitious root or shoot formation under controlled environmental conditions. Vegetative propagation is an irreplaceable tool for tree domestication and breeding with many advantages which include rapid multiplication of a species under threat, offers alternative means for the domestication of trees because of their (1) relatively long generation times, (2) irregularity in flowering and fruiting, (3) predominantly outbreeding nature, with most traits being of low heritability and (4) assembly of germ plasma for base populations to maintain certain desired characteristics (Leakey and Simons, 2000; Hartmann *et al*., 2002). Other advantages of vegetative propagation is to generate disease-free planting material (Hartmann *et al*., 2002; Tchoundjeu *et al*., 2004). Vegetative propagation also offers a unique opportunity of avoiding the problem of poor seed viability and recalcitrant seeds predominant in tropical tree species.

Vegetative propagation techniques are increasingly being applied to the domestication of tropical tree species (Leakey *et al*., 1990). Although efforts have traditionally focused on economically important tropical tree species such as medicinal plants (Tchoundjeu *et al*., 2004; Teklehaimanot *et al*., 2004; Mng'omba *et al*., 2008), with a current scenario of rapid climate changes (IPCC, 2008) and increasing land degradation in many tropical countries, certain multi-purpose tree species are becoming rare and threatened with local extinction. These species frequently provide a combination of the following: food, medicine, fuel, fodder, wood and income through sale of products. The level of knowledge of cost-effective vegetative propagation of tropical and sub-tropical tree species is not common and has slowed down domestication of many trees (Akinnifesi *et al*., 2006). The low cost vegetative propagation is a solution for domestication and conservation of indigenous and threatened tree species.

The need for low cost vegetative propagation technology: Low-cost vegetative propagation technology is the adoption of practices and use of inputs and equipment to reduce the unit cost of propagule and plant production. Potential factors for low cost vegetative propagation discussed in this study are those which should be opted to lower the cost of production without compromising the quality of the propagules and plants. The broad application of existing vegetative propagation technologies is important for tree improvement and the most relevant aspects for programs involving indigenous species and impoverished communities (Leakey, 2005). However, the high costs in the technologies may be an obstacle to the direct use of propagules as planting stock. The review describes the potential factors in consideration for low cost vegetative propagation of tropical trees.

Major types of vegetative propagation methods and costs comparison: A range of approaches can be utilized for vegetative propagation but the major types are macropropagation which involves vegetative propagation by cuttings and micropropagation through *in vitro* culture to multiply ontogenetically mature shoots that are very difficult to propagate by cuttings. Micropropagation offers the high multiplication rates of propagules and much quicker to capture of genetic gains in forest tree breeding programs than macropropagation through stem cuttings (Minghe and Ritchie, 1999). Micropropagation is also appropriate for tree improvements, to free tree from the known viral diseases or when there is a need for a wider cultivation (Mng'omba *et al*., 2008). However, the current high costs for micropropagation in terms of the supply of culture containers, media, chemicals, equipment and instruments has caused a major impediments to the direct use of micropropagation in many programs (FAO, 2000). Even the relative cost of labour and expertise is very high in micropropagation compared to macropropagation by stem cuttings which is generally more cost effective (Abbasi *et al*., 2007). In addition, for macropropagation the time required for plant regeneration is generally very short, often just days or weeks. Although, macro propagation by stem cuttings has low cost compared to micropropagation, in both methods there are potential factors to be considered in order to lower propagation costs.

LOW COSTS IN MICROPROPAGATION

In tropical tree species, the practical applications of micropropagation seem to concentrate on tissue culture techniques. A few woody trees have been propagated using tissue culture *Maytenus senegalensis* (Matu *et al*., 2006) and *Pappea capensis* (Mng'omba *et al*., 2007). Tissue culture-based plant propagation is carried out in highly sophisticated facilities which are expensive and often are not available in the developing countries of tropical Africa. For example, the cost media, chemicals, equipment and instruments used in micropropagation such as autoclaves for sterilization of media and instruments are often very expensive. Hence, options to expensive inputs and infrastructure are described and can be sought and developed to reduce the costs in micropropagation.

Low cost option for culture media: A conventional plant culture medium usually contains a basal solution with major and minor mineral elements, a source of carbon (that is, sucrose), vitamins, growth regulators, a gelling agent for semi-solid media and water (Trigiano and Gray, 2000). In a conventional medium, if agar is used as a gelling agent, it can represent up to 70% of the total cost, followed by the minerals, water, sucrose and other minor media components (Prakash *et al*., 2004). As a substitute for agar, cheaper alternative sources of gelling agent such as starches and plant gums can be used (Kaur *et al*., 2005). Table sugar and molasses are suitable and cheap alternative to pure carbohydrates (Prakash *et al*., 2004). Molasses is not only a source of carbohydrates but vitamins as well, especially inositol, niacin, pyridoxine, pantothenic acid, thiamin, riboflavin, biotin, choline and minerals (Santana *et al*., 2009). Many laboratories have reported the use of table sugar (sucrose) on *in vitro* plant propagation medium (Kodym and Zapata-Arias, 2001; Prakash *et al*., 2004; Kaur *et al*., 2005; Tyagi *et al*., 2007). Plant cultures can be maintained in rooms with air conditioners and tube lights instead of highly priced plant growth chambers. The conventional method of downward illumination can be replaced by sidewise lighting systems, which not only reduce the number of lights but also provide more uniform illumination to the cultures (Nagamori and Kobayashi, 2001; Savangikar *et al*., 2002).

Low cost option for washing and sterilising operations: Costly dishwashing machines for cleaning the culture containers can be replaced by manual washing if labour is relatively inexpensive. The washed culture containers can be dried in sun instead of costly hot air ovens (Prakash *et al*., 2004). In small-scale laboratories, the autoclaves can be replaced by large sized pressure cookers, which are much cheaper (FAO, 2000). Instead of having one or two huge horizontal autoclaves, which generate hot air pockets in the sterilising rooms, it is better to have more of smaller vertical autoclaves, which keep the air cool. The normal practice to use costly aluminium foil for wrapping instruments for sterilisation can be replaced by stainless steel containers, which are autoclavable (Escobar *et al*., 2005). Glass bead sterilizers can be used to sterilize forceps and scalpels instead of the conventional flame sterilization using spirit lamps or gas cylinders. Water is one of the major medium components. Distilled water obtained by electrical distillation is expensive and required a sophisticated distillation apparatus. However, rain water or tap water can be used as a cheap low cost substitute as it has previously reported by Kaur *et al.* (2005) and Tyagi *et al.* (2007).

Low cost option for containers: Proper choice of containers can reduce the cost in micropropagation. The expensive imported vessels can be replacement with reusable glass jars and lids which can reduce costs of production (Prakash *et al*., 2004). Disposable plastic bags eliminate the cost of washing and of lids; the system of using plastic bags has been reported to reduce labour cost per propagule by 60% (Savangikar *et al*., 2002). Glass bottles and baby-food jars with polypropylene caps are the most widely used containers and the most economic and low cost option compared to conical flasks which are more expensive than glass bottles (Kodym and Zapata-Arias, 2001). The production cost of tissue-cultured plants can be reduced by 50-90% by using low cost containers (Abbasi *et al*., 2007).

LOW COSTS IN MACRO PROPAGATION

Low cost option for propagation system: There are many different types of propagation systems for stem cuttings in macropropagation but the most common are (1) intermittent mist, controlled by a range of different sensors and (2) air-tight, water-tight, high humidity, non-mist propagators (Hartmann *et al*., 1997). The basic principles behind all these systems are that the cuttings are well supplied with water at the cutting base while the leaves are in a cool, shady environment with low vapour pressure deficit to minimise water stress. Intermittent mist and non-mist propagators are all very effective, but vary in cost of materials be used, sophistication and training needed. Mist propagation system involves a lot of cost in terms of materials needed for construction of the units and requires skilled personnel (Hartmann *et al*., 2002). Mist units in intermittent mist propagation system usually are programmed to run continually or intermittently to ensure cuttings do not dry and wilt which also involves the cost of piped water and electricity.

The non-mist propagators (Leakey *et al*., 1990) have the advantage of being very low cost in terms of materials needed for its construction and so are highly suitable for use in developing country or rural situations, where electricity and piped water are not available. Non- mist plant propagator can be constructed from cheap, locally available material in tropical areas (Mbile *et al*., 2004). The system is made of a wooden frame enclosed in a single sheet of polythene such that the base is completely water tight and the lid is airtight. The system is covered by successive layers of small stones and gravel which may be covered by the sand as rooting media. A low-technology non-mist propagator has been developed that is extremely effective with low cost and meets the needs of most tree improvement projects in both the moist and dry tropics (Leakey *et al*., 1990). Non-mist propagators have successful rooted cuttings of *Irvingia gabonensis*, *Dacryodes edules* (Tchoundjeu *et al*., 2006), *Dalbergia melanoxylon* (Amri *et al*., 2010) and several other tropical tree species.

Low cost option for the choice of age of donor plant: Effect of age of donor plant on rooting ability of stem cuttings has been reported in many trees (Stenvall *et al*., 2004; Bhardwaj and Mishra, 2005; Husen and Pal, 2007). The ease of adventitious root formation tends to decline with the physiological age of the stock plants, due to several progressive changes in morphological, anatomical and biochemical traits such as decreased sensitivity of aging tissues to rooting promoters and/or accumulation of inhibitory substances which inhibit rooting (Hartmann *et al*., 2002; Husen and Pal, 2006). Stem cuttings from mature donor plants have decreased content of endogenous auxins (Leakey, 2004; Husen and Pal, 2007), which requires application of higher quantity of exogenous auxins as rooting hormone than stem cuttings from juvenile donor plant as a results the overall costs of rooting hormones in mature cuttings may be higher than juvenile cuttings. In general, the more lignified the vegetative material, the higher the hormone doses should be applied (Hartmann *et al*., 2002; Amri, 2009).

Significant interactive effect of age of donor and auxin such as indole-3-butyric acid (IBA) has been reported in many tree species such as *Robinia pseudoacacia* and *Grewia optiva* (Swamy *et al*., 2002), *Khaya anthotheca* (Opuni-Frimpong *et al*., 2008) and *Dalbergia melanoxylon* (Amri *et al*., 2010) where percent rooting for IBA treated cutting from juvenile donor plant had higher rooting percentage than IBA treated cuttings from mature donor plant. Cuttings from mature trees have a low rate of propagative success and the number of people with the appropriate skills to carry it out may be a constraint to its widespread application in the future (Simons and Leakey, 2004). However, propagation by juvenile leafy cuttings is very easy probably over 90% of tropical trees are amenable to propagation by juvenile stem cuttings (Leakey *et al*., 1990) and currently is the preferred option for participatory domestication in village nurseries (Amri, 2002; Mbile *et al*., 2004; Mialoundama *et al*., 2002).

Low cost option for the type of stem cuttings to be used: Stem cuttings of tropical trees can come in many forms, but the two major groups are leafy softwood cuttings from relatively unlignified, young shoots and leafless hardwood cuttings from older and more lignified shoots which typically have already shed their leaves due to the onset of dry season. It is difficult and expensive to root leafless hardwood cuttings compared to leafy softwood cuttings in terms of labour and quantity of rooting hormones to be used (Amri, 2009). Hardness of cuttings determines the quantity of rooting hormones to apply. Generally, leafy softwood cuttings require 0.05-0.3%, while semi-hardwood cuttings require 0.1- 0.5% of rooting hormone. Leafless hardwood cuttings require 0.25-1.0% or higher concentration of rooting hormone (Hartmann *et al*., 1997; Amri, 2002; Amri and Friedricks, 2006). More than 80% of tropical forest trees so far tested can be rooted as leafy stem cuttings in low-technology poly-propagators and/or under mist (Mudge and Brennan, 1999). By selecting for those characteristics of stem form and branching habit that show up early in life and making sure that cuttings come from a suitable shoot may lower the cost of propagules production.

Low cost option for hormone (auxins) treatment: Typically cuttings treated with auxins root more rapidly and produce more roots and usually with a higher percentage than untreated cuttings. Indole-3-acetic acid (IAA), indole-3-butyric acid (IBA) and 1-naphthalene acetic acid (NAA) are three synthetic rooting chemicals that have been found to be reliable in the promotion of rooting in cuttings (Hartmann *et al*., 2002). IBA is the most effective root promoting auxin and widely applied in general use because it is non-toxic to most wood plants over a wide range (Tchoundjeu *et al*., 2004). IBA has an important role in the development of adventitious roots, increasing rooting percentage, improving quality of roots and uniformity in rooting of cuttings (Negash, 2002; Tchoundjeu *et al*., 2002; Teklehaimanot *et al*., 2004; Husen and Pal, 2007; Amri, 2009). Root formation process in cuttings is intensified by IBA which influences polysaccharide hydrolysis resulting in increased content of physiologically active sugar needed to provide energy for meristematic tissues and later for root primordia and roots formed as reported in *Tectona grandis* (Husen and Pal, 2007), *Swartzia madagascariensis* (Amri and Friedricks, 2006) and *Dalbergia melanoxylon* (Amri *et al*., 2010).

IBA is applied to plant cuttings for rooting using powder or liquid carrier. The use of powder may be expensive as it requires large quantity of powder and if a non-uniform amount of powder is applied there may be inconsistent results. Also much powder on the base of the cutting can sometimes stop the outgrowth of the new roots and the powder loses its effectiveness if not kept dry and in a refrigerator. Liquid carrier may be alcohol or water, while alcohol is very expensive water is cheap and easily available. Moreover, IBA dissolved in water is more effective for rooting most plant species than IBA dissolved in alcohol. High concentration of alcohol may dehydrate, injure and be toxic to basal stems, scions and other plant tissue.

Low cost option for type of rooting media to be used: The importance of rooting media for rooting of cuttings is widely known to provide sufficient porosity to allow good aeration and ensure adequate oxygen availability for the developing rooting system (Hartmann *et al*., 2002; Baiyeri, 2005; Allaire *et al*., 2004; Shah *et al*., 2006). Low cost option for rooting media should be single or mixtures of common and easily available materials, such as river sand, sharp sand, grit or fine gravel, forest top soil, old weathered sawdust and coconut palm husks. It is not necessary to buy expensive materials such as peat, vermiculite or perlite, except for special purposes.

Sand as low cost rooting media has been identified as the best rooting media for stem cuttings of *Gongronema latifolia* (Agbo and Omaliko, 2006), *Dalbergia melanoxylon* (Amri and Friedricks, 2006; Amri *et al*., 2009). The use fine sand and gravel as rooting media has also been reported to enhance high rooting percentage for stem cuttings of *Cordia alliodora* and *Vochysia hondurensis* respectively (Leakey *et al*., 1990). Vegetative propagation by stem cuttings of *Irvingia wombolu* revealed high rooting percentage in coarse sand rooting media (Dickens *et al*., 2009). Sawdust also as low cost rooting media has been reported with highest rooting percentages of *Milicia excelsa* (Ofori *et al*., 1996). Stem cuttings of *Pausinystalia johimbe* rooted better in sand than in the mixture of sand/sawdust (Tchoundjeu *et al*., 2004). Sand, gravel, forest top soil and saw dust are easy low cost locally available rooting media which can be used for propagation of tropical trees. However, forest top soil is not advisable because it is bulky, heterogeneous in mineral composition and could cause environmental hazard such as soil erosion (Ekwu and Mbah, 2001).

Low cost consideration for sites of cuttings collection: There is a need to recognize the additional expense associated with site for cuttings collection and the cost of maintenance of these sources. Cutting sites or sources associated with factors such as diseases, insects and environmental stresses on donor plants may increase the cost of production (Amri, 2009). All donor plants sources should be relatively vigorous and free of insects and disease (Hartmann *et al*., 2002). One year prior to taking cuttings, potential donors should be scouted during the growing season, their location marked and recorded and the plants revisited just prior to taking cuttings to assure the availability of an adequate quantity and quality of cuttings. Avoid plants showing signs of severe environmental stress or isolated groups of few individual plants.

The low-cost vegetative propagation of tree species is an important component of strategies to achieve the UN Millennium Development Goals through its contribution to eradication of extreme poverty, enhance food and nutritional security and ensuring environmental sustainability (Garrity, 2004). Low-cost vegetative propagation will not only stay a high priority in forestry for tropical areas but also in agriculture, horticulture and floriculture of many developing countries for the production of suitably priced high quality planting material.

CONCLUSIONS

Low cost vegetative propagation can achieved through consideration of factors useful in improving process efficiency and better utilization of resources. For tropical trees, vegetative propagation should be particularly interested in methods for producing own rooted plants, which require low investments in equipment, inputs and personnel training. It is recommended that potentially low cost factors should be considered for vegetative propagation of tropical trees, since the resources of trained personnel and equipment are often not readily available. This review has focused on how to lower to cost for vegetative propagation, the factors discussed here can be adopted in tropical areas by forest tree breeders or farmers for domestication of economically important tropical tree species which are threatened by over exploitation.

REFERENCES

Abbasi, B.H., P.K. Saxena, S.J. Murch and C.Z. Liu, 2007. *Echinacea* biotechnology: Challenges and apportunities. *In vitro* Cell. Dev. Biol. Plant, 43: 481-492.

Agbo, C.U. and C.M. Omaliko, 2006. Initiation and growth of shoots of Gongronema latifolia Benth stem cuttings in different rooting media. Afr. J. Biotechnol., 5: 425-428.

Akinnifesi, F.K., F. Kwesiga, J. Mhango, T. Chilanga and A. Mkonda *et al*., 2006. Towards the development of miombo fruit trees as commercial tree crops in Southern Africa. For. Trees Livelihoods, 16: 103-121.

Allaire, S., J. Caron, C. Menard and M. Dorais, 2004. Growing media varying in particle size and shape for greenhouse tomato. Acta Hort., 644: 307-311.

Amri, E., 2002. Vegetative propagation studies of selected threatened economically important species *Swartzia madagascariensis* and *Prunus africana*. M.Sc. Thesis, University of Dar-es-Salaam, Tanzania.

Amri, E. and J. Friedricks, 2006. Propagation of African blackwood (*Dalbergia melanoxylon*) by stem cuttings and seasonal variation in rooting ability. Proceedings of COSTECH 1st National Scientific and Technological Conference, May 24-26, Dar-es-Salaam, Tanzania, pp: 45-58.

Amri, E., 2009. Investigation on the propagation potential of *Dalbergia melanoxylon* Guill. And Perr. provenances and their genetic diversity from selected areas of Tanzania. Ph.D. Thesis, University of Dar es Salaam, Tanzania

Amri, E., H.V.M. Lyaruu, A.S. Nyomora and Z.L. Kanyeka, 2009. Evaluation of Provenances and Rooting Media for Rooting Ability of African Blackwood (*Dalbergia melanoxylon* Guill. and Perr.) stem cuttings. Res. J. Agric. Biol. Sci., 5: 524-532.

Amri, E., H.V.M. Lyaruu, A.S. Nyomora and Z.L. Kanyeka, 2010. Vegetative propagation of African Blackwood (*Dalbergia melanoxylon* Guill. and Perr.): effects of age of donor plant, IBA treatment and cutting position on rooting ability of stem cuttings. New Forests, 39: 183-194.

Baiyeri, K.P., 2005. Response of musa species to macropropagation: The effects of genotype, initiation and weaning media on sucker growth and quality in the nursery. Afr. J. Biotechnol., 4: 229-234.

Bhardwaj, D.R. and V.K. Mishra, 2005. Vegetative propagation of *Ulmus villosa*: effects of plant growth regulators, collection time type of donor and position of shoot on adventitious root formation in stem cuttings. New Forests, 29: 105-116.

Dickens, E.D., O.I. Felix and U.N. Godwin, 2009. Effect of propagation media on the rooting of leafy stem cuttings of *Irvingia wombolu* (Vermoesen). Res. J. Agric. Biol. Sci., 5: 1146-1152.

Ekwu, L.G. and B.N. Mbah, 2001. Effect of varying levels of nitrogen fertilizer and some potting media on the growth and flowering response of marigold (*Targetes erecta* L.). Nig. J. Hort. Sci., 5: 104-109.

Escobar, R.H., C.M. Hernandez, N. Larrahondo, G. Ospina and J. Restrepo *et al*., 2005. Tissue culture for farmers: Participatory adaptation of low-input cassava propagation in Colombia. Exp. Agric., 42: 103-120.

FAO, 2000. How appropriate are currently available biotechnologies in the crop sector for food production and agriculture in developing countries. Proceedings of the Electronic forum on Biotechnology in Food and Agriculture: Conference 1. March 20-May 26, Food and Agriculture Organization of the United Nations, Rome, Italy, http://www.fao.org/biotech/Conf1.htm.

Garrity, D., 2004. World agroforestry and the achievement of the millennium develop-ment goals. Agrofor. Syst., 61: 5-17.

Hartmann, H.T., D.E. Jr. Kester, F.R. Davies and R.L. Geneve, 1997. Plant Propagation, Principles and Practices. 6th Edn., Prentice Hall of India Pvt. Ltd., New Delhi, India, pp: 649-650.

Hartmann, H.T., D.E. Kester, F.T. Davies and R.L. Geneve, 2002. Plant Propagation: Principles and Practices. 7th Edn., Prentice Hall, USA., pp: 199-236.

Husen, A. and M. Pal, 2006. Variation in shoot anatomy and rooting behaviour of stem cutting in relation to age of donor plants in teak (*Tectona grandis* Linn. F). New For., 31: 57-73.

Husen, A. and M. Pal, 2007. Metabolic changes during adventitious root primordium development in *Tectona grandis* Linn. f. (teak) cuttings as affected by age of donor plants and auxin (IBA and NAA) treatment. New Forests, 33: 309-323.

IPCC, 2008. Climate Change and Water. In: Intergovernmental Panel on Climate Change Technical Paper VI, Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof (Eds.). IPCC Secretariat, Geneva, Switzerland, pp: 210.

Kaur, R., H. Gautam and D.R. Sharma, 2005. A low cost strategy for micropropagation of strawberry (*Fragaria* × *Ananassa* Duch.) Cv. Chandler. Acta Hort., 696: 129-133.

Kodym, A. and F.J. Zapata-Arias, 2001. Low-cost alternatives for the micropropagation of banana. Plant Cell Tissue Organ Culture, 66: 67-71.

Leakey, R.R.B., J.F. Mesen, Z. Tchoundjeu, K.A. Longman and J.M. Dick *et al*., 1990. Low technology techniques for the vegetative propagation of tropical trees. Commonwealth For. Rev., 69: 247-257.

Leakey, R.R.B. and A.J. Simons, 2000. When does Vegetative Propagation Provide a Viable Alternative to Propagation by Seed in Forestry and Agroforestry in the Tropics and Sub-Tropics. In: The Procurement of Forestry Seeds in Tropical and Subtropical Countries-The Example of Kenya Contributions to Forest Sciences, Wolf, H. and J. Albrecht (Eds.). Verlag, India, pp: 67-81.

Leakey, R.R.B., 2004. Physiology of Vegetative Reproduction. In: *Encyclopaedia* of Forest Sciences, Burley, J., J. Evans and J.A. Youngquist (Eds.). Academic Press, London, UK., pp: 1655-1668.

Leakey, R., 2005. Domestication potential of Marula (*Sclerocarya birrea* subsp. caffra) in South Africa and Namibia: 3. Multiple trait selection. Agrofor. Syst., 64: 51-59.

Matu, E.N., K.L. Lindsey and J. van Staden, 2006. Micropropagation of *Maytenus senegalensis* (Lam) Excell. South Afr. J. Botany, 72: 409-415.

Mbile, P.Z., A. Tchoundjeu, M.L. Degrande and C. Tsobeng, 2004. Non-mist vegetative propagation by resource-poor rural farmers of the forest zone of Cameroon: Some technology adaptations to enhance practice. Forest Trees Livelihoods, 14: 43-52.

Mialoundama F., M.L. Avana, E. Youmbi, P.C. Mampouyl, Z. Tchoundjeu, M. Mbeuyo, G.R. Galamo, J.M. Bell, F. Kopguep, A.C. Tsobeng and J. Abega, 2002. Vegetative propagation of Dacrodes edulis (G.Don) H.J. Lam by marcots, cuttings and micropropagation. For. Trees Livelihoods, 12: 85-96.

Minghe, L. and G.A. Ritchie, 1999. Eight hundred years of clonal forestry in China: II. Mass production of rooted cuttings of Chinese fir (*Cunninghamia lanceolata* (Lamb.) Hook.). New Forests, 18: 143-159.

Mng'omba, S.A., E.S. du Toit, F.K. Akinnifesi, H.M. Venter, 2007. Repeated exposure of jacket plum (*Pappea capensis*) micro-cuttings to indole-3-butyric acid (IBA) improved *in vitro* rooting capacity. South Afr. J. Botany, 73: 230-235.

Mng'omba, S.A., E.S. du Toit, F.K. Akinnifesi, S. Gudeta, C. Oluyede, S.C. Ajayi and W.F. Mwase, 2008. A decision support tool for propagating Miombo indigenous fruit trees of southern Africa. Afr. J. Biotechnol., 7: 4677-4686.

Mudge, K.W. and E.B. Brennan, 1999. Clonal Propagation of Multipurpose and Fruit Trees used in Agroforestry. In: Agroforestry in Sustainable Agriculture Systems, Buck, L.E., J.P. Lassoie and E.C.M. Fernandes (Eds.). CRC Press, New York, USA.

Nagamori, E. and T. Kobayashi, 2001. Viscous additive improves micropropagation in liquid medium. J. Biosci. Bioeng., 91: 283-287.

Negash, L., 2002. Successful vegetative propagation techniques for the threatened African pencil cedar (*Juniperus procera* Hoechst. ex Endl.). For. Ecol. Manage., 161: 53-64.

Ofori, D.A., A.C. Newton, R.R.B. Leakey and J. Grace, 1996. Vegetative propagation of *Milicia excelsa* by leafy stem cuttings. Effect of auxin concentration, leaf area and rooting medium. For. Ecol. Manage., 84: 39-48.

Opuni-Frimpong, E., D.F. Karnosky, A.J. Storer and J.R. Cobbinah, 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 Forests, 36: 115-123.

Prakash, S., M.I. Hoque and T. Brinks, 2004. Low cost options for tissue culture technology in developing countries: culture media and containers. Proceedings of the a Technical Meeting organized by the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, Aug. 26-30, Vienna, pp: 29-40.

Santana, M.A., G.A. Romay, J. Matehus, J.L. Vicente-Villardón and J.R. Demey, 2009. Simple and low-cost strategy for micropropagation of cassava (*Manihot esculenta* Crantz). Afr. J. Biotechnol., 8: 3789-3897.

Savangikar, V.A., C. Savangikar, R.S. Daga and S. Pathak, 2002. Reduction in cost in micropropagation: Achievements and further prospects. Proceedings of Ist International Symposium Liquid System for *in vitro* Mass Propagation of Plants, May 29-June 2, Norway, pp: 3-8.

Shah, M., K.A. Mateen and N. Amin, 2006. Effect of different growing media on the rooting of *Ficus binnendijkii* amstel queen cuttings. J. Agric. Biol. Sci., 1: 15-17.

Simons, A.J. and R.R.B. Leakey, 2004. Tree do-mestication in tropical agroforestry. Agrofor. Syst., 61: 167-181.

Stenvall, N., T. Haapala and P. Pulkkinen, 2004. Effect of genotype, age and treatment of stock plants on propagation of hybrid aspen (*Populus tremuloides*) by root cuttings. Scand. J. Forest Res., 19: 303-311.

Swamy, S.L., S. Puri and A.K. Singh, 2002. Effect of auxins (IBA and NAA) and season on rooting of juvenile and mature hardwood cuttings of *Robinia pseudoacacia* and *Grewia optiva*. New Forests, 23: 143-157.

Tchoundjeu, Z., M.L. Avana, R.R.B. Leakey, A.J. Simons, E. Asaah, B. Duguma and J.M. Bell, 2002. Vegetative propagation of *Prunus africana*: Effects of rooting medium, auxin concentrations and leaf area. Agrofor. Syst., 54: 183-192.

Tchoundjeu, Z., M.L.N Mpecka, E. Asaaha and A. Amougoub, 2004. The role of vegetative propagation in the domestication of *Pausinystalia johimbe* (K. Schum) a highly threatened medicinal species of West and Central Africa. Forest Ecol. Manage., 188: 175-183.

Tchoundjeu, Z., E.K. Asaah, P. Anegbeh, A. Degrande and P. Mbile *et al*., 2006. Putting participatory domestication into practice in West and Central Africa. Forests Trees Livelihoods, 16: 53-69.

Teklehaimanot, Z., P.L. Mwang'ingo, A.G. Mugasha and C.K. Ruffo, 2004. Influence of the origin of stem cutting, season of collection and auxin application on the vegetative propagation of African Sandalwood (*Osyris lanceolata*) in Tanzania. South Afr. For. J., 201: 13-24.

Trigiano, R.N. and D.J. Gray, 2000. Plant Tissue Culture Concepts and Laboratory Exercises. 2nd Edn., CRC Press, Boca Raton.

Tyagi, R.K., A. Agrawal, C. Mahalasksmi, Z. Hussain and H. Tyagi, 2007. Lowcost media for *in vitro* conservation of turmeric (*Curcuma longa* L.) and genetic stability assessment using RAPD markers. *In vitro* Cell. Dev. Biol. Plant, 43: 51-58.