EFFECT OF SEED TREATMENTS AND SHADE ON SEEDLING GROWTH DYNAMICS OF *PONGAMIA PINNATA* (Linn.) Pierre IN THE NURSERY

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled **"Effect of seed treatments and shade on seedling growth dynamics of *Pongamia pinnata* (Linn.) Pierre in the nursery"** is a bonafide record of research done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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Dedicated

to

My beloved parents,
Family members and
late Gopikumar sir

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Introduction

INTRODUCTION

Pongamia pinnata (Linn.) Pierre is a medium sized evergreen tree planted for shade and as an ornamental tree in the greater part of the country. It is a drought resistant, salt tolerant, nitrogen fixing leguminous tree and to some extent tolerant to slight frost. The seeds are largely exploited for extraction of non-edible oil, commercially known as 'karanja oil' well recognized for its medicinal properties and also used in the manufacture of soap. Leaves are used as fodder and green manure. The wood of this tree is used as fuel throughout the country and is also used for construction, tool handles and agricultural implements. The seeds contain around 30-40 per cent of oil, which has been identified as a source of bio-fuel. Oil from *Pongamia pinnata* trees, with a suitable trans-esterification process, can be upgraded to diesel quality and mixed to standard diesel grade and marketed.

This tree is wonderfully adaptable to any locality; although commonly found wild in the sandy beds of streams or along the sea- shore, thriving with its roots in fresh or salt water. It is grown successfully as a roadside tree in comparatively dry parts of the Indian peninsula or on the alluvial plains of northern India. In localities in which it is known to have been cultivated successfully the absolute maximum shade temperature varies from 37.7°C to 48.8°C; the absolute minimum from under -1°C to over 15.5°C and the rainfall from 20 to over 100 inches.

The forest department has identified this species for avenue planting and for afforestation of watersheds in drier parts of India. It is also very important from agroforestry point of view wherein the species finds application in the agrosilvopastoral system as well as multipurpose forest tree production system. Supply of good quality planting stock is one of the governing factors in any afforestation programme. Field establishment and survival of the planting stock are highly dependent on the stock quality, which is, in turn, controlled by healthy seeds and its germination. In forestry, various treatments are applied to seed prior to sowing in order to increase the rapidity or completeness of germination. Rapid, uniform and early germination along with vigorous seedlings are the pre- requisites for obtaining good quality seedlings in the nursery.

Previous works suggests that when seeds are sown in growing media, some seeds fail to germinate, some others germinate in few days and others take some more time for germination. In order to obtain rapid, uniform, early and complete germination pretreatment is applied. The pretreatments enhance speed of germination and thereby helps in faster seedling establishment.

It has also been reported by many workers that the requirement of sunlight varies widely for the species and their growing conditions, particularly during the nursery stage. Understanding the response of seedlings of *Pongamia pinnata* towards various shade levels in the nursery will help to produce a healthy nursery stock. This information will also enable foresters for proper site selection for establishing commercial nurseries of this species for large scale seedling production.

The current study was carried out with the following objectives:

1. To study the effect of various pre-treatments on germination of seeds of *Pongamia pinnata.*
2. To study the effect of varying levels of shade on growth and vigour of seedlings of *Pongamia pinnata* grown in the nursery.

Review of Literature

REVIEW OF LITERATURE

Pongamia pinnata is an important non-edible minor oilseed tree that grows in the semi-arid regions. The leaves are a good source of green manure and being leguminous, they enrich the soil with nitrogen. The seeds contain around 30- 40 per cent of oil, which has been identified as a source of bio-fuel and has medicinal value. It is predominantly cultivated through seeds. Rapid, uniform and early germination along with vigorous seedlings are the pre- requisites for obtaining good quality seedlings in the nursery. The effect of different treatments on tree seeds has been studied by various workers.

Sunlight is one of the most important factors, sustaining life on the planet by providing energy that is assimilated by green plants. Sunlight plays the key role in the physiology of plants, their growth and phenology. The requirement of sunlight varies according to species and their growing conditions. The degree of shade is a key determinant of light related functions of the plant body. Number of studies were conducted on the effects of various levels of shade on the growth and productivity of plants, like vegetables and ornamentals. However, such studies are scanty in tropical tree species, particularly *Pongamia pinnata* that is very important from agroforestry point of view wherein the species finds application in the agrosilvopastoral system as well as multipurpose forest tree production system and also for avenue planting.

2.1 Effect of various pretreatments on germination of seeds

2.1.1 Effect of cold and hot water treatment on seed germination

Kumar and Purkayastha (1972) reported that hot water treatment is highly beneficial in *Albizia richardiana*. Valencia (1973) found that 20-30 minutes soaking in water at 38 ^{0}C gave optimum germination in *Albizia falcataria* seeds. Most tropical seeds have little resistance to germination, may respond well to soaking in water for 24 hours at ambient temperature (Kemp, 1975). Agypaoa and Pulmano (1978) observed that soaking of *Pinus kesiya* seeds in cold water for 15 hours and 24 hours has no effect on germination.

Mathur *et al.,* (1984) reported that hot water treatment gave the highest rate of germination in *Acacia nilotica*. Thus hot and cold water treatment has a profound significance in improving the germination of some seeds. Krishnamurthy and Munegowda (1985) reported that pre-treatment of seeds of *Leucaena leucocephala* with cold water for 48 hours was easiest and best method for increasing germination. Willan (1985) reported that general soaking of seeds in water or other liquids could effect softening of hard seed coats and leaching out of chemical inhibitors.

Hot water (50°C) treatment of fresh seeds of *Derris indica* (*Pongamia pinnata*) for 15 minutes improved both speed and percentage of germination over that of untreated seeds; germination percentages were 98 and 82 respectively at 35 days. Increasing the period of hot water soaking to 30 or 60 minutes did not increase speed or percentage germination further (Ramamoorthy *et al.,* 1989). Hot water treatment has been tried in the case of *Albizia* seeds by several workersTreatments with hot water significantly enhanced percentage germination in seeds of *Grewia oppositifolia* (Uniyal *et al.,* 2000).

A pre-treatment in the form of soaking the seeds in water for about 2 to 3 hours enhanced the germination of *Hydnocarpus pentandra* (Gopikumar *et al.*, 2003). Veena and Gupta (2003) studied the effect of scarification, hot water treatment, and cold scarification in *Caesalpinia sappan* L. Results showed a 10 per cent increase in germination of seeds treated with hot water than the controlled condition. Thus hot water and cold water has a profound significance in improving the germination of seeds. The germination test of *Pongamia* seeds conducted by NBPGR, New Delhi showed 44 per cent and 68 per cent in control condition and pre- soaked in water respectively (Kumar *et al.*, 2007). Various seed treatments were attempted for improving germination percentage. A set of seeds without any treatment was used as control. Of these, hot water treatment at 60°C for 30 minutes increased germination percentage significantly from 44 to 100 per cent, showing an increase of 56 per cent over control (Kumar *et al.,* 2007).

2.1.2 Effect of GA_3 on seed germination

Bachelard (1968) reported that seeds, treated with GA at 50mg/litre produced vigorous seedlings in *Eucalyptus regnans* and *E. pauciflora*. These seedlings were having more number of leaves and increased shoot elongation, but with less root growth, root/ shoot ratio, total dry weight and leaf area. Vogt (1974) reported that GA at 500 ppm improved the initial root length, height and number of leaves in individual seedlings in *Quercus rubra*. However root length was found to be slightly inhibited. He emphasized the use of GA for the manipulation of root/ shoot ratio. Bhatnagar (1980) reported that GA_3 at 10 and 50 ppm increased the germination of *Pinus caribea* and *P. patula* seeds respectively. Gibberlic acid is reported to be responsible for mobilization of nutrients from endosperm to the embryo (Kumar and Purohit, 1986).

In *Michelia champaca* seeds when sown untreated recorded poor germination but treatment with gibberrellic acid (GA_3) enhanced both total germination and speed of germination (Bahuguna *et al.*,1988). Bal *et al.* (1990) reported that *Pyrus pashia* seeds treated with GA_3 at 50 ppm and then stratified at 4.5° C for seven days produced seedlings having maximum collar girth of 1.9 mm. In *Albizia odoratissima*, GA_3 at 50 and 100 ppm enhanced seed germination (Gopikumar and Moktan, 1994). GA_3 treatment facilitates the release of various enzymes which weaken the tensile strength of the seed coat. Gibberlic acid at 50 and 100 ppm enhanced seed germination (Gopikumar and Moktan, 1994). Sita *et al.* (1996) reported that the percentage of germination in *Emblica officinalis* was maximum with 300 ppm GA. GA_3 (100 ppm) enhanced the shoot length, total leaf area, total dry weight and total chlorophyll content more than other treatments in seedlings in *Pongamia pinnata* (Venkatesh *et al.*, 2000)

2.1.3 Effect of Con. H_2SO_4 and seed coat removal on germination

Jones (1963), found that removal of seed coat was most effective treatment in terms of germination percentage and speed of germination in *Acacia cyclops* and *Acacia cyanophylla.* Ramdeo (1971) found that 20-30 minutes soaking in concentrated H_2SO_4 increased germination of *Leucaena glauca* seeds. Seeber and

Agypaoa (1976) found that in *Calophyllum inophyllum* complete removal of seed coat produced better germination than nicking. Rai (1978) reported that soaking in concentrated sulphuric acid for 10 minutes and subsequently washing and soaking in water for 18 hours significantly increased the germination of *Albizia falcataria* and *Albizia chinensis*. Soaking in concentrated sulphuric acid for 25-30 minutes followed by soaking in water for 24 hours was most beneficial in *Albizia richardiana.*

In *Acacia mearnsii* chipping the seed coat at micropylar end increased germination (Henry and Staden, 1982). Removal of seed coat increased germination percentage in *Albizzia richariadana.* (Roy and Pathak, 1983). In the case of hard coated seeds like *Albizia lebbek*, *Cassia fistula* and *Cassia siamea*, repeated scarification with concentrated sulfuric acid gave up to 95 per cent germination (Rai *et al.*, 1986). Khan and Tripathi (1987) reported that removal of seed coat increased germination in *Albizzia lebbeck.* Soaking of seeds in water and complete removal of seed coat resulted in significantly high germination percentage and speed of germination in *Albizzia falcataria* and *Albizzia procera* (Sajeevukumar, 1991). Anoop and Gopikumar (1994) reported that treating the seeds with concentrated H_2SO_4 for 2-3 minutes was the best seed pre treatment in most of the selected agroforestry tree species. Sajeevukumar *et al.* (1995) reported that chemical scarification by sulphuric acid gave the highest germination per cent in *Albizia procera* and *Albizia falcataria.*

Treating the seeds with concentrated sulphuric acid for 5 minutes proved to be the best seed pretreatment in *Prosopis cineraria*, *Albizia falcataria* and *Leucaena leucocephala* in terms of germination (Gopikumar, 2002). Seeds of *Pongamia pinnata*, a medicinally important ornamental tree in Agra, Uttar Pradesh, India, were subjected to mechanical and chemical treatments for enhancing seed germination. The treatments include seed coat removal using a nail clipper, scarification, washing with concentrated H_2SO_4 (15-30 minutes) and Hydrochloric acid (0.5 to 2 minutes), immersion in hot water (5°C- 45°C, 5-10 minutes) and untreated seeds sown at different depths (2-5 cm). Results showed that mechanical treatments enhanced seed germination up to 85 per cent (Singh *et al.*, 2005).

2.2 Effect of shade on growth of seedlings

2.2.1 Effect of shade on growth of shoot

Fairbarian and Neustein (1970) reported that seedlings of six species viz. *Ricea sitchensis, Pseudotsuga menziesii, Tsuga heterophylla, Abies grandis, Picea abies* and *Abies alba* showed highest shoot length when grown under 50 per cent shade. However, collar diameter, ratio of collar diameter to shoot length and total dry weight showed highest values when grown under full sunlight. In *Casuarina equisetifolia,* height of seedlings was reported to be unaffected by shading, but dry weight was maximum in full sunlight (Shafiq *et al.*, 1974).

Seedlings of *Pinus sylvestris, P.nigra, Tilia tomentosa, Acer pseudoplatanus, Quercus petraea and Fagus sylvatica* when grown in 100, 50, 25 and 12.5 per cent of full sunlight upto a period of eight years showed that except *Tilia tomentosa*, all other species produced greater aerial biomass under full sunlight, whereas *T.tomentosa* performed well under 50 per cent shade (Lyapova and Palashev, 1982).

Rao and Singh (1985) studied the growth of seedlings of *Pinus roxburghii* and *Quercus butrichopleorea* under 100, 70, 50 and 18 per cent sunlight and concluded that *P.roxburghii* was less tolerant to shade. Studies on the effect of shade on seedlings of *Shorea almon, Parashorea malanonan, Anisoptera thurifera, Shorea polyspermum, Hopea parviflora* and *Vatica managachopi* indicated that in all the species, maximum growth in height, diameter and dry weight was observed when plants were grown in full sunlight (Suzuki and Jacaline, 1986).

Bush and Auken (1987) showed that light intensity had substantial relationship with the growth of aerial parts of plants, especially at seedling stage of *Prosopis glandulosa.* Light intensity increased stem length, dry weight and basal diameter of the seedlings. Decrease in sunlight leads to a reduction in the diameter growth and number of side shoots in seedlings of *Pinus sibirica* (Yushkov and Zavi'yalova, 1988). Orians (1991) studied the *response* of *Inga oerstediana* grown under three different light environments viz, the understory, tree fall gap and full sunlight. Growth of the plant was found to be better when grown under full sunlight compared to other situations. Studies done by Oscinkoya and Ash (1991) with seedlings of Australian rainforest tree species species at 37, 10 and 2.5 per cent shades showed the positive effect of 37 per cent shade on shoot growth of all the species. The three evergreen conifers *Abies scholinensis, Picea jenfonensis* and *P.glehmii*, showed variations in tolerance to shade levels. Ability to tolerate shade stress was higher for *A.schalinensis* compared to *Picea* spp. (Tujimoto and Shimada, 1991). Responses of shade on growth of douglas fir (*Pseudotsuga menziesii*), Western hemlock (*Tsuga heterophyll*a) and Western red cedar (*Thuja plicatus*) was studied by Carter (1992) and found that Western red cedar performed better at lower light levels compared to other species.

Quercus lobata, Q.douglasii and Q.agrifolia were grown under different shade levels and full sunlight. No variations were noticed in growth with regard to different shade levels. In *Q.lobata* and *Q.douglasii* shade did not affect the seedling biomass (Callaway, 1992). Cornelissen (1992) studied the growth of *Gordonia acuminata* grown under four shade levels (55%, 33%, 18% and 0%). Best growth was noticed at 33 per cent shade. Seedlings of *Azadirachta indica* recorded more height and collar diameter under open conditions, while seedlings of *Leucaena leucocephala* recorded more girth when grown under 25 and 50 per cent shade levels. However, height was more when *Leucaena .leucocephala* was grown under 25 per cent shade (Vimal, 1993). Cregg and Teskey (1993) in loblolly pine observed a reduction in growth in the shaded seedlings. Studies using seedlings of *Pinus brutia, Cupressus sempervirens* and *Casuarina equisetifolia* showed that in *P.brutia*, plant height and weight of branches were greatest and number of branches least when grown under 25 per cent shade. However, in *Cupressus sempervirens* maximum plant height, weight and number of branches were produced under 75 per cent shade.

The effect of shade on seedlings of *Dalbergia sissoo, Acacia catechu* and *Casuarina equisetifolia* were studied under nursery conditions in Uttar Pradesh (Saxena *et al.*, 1995). Artificial shade was provided by using varying layers of muslin clothes. Growth of *D.sissoo and A.catechu* was the maximum when grown under low shade condition while *C.equisetifolia* showed maximum growth in unshaded conditions. Root/shoot ratio was found to be lowest in *C.equisetifolia.* In all the species, increment in height and stem diameter per unit dry weight was greater when grown under higher shade conditions. Barizan *et al.* (1996) studied the growth and survival of *Hopea odorata* grown under different light conditions and fertilizer levels in Malaysia. Three different conditions were selected viz., open area with compacted soil (80-100 % of opening) and closed canopy areas, not subjected to silvicultural treatments. The mean growth of seedlings in terms of height and girth was significantly better under first and third situations. The height increment of seedlings under the third conditions was very low compared to the others.

In *Phyllanthus stipulatus* plant height was found to be higher when grown under 30 per cent shade than in sun in a study done in Brazil (Silva *et al.*, 1997). A study done to find out the effect of shade (0, 55 and 95%) on *Hibiscus syriacus* L. showed that the shoot lengths of most of the cultivars were longer in shade grown plants compared to control plants. Two cultivars showed a reduction in height compared to control plants. However, shoot dry weights under 95 per cent shade, compared to control plants did not show any substantial variations. But there was a reduction of root dry weight in some cultivars (Yoo and Kim, 1997).

Alphalo and Lehto (1997) studied the effect of quality of light on the growth of birch seedlings. During the first 15 days, largest effect of light was on height growth, which was greater for seedlings grown in simulated shade light. During this period, light quality was found to have little effect on dry weight.

Chen (1997) studied interspecific responses of planted seedlings to light availability and revealed that with decreasing light availability, did not affect survival of *Pseudotsuga menziesii* and *Picea engelmannii* seedlings while in *Pinus ponderosa* seedlings survival rate was reduced significantly. The seedlings of *Picea engelmannii* recorded maximum reduction in height growth, while *P. menziesii* recorded maximum reduction in diameter growth with decreasing light. Height-diameter ratio remained almost constant *P.ponderosa*. They also observed that morphological characters were more plastic in shade tolerant species.

Growth of *Cryptocaria aschersoniana* seedlings under different light regimes viz.; 0, 50, 70 and 90 per cent in the nursery was studied by Rezende *et al.* (1998). Maximum height growth was recorded for 90 per cent shade followed by 50 per cent shade. More or less similar trend was noticed with regard to collar diameter also.

Williams *et al.* (1999) found that the shade tolerance of Douglas fir (*Pseudotsuga menziesii*) and Lodgepole pine (*Pinus contorta*) was found to be more when grown in dry sites compared to moist sites.

Four species of Pacific Northwest conifer seedlings ponderosa pine (*Pinus ponderosa)*, Douglas-fir (*Pseudotsuga menziesii*), western redcedar (*Thuja plicata*) and western hemlock (*Tsuga heterophylla*) were grown under shade-cloth shelters that provided four levels of shade viz., 0 per cent (full sunlight), 35 per cent , 55 per cent , and 75 per cent for approximately 30 weeks. All species responded similarly to shade. Although height growth was greatest under 75 per cent shade and least in 0 per cent shade (Khan *et al.,* 2000). The seedlings of *Grevillea robusta, Tectona grandis* and *Ailanthus triphysa* were grown under varying shade conditions and full light. Seedlings of *G.robusta* and *T. grandis* performed well under full sunlight, while *Ailanthus triphysa* performed well under 75 per cent shade with regard to stem height, diameter and shoot dry weight (Saju *et al.,* 2000). The leaf and root growth parameters were also found to be influenced by shade. *Santalum album* showed better shoot growth under 75 per cent shade in the nursery stage (Kamalolbhavan, 2002; Singh, 2008).

Hence it is clear that plant species respond to varying light conditions in a variety of ways with regard to shoot growth parameters and the responses differ from one species to another species. The response may sometimes vary in accordance to the environmental conditions as plant responds to an array of environmental factors.

2.2.2 Effect of shade on leaf growth parameters

In seedlings of *Guarea gindimia*, larger leaves were produced in shade, but with thinner blades and lower specific weight (Fischer and Hsiao, 1968). Wadsworth and Lawton (1968) conducted studies on the effect of shade in *Pinus caribea, Eucalyptus deglupta* and *Khaya grandifolia* seedlings and reported an increase in leaf area ratio with increase in shade. In maple and aspen, increase in shade reduced the leaf thickness while number of layers and length of palisade cells increased in the intercellular spaces in spongy parenchyma. In oak and birch, however, shading had less marked effect on structure and thickness of leaf (Malkina and Kovalev, 1973). On the contrary, Scifres *et al.* (1973) reported that increase in shading decreased leaf area of seedlings of *Prosopis glandulosa*. In *Betula pendula* and *B. pubescens* seedlings, shading was found to increase the specific leaf area with a decrease in leaf mesophyll thickness and amount of chlorophyll per unit area of leaf (Nygren and Kellomaki, 1983). Masarovicova (1985) reported that *Fagus sylvtica* grown under different shade levels showed an increase in average leaf area, specific leaf area and leaf mass with increased light intensity. Singh (1986) studied the effect of light intensity on growth and yield of rain fed cotton and found that low irradiance increased the Leaf Area Ratio (LAR), but decreased the relative growth rate, leaf area and net assimilation rate.

Studies by Bush and Auken (1987) using *Prosopis glandulosa* seedlings revealed that maximum leaf and leaf dry weight were produced as a result of full sunlight. In *Acacia tortilis* leaf area ratio increased with decreasing light intensity (Smith and Shackleton, 1988). In *Betula pendula*, as PAR decreased, reduction in leaf extension was observed. However, in *Acer pseudoplantanus,* it had no effect (Taylor and Davies, 1988). *Shorea trapezifolia* seedlings showed no effect with regard to number of leaves when grown in partial shade or full sunlight (Ashton and Zoysa, 1989). Fitter and Ashmore (1989) found that *Veronica montana* seedlings were unaffected by supplementary far red radiation, while *V.persica* showed a reduction in leaf area in response to supplementary far red radiation. Hazra (1989) reported that there was an increase in the leaf production in pulses, for plants exposed to sunlight when compared to those under tree canopy. The seedlings of *Nothofagus procera* when grown under partial shade resulted in the production of less number of leaves (Igboanugo, 1990).

Allard *et al.* (1991) reported an increase in leaf area under shade in tall fescue grass. Low irradiance was found to increase the leaf area ratio, but decreased the relative growth rate and net assimilation rate. Callaway (1992) studied the changes in leaf area of *Quercus lobata*, *Q. Douglas* and *Q agrifolia* seedlings when grown under 10 per cent, 30 percent and 100 percent sunlight. Total leaf area of *Q,lobata and Q douglasii* did not increase due to shade whereas at 10 per cent shade, *Q agrifolia* seedlings produced greater leaf area.

Potted seedlings of *Acacia mangium*, *A.auriculiformis* and *A.mearnsii* were grown under different shade condition. Leaf area was reported to be in maximum in *A.mearnsii* and least in *A.auriculiformis* due to shade. The chlorophyll ratios were found to be reduced with decrease in light levels (Lovelock, 1992). In *Pongamia pinnata*, the leaf area was found to be increased due to increase in shade (Naidu and Swami, 1993). *Ailanthus triphysa* and *Leucaena leucocephala* seedlings showed maximum leaf weight under 25 per cent shade while *Azadirachta indica* showed the maximum weight under 50 per cent shade (Vimal, 1993).

Sharma *et al.* (1994) studied the growth behaviour of *Enicostemma littorale* grown under light and shade conditions. The number of leaves and branches was enhanced when grown under shade compared to full sunlight. Gross *et al.* (1996) has reported the effect of shade on stomatal conductance, net photosynthesis, photochemical efficiency and growth of oak saplings in relation to full and 50 per cent sunlight. Stomatal conductance and photosynthesis were found to be increased in open field while shaded plants produced larger leaves with fewer stomata per unit leaf area.

Hampson *et al.* (1996) conducted a study to quantify the effect of shade on reproduction and photosynthetic rate in seedlings of Hazelnut, a shade tolerant species. Plants were grown under 30,47,63,73 and 92 per cent shade levels. Leaf area increased by 49 per cent and chlorophyll concentration by 157 per cent as shading increased from 0 to 92 per cent. The 92 per cent shading treatment reduced specific leaf wight, stomatal density and light compensation point compared to the control. Influence of shade on specific leaf weight, leaf thickness and internal structure of leaves of *Euonymum japonicus* cv. Luna was studied by Hosni and Shehata (1996) in Egypt. Compared to control, shade increased leaf area with reduced leaf thickness per leaf. Leaf fresh weight was found to be reduced, when grown under 65 per cent shade. The specific leaf weight was also reduced by shading. Moreover shading reduced the thickness of palisade layer by 37 to 45 per cent..

Studies on seedling development under varying photon flux density (PFD) and spectral quality (red to far red) along with various shade levels of 40, 12 and 3 per cent PFD revealed that total height, internode distance, stem length, leaf area, percentage allocation to leaf, stem and root mass, specific leaf mass, mean leaf area and stomatal density were dependent on light intensity (Lee *et al.,* 1996). Mazzei et al. (1998) studied the growth of *Schefflera morototoni* seedlings in the nursery at 0, 50, 70 and 90 per cent shade. Seedlings grown under open recorded the smallest average with regard to all growth parameter except for root and shoot ratio which was the least under 90 per cent shade. Generally, an intermediate shade was found most favourable for development. Studies done on some broad leaved trees and conifers revealed that more shade tolerant species generally possessed a lower leaf area ratio. Suk and Ja (1998) studied the growth and flowering of *Orostachys iwarenge* as influenced by day length and light intensity. Leaf width and leaf length increased more under short or intermediate photoperiods than under long day conditions the leaf number decreased significantly with increase in shade. In shade, leaf orientation turned downward as against upward orientation in full sunlight.

The highest leaf area was recorded in *Artocarpus hirsutus* under shade (Gopikumar and Bindu, 1999). Vyas and Nein (1999) studied the effect of shade on growth of *Cassia angustifolia.* Shade was found to increase node number, leaf number, leaf area and length of internodes. The leaf area of plants exposed to shade also increased and followed the pattern similar to other growth parameters. The leaf stem ratio and leaf area ratio increased by 37.4 and 30.4 per cent respectively at 25 per cent shade compared to unshaded plants. Studies conducted at Vellanikkara revealed that in *Grevillea robusta* and *Tectona grandis* seedlings, shade reduced leaf area, leaf size and leaf dry weight (Saju *et al.,* 2000). There was a consistent trend for higher specific leaf area (SLA) and leaf area ratio (LAR) at lower growth light regimes in *Olea europaea* and *Podocarpus falcatus* (Fetene and Feleke, 2001). Seedlings of *Paulownia tomentosa* grown in shade had lower relative growth rates (RGR) and higher specific leaf areas (SLA) and leaf area ratios than plants in other light treatments. (Longbrake and McCarthy, 2001).Specific Leaf Area (SLA) increases; whereas Leaf Weight Ratio (LWR) decreases, indicating that increasing shade percentage could decrease leaf thickness (Hadi *et al.,* 2006).

2.2.3 Effect of shade on growth of root

The growth and development of roots in relation to light availability was studied by many scientists. Seedlings of *Pinus dorsifolia* showed a reduction in root weight when grown under shade conditions (Negisi and Magi, 1986). The stem to shoot ratio of *Pinus koraiensis* was found to increase when grown under shade (Kim, 1987).

In *Pinus palustris* and *P.taeda* seedlings, root growth showed greatest response to light when grown in full sunlight conditions (Barret, 1989). Burmeister and Auken (1989) reported an increase in number and weight of root nodules with increasing light intensity. Seedlings of *Leucaena leucocephla* and *Azadirachta indica* showed maximum dry root weight when grown in open and minimum when grown under 75 per cent shade. However, *Ailanthus triphysa* recorded maximum root dry weight under 25 per cent and minimum under full sunlight (Vimal, 1993).

Kung *et al.* (1998) studied the root to shoot algometry and root architecture of understorey saplings grown in deciduous forests. Root to shoot ratio was found to be decreased rapidly with increasing plant height for sapling shorter than 1.5 m. Less shade tolerant species showed smaller root:shoot ratio. The planting depth was not found to be significantly related to shade tolerance.

Influence of light on the growth of nine tree species was studied by Reich *et al.* (1998). They found that under full sunlight conditions, the root length per unit plant mass i.e root length ratio (RLR) increased in all the species. The shade intolerant deciduous tree species showed higher Relative Growth Rate (RGR) and specific root length (SRL), compared to evergreen species. Variations in interspecific RGR under high and low light intensities were found to be positively correlated with SRL and RLR.

A study was conducted to investigate the effect of different light conditions on germination and seedling growth of some selected forest tree species by Chathurvedi and Bajpai (1999) under three light conditions viz., semi shade, shade and full sunlight. The study revealed that root length was the maximum under semi shady condition in *Bridelia retusa and Holarrhaena antidysenterica*, while in *Lagerstroemia* *parviflora and Wrightia tinctoria,* it was maximum in full sunlight. Root to shoot ratio was highest under shady condition in *Holorrhena antidysenterica*, *L.parviflora* and *W.tinctoria*. The dry weight of root was found to be the maximum when grown under full sunlight in *Grevillea robusta* and *Tectona grandis,* whereas *Ailanthus triphysa* seedlings recorded more root weight when grown under shade (Saju *et al.*, 2000).

Hence, it can be concluded that root growth pattern differs from species to species with varying light qualities and quantities, which directly or indirectly affect the physiological functioning of the plant.

2.2.4 Effect of shade on biomass production

Robert (1971) found that in red oak (*Quercus rubra* L.), the tallest seedlings grown under 30 per cent light recorded lowest dry matter production. It was also observed that heavy shade leads to a higher concentration of nutrient in foliage. Lyapova and Palashev (1982) studied the growth of seedlings of *Pinus sylvestris, P nigra, Tilia tomentosa, Acer psuedoplatanus, Quercus petrae and Fagus sylvatica* grown under 100, 50, 25 and 12.5 percent of full sunlight up to eight years. The study revealed that except *Tilia tomentosa*, all other species produced greater aerial biomass under full sunlight. *Tilia tomentosa* performed well under 50 per cent shade.

Pathak *et al.* (1983) reported that *Leucaena leucocephala* seedlings raised under 45 per cent light conditions showed higher total dry matter production. Studies on the effect of shade on seedlings of *Shorea almon*, *Parashorea malaanonan*, *Anlsoptera thurifera*, S*horea polyspermum*, *Hopea parviflora* and *Vatica mangachopi* seedlings indicated that in all the species, maximum growth in height, diameter and dry weight were observed when plants were grown under full sunlight (Suzuki and Jacaline, 1986). Bush and Auken (1987) reported that light intensity increased stem length, dry weight and basal diameter of seedlings of *Prosopis glandulosa.* A decrease in illumination was found to result in reduction of diameter growth and number of side shoots resulting more dry matter production in seedlings of *Pinus sibirica* (Yushkov and Zavi'yalova, 1988).

The seedlings of *Platanus orientalis, Sorbus torminalis and Corylus avelana* were grown under 100, 50, 25 per cent of full sunlgiht to study the impact of shading on growth (Lyapova and Palashev, 1988). Seedling biomass was seen unaffected due to shade in *Quercus agrifolia, Q.douglasii and Q.lobata* (Callaway, 1992).

Seedlings of *Amphopterugium adstringens, Caesalpinia eriostachys, C.playtylotia, Apoplanesia paniculata and Helicarpus pollidus* were grown under two light treatments viz. high (400µ mol m^{-2} s^{-1}) and low (80µ mol m^{-2} s^{-1}) to study the impact of light on growth. In all the species, relative growth rate and net assimilation rate were greater when grown under high light treatments (Rincon and Huante, 1993). Morphological features of the semi-parasite *Santalum album* Linn. (Indian sandalwood) were examined on tree seedlings raised under different shade treatments by Barrett and Fox (1994). Treatment levels were varying from full sunlight to 80 per cent shade. They found that the level of shade significantly affected many morphological characteristics. Leaf area was the least in full sun and greater under all shade levels. Leaves were thicker, shorter and narrower in full sun than in 80 per cent shade. Leaf length/width ratio was greater when shade exceeded 50 per cent, petioles were shorter in 50 per cent and more shade. Stomatal numbers were higher and internodes longer in shade than in full sun. They also found that plant heights, leaf numbers, crown widths and stem diameters were not significantly different. Saxena *et al.* (1995) reported that seedling growth of *Dalbergia sissoo* and *Acacia catechu* was maximum under lower shade treatment, while *Casuarina equisetifolia* showed maximum growth in unshaded conditions. Root to shoot ratio was found to be lowest in *Casuarina equisetifolia*. In all the species, production of stem dry matter was greater under higher shade conditions. *Leontodon hispidus*, a perennial bush, showed reduced dry weight under low PPFR (photosynthetic photon fluence rates) while *Orchis morio*, an orchid showed only slight reduction in dry weight due to low PPFR (McKendrick, 1996).

Seedlings of *Betula peapyrifera*, *B.alleghaniensis*, *Ostrya virginiana*, *Acer saccharum* and *Quercus rubra* were grown to study the effects of light and N and their inter relationships on survival and growth. In very low light conditions, greater growth and survival rates were shown by shade tolerant species, while shade intolerant species performed best under higher light conditions. The concluded that light requirement depended on species (Walters and Reich, 1996).

A study done to find out the effect of shade (0, 55 and 95%) on *Hibiscus syriacus* L. showed that the shoot lengths of three cultivars were longer in shade grown plants compared to control plants. However, compared to control, there was no much variation in dry matter production. There was also a reduction in root dry weight of some cultivars (Yoo and Kim, 1997).

Cruz (1997) studied the effect of shade on growth of *Dicanthium artistatum* seedlings grown under full sunlight and under *Gliricidia sepium* and *Leucaena leucocephala* with light transmission levels ranging from 80 to 30 per cent of insolation. Dry matter production was not found to be reduced by reduction in PAR. Rezende *et al.* (1998) observed that *Cryptocaria aschersoniana* seedlings recorded more dry weight of roots, leaves and stems when grown under 50 per cent light conditions. Mazzei *et al.* (1998) also conducted similar studies in *Schefflera morototoni* seedlings, a shade loving plant. Intermediate (50-70%) shades were found to be best suited for this species with regard to all growth attributes. Vyas and Nein (1999) reported that increasing shade increased the dry matter accumulation in *Cassia angustifolia*. Increase of leaf dry weight was more, when compared to that of stem. The study carried out in four species of Pacific Northwest conifer seedlings when grown under different levels of shade revealed that shootroot ratio significantly higher in 75 per cent shade than in 0 per cent shade (Khan *et al.*, 2000). Kamalolbhavan (2002) found that 50 per cent shade is the most favourable for the growth of sandal. Shade decreased total biomass for all species, with loblolly pine showing the greatest shade-induced growth reduction. As light availability increased, all species decreased biomass allocation to leaf tissue (mass and area) and showed a trade-off between allocation to leaf area at a given plant mass (LAR) and net gain in mass per unit leaf area (net assimilation rate, NAR). This trade-off largely reflected declines in SLA with increasing light(Montgomery, 2004). *Quercus suber* seedlings grown under moderate shade (15% of full sunlight) accumulated similar amount of biomass than those grown under more illuminated environments by increasing their SLA (Puertolas *et al.*, 2008).

Biomass production is a function of light and different species responds differently to the varying light conditions. The production of fresh weight and dry weight of the parts of the plant, which adds directly to biomass, also depends on the amount of light reaching the plant and the actual amount needed by the plant. Hence, it can be concluded that different plant species need different light condition according to which they respond physiologically and morphologically.

Materials and Methods

MATERIALS AND METHODS

The present study was conducted at College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur with an objective of studying the effect of various pre treatments on germination of seeds of *Pongamia pinnata* and the effect of varying levels of shade on growth and vigour of seedlings of *Pongamia pinnata* grown in the nursery.

3.1 Location of the study

The College of Forestry, Kerala Agricultural University, Vellanikkara, comes under the Madakkathara Panchayat of Thrissur district. The study area lies between 10°32' N latitude and 76°26' E longitude. The climate is warm humid with an average annual rainfall of 3000 mm. The temperature variation during the day is not very wide. The soil is of lateritic origin. The area has an altitude of about 40 m above MSL. The mean maximum temperature ranged from 28.4°C (July) to 36.0°C (March) and mean minimum temperature from 21.6°C (January) to 25°C (April) during the study period.

3.2 Collection of seeds

Seeds of *Pongamia pinnata* were collected during April - May from Shimoga seed source of the Karnataka state. Healthy, matured and cleaned seeds only were used for the study (Plate 1).

3.3. Seed treatments

Healthy, viable and uniform seeds were subjected to the following treatments:

1. Treating the seeds with cold water for 20 hours
2. Treating the seeds with hot water (50°C) for 15 minutes
3. Treating the seeds with Con. H_2SO_4 for 2 minutes
4. Treating the seeds with GA_3 (100 ppm) for 20 minutes
5. Sowing the seeds after removing seed coat
6. Control (Untreated)

Plate 1. Seeds of *Pongamia pinnata* (Linn.) Pierre

The pre-treated seeds were sown in standard nursery beds of the size 12 m x 1.2 m x 0.3 m. Daily observation was taken on the germination of seeds from the nursery bed.

3.4 Seedlings establishment and care

One and half month old, uniform vigorous seedlings were planted in 200 gauge polythene covers of 40 cm x 20 cm size filled with standard potting media containing soil, sand and decomposed cow dung prepared in 1:1:1 ratio. Before uprooting the seedlings, the nursery beds were watered so as to facilitate easy removal of the seedlings. The seedlings after planting in polythene covers were kept in shade for a week to overcome the transplantation shock.

The established seedlings after one week were arranged in nursery for taking the observations. The effect of seed treatments on the various growth parameters like height, collar diameter, number of leaves and number of primary branches were recorded for eight weeks. Watering of the seedlings was done daily. Weeding and necessary plant protection measures were also adopted periodically.

3.5 Shade levels

Different levels of shade was made and shade was provided using shade nets. The shade houses were constructed in the nursery towards the north south direction. The following four shade levels were tested.

1. T_1 -25 per cent shade
2. T_2 -50 per cent shade
3. T_3 – 75 per cent shade
4. T_4 - Full sunlight

3.6 Experimental layout

The study was laid out in CRD with four shade levels (Plate 2), each having five replications. The number of bags for each treatment was 100, making the total number of bags to 400 for the entire study. The seedlings were placed under different shade levels (Plate 3, 4, 5 and 6). The observations were recorded at fortnightly intervals for a period of six months.

Plate 2. Overview of the experimental plot

3.6 Observations

3.6.1 Seed characteristics

3.6.1.1 Germination percentage

Germination percentage was calculated by using the following formula.

$$\text{Germination percentage} = \frac{\text{Number of seeds germinated}}{\text{Total number of seeds sown}} \times 100$$

3.6.1.2 Days for germination

The number of days taken for germination was recorded.

3.6.1.3 Germination value

Number of seeds germinated on each day and the days taken for germination were recorded. Cumulative germination percentage was calculated for each treatment at the end of the test. Germination value was calculated using the following formula as suggested by Czabator (1962).

G.V = Final M.D.G x P.V

where,

G.V. is the germination value

Final M.D.G. is final mean daily germination (Final M.D.G. is calculated at the cumulative percentage of full seed germination at the end of the test divided by the number of days from sowing to the end of the test).

P.V. is the Peak value (the maximum mean daily germination recorded at any time during the test).

Plate 3. Seedlings under 25 per cent shade

Plate 4. Seedlings under 50 per cent shade

Plate 5. Seedlings under 75 per cent shade

Plate 6. Seedlings under full sunlight

3.7.2 Shoot growth parameters

3.7.2.1 Height

The height of individual seedlings was measured from collar region to terminal bud at fortnight interval using a meter scale and expressed in centimeters.

3.7.2.2 Collar diameter

The collar diameter was measured using a digital vernier calliper at fortnightly interval and expressed in millimeters.

3.7.2.3 Number of leaves

The number of leaves produced by individual seedlings was counted at fortnightly intervals.

3.7.2.4 Number of primary branches

The number of primary branches produced by individual seedlings was counted at fortnightly intervals.

3.7.3 Growth analysis

3.7.3.1 Relative growth rate

The Relative Growth Rate (RGR) of plant dry weight was found out by using the following formula:

$$RGR = \frac{\mathrm{Ln}\, W_2 - \mathrm{Ln}\, W_1}{t_2 - t_1}$$

W_1 and W_2 are dry weights at the beginning and the end of the sampling period, t_1 and t_2 are the dates of sampling respectively, and Ln is the natural logarithm of the numbers (McGraw and Garbutt, 1990).

3.7.3.2 Leaf area

Individual and total leaf area were measured at periodic interval using leaf area meter (LICOR) and expressed as cm^2.

3.7.3.3 Specific leaf area (SLA)

Specific leaf area was found out by using the following formula:

$$SLA = \frac{\text{Leaf area}}{\text{Leaf dry weight}}$$

3.7.3.4 Specific leaf weight (SLW)

Specific leaf weight was found out by using the following formula:

$$SLW = \frac{\text{Leaf weight}}{\text{Leaf area}}$$

3.7.3.5 Leaf area ratio (LAR)

Leaf area ratio was found out by using the following formula:

$$LAR = \frac{\text{Leaf area/ plant}}{\text{Whole plant dry weight}}$$

3.7.3.6 Leaf weight ratio (LWR)

Leaf weight ratio was found out by using the following formula:

$$LWR = \frac{\text{Dry weight of leaves}}{\text{Plant dry weight}}$$

3.7.3.7 Number of stomata

Leaf samples were collected representing each treatment to find out the stomatal frequency. A thin layer of quick fix was spread on the under surface of leaf and the membranous layer was peeled off carefully. The number of stomata per field was counted using a binocular microscope and stomata per mm^2 was estimated.

3.7.4 Root growth parameters

Destructive sampling was done at monthly interval for a period of six months and the following root observations were made.

3.7.4.1 Length of roots

Length of roots was measured from the collar region to the tip of the longest root and expressed in centimeter.

3.7.4.2 Spread of roots

Spread of roots was measured in both (mutually perpendicular) directions and average spread was worked out and expressed in centimeter.

3.7.4.3 Biomass production

3.7.4.3.1 Fresh weight of shoot and root

Representative seedlings were sampled from each treatment at monthly intervals for estimating the total biomass. The shoot and root portion of seedlings were separated and fresh weight was determined separately using precision balance and expressed in grams.

3.7.4.3.2 Dry weight of shoot and root

The shoot and root portion of the samples were dried separately in hot air oven at a temperature of 80^0 C$\pm5^0$C for about 24 to 48 hours. Dry weights were taken using a precision balance and expressed in grams.

3.7.5 Statistical analysis:

Treatment means of cumulative germination percentage, Final Mean Daily Germination, Peak Value, Germination Value and all the biometric observations were analysed using analysis of variance (Snedecor and Cochran, 1967). The superiority of treatment means were tested using Duncan multiple range test (DMRT) analysis.

Results

RESULTS

The present study on effect of seed treatments and shade on seedling growth dynamics of *Pongamia pinnata* (Linn.) Pierre in the nursery was carried out during 2007-09 at College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur. The salient finding of the study are furnished below.

4.1 Effect of seed treatments on germination behaviour of seeds of *Pongamia pinnata*

Germination percentage, Final Mean Daily Germination (FMDG), Germination Value (GV) and Peak Value (PV) were studied in relation to the germination characters of seeds treated with different seed treatments. The observations related to the above aspects are furnished in Table 1.

4.1.1 Germination percentage

The germination percentage showed significant difference among the seed treatments. Seeds treated with GA_3 (100 ppm) for 20 minutes (Figure 1) recorded highest germination percentage (35.21 %). The control (untreated) seeds showed 26.87 per cent germination followed by seeds treated with hot water (50°C) for 15 minutes (26.36%). It could be seen from the Table 1 that the seeds treated with Con. H_2SO_4 for 2 minutes showed lowest germination percentage (15.19 %).

4.1.2 Final Mean Daily Germination

The value of Final Mean Daily Germination (FMDG) varied significantly among the seed treatments (Table 1). Significantly higher (0.86) FMDG was observed by GA_3 (100 ppm) for 20 minutes treatment. The control (untreated) and seeds treated with hot water (50°C) for 15 minutes showed 0.7 and 0.68 FMDG respectively. Con. H_2SO_4 for 2 minutes treatment showed lowest FMDG (0.36).

4.1.3 Peak Value

The data pertaining to Peak Value (PV) is furnished in Table 1. Significant difference was observed in the PV for the seeds treated with various seed treatments. The maximum value

Table1. Effect of seed treatments on germination behaviour of seeds of *Pongamia pinnata*

Sl. No.	Treatment details	No. of days taken for germination	Germination percentage (%)	Final Mean Daily Germination	Germination value	Peak value
1	Cold water for 20 hours	19.75	19.20 (25.94^{a})	0.47^{ab}	0.22^{a}	0.46^{ab}
2	Hot water (50°C) for 15 minutes	19.00	26.36 (30.79^{ab})	0.68^{bc}	0.48^{ab}	0.68^{bc}
3	Con. H_2SO_4 for 2 minutes	23.00	15.19 (22.7^{a})	0.36^{a}	0.14^{a}	0.34^{a}
4	GA_3 (100 ppm) for 20 minutes	17.50	35.21 (36.61^{b})	0.86^{c}	0.82^{b}	0.93^{b}
5	Seed coat removed	20.25	20.35 (26.32^{a})	0.48^{ab}	0.28^{a}	0.49^{ab}
6	Control (Untreated)	20.75	26.87 (30.82^{ab})	0.70^{bc}	0.55^{ab}	0.69^{bc}
	F test	NS	*	*	*	**
	CD (0.05)	-	7.92	0.28	0.42	0.29
	SEm ±	2.17	3.71	0.13	0.20	0.14

NS –Non significant * Significant at 5 per cent level ** Significant at 1per cent level
Values in parentheses are arc- sine transformations

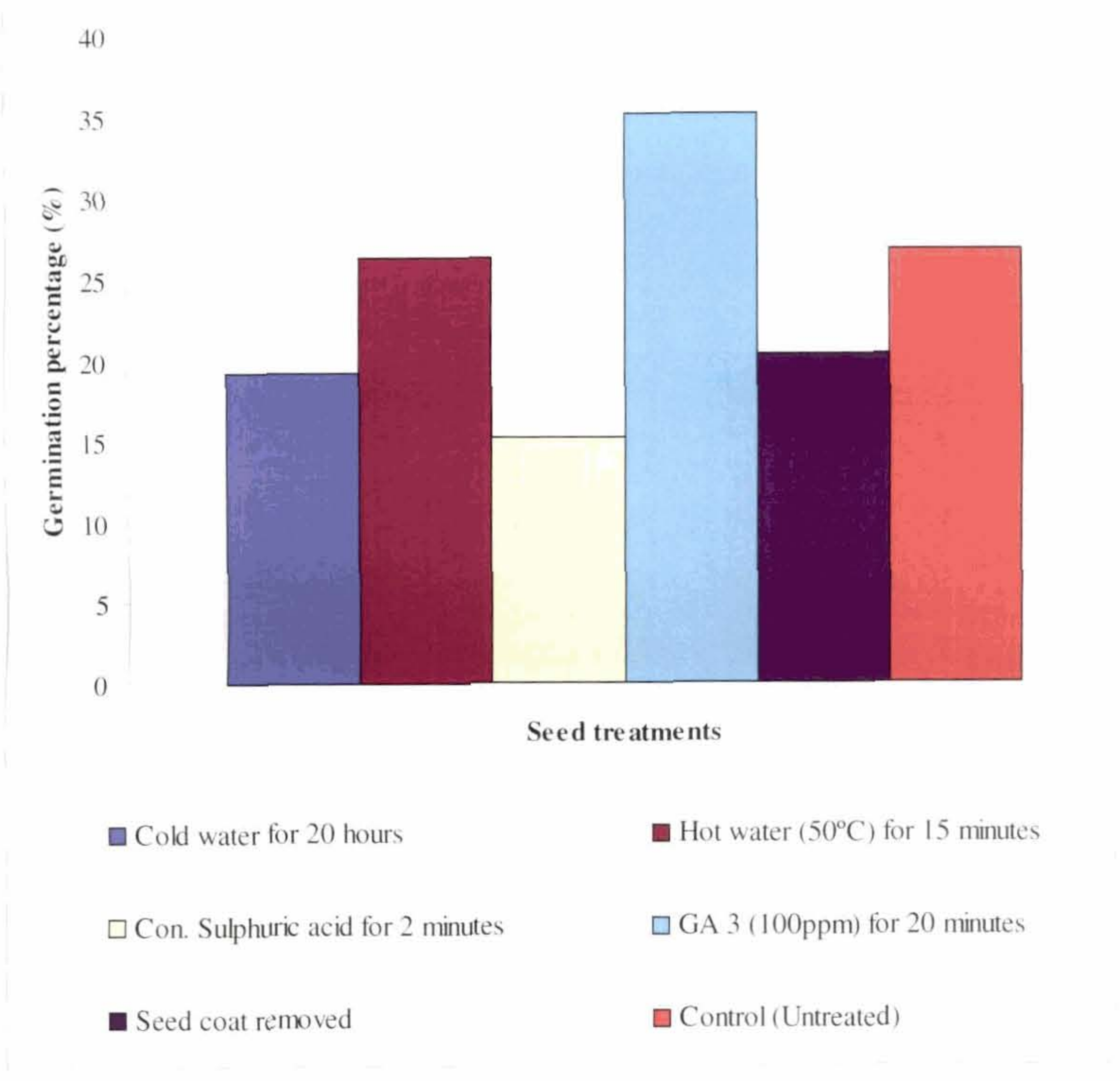

Figure 1. Effect of treatments on seed germination of *Pongamia pinnata*

(0.93) was recorded by GA_3 (100 ppm) for 20 minutes treatment while seeds treated with Con. H_2SO_4 for 2 minutes showed lowest (0.34) PV.

4.1.4 Germination value

Germination value of different seed treatments showed significant difference. The GA_3 (100 ppm) for 20 minutes treated seeds higher (0.82) Germination value (GV) and there was significant difference with rest other treatments. Seeds treated with Con. H_2SO_4 for 2 minutes recorded the lowest (0.14) GV (Table 1).

4.2 Effect of seed treatments on growth characters of seedlings of *Pongamia pinnata*

The observations on height, collar diameter, number of leaves, number of primary branches and total biomass are tabulated in Table 2 to 6.

4.2.1 Height

The data pertaining to seedling height recorded at weekly intervals are presented in Table 2 and Figure 2. The seed treatments showed significant difference for the first three weeks. During the first week the control (untreated) seeds produced the maximum height (11.41 cm) and significantly differed from other treatments like cold water for 20 hours and Con. H_2SO_4 for 2 minutes. The treatment with cold water for 20 hours recorded lowest value (7.08 cm) for height of the seedlings. At the end of second week, control (untreated) seeds produced the maximum height (12.22 cm). The treatments with Con. H_2SO_4 for 2 minutes recorded the lowest value (8.86 cm) for height of the seedlings. Similar trend was noticed during the third week also. The treatments did not induce significant effect during fourth, fifth and sixth week of study. However, during seventh and eighth week seed treatments showed significant effect on the height of seedlings. During the end of study the maximum height (18.93 cm) was recorded by cold water for 20 hours treatment and there was significant difference of this treatment with other treatments like hot water (50°C) for 15 minutes, Con. H_2SO_4 for 2 minutes, GA_3 (100 ppm) for 20 minutes and control (untreated) seeds. The lowest value (15.05 cm) was recorded by Con. H_2SO_4 for 2 minutes treatment.

Table 2. Effect of seed treatments on height (cm) of seedlings of *Pongamia pinnata* at weekly intervals

Sl. No.	Treatment details	Weeks							
		1	2	3	4	5	6	7	8
1	Cold water for 20 hours	7.08[a]	9.00[a]	11.15[ab]	13.04	14.72	16.16	17.55[b]	18.93[b]
2	Hot water (50°C) for 15 minutes	10.17[b]	11.32[b]	12.01[b]	12.90	13.90	14.90	15.87[ab]	16.83[ab]
3	Con. H_2SO_4 for 2 minutes	7.98[a]	8.86[a]	9.61[a]	10.72	11.89	12.87	13.96[a]	15.05[a]
4	GA_3 (100 ppm) for 20 minutes	10.37[b]	11.35[b]	12.22[b]	12.97	14.65	15.80	16.94[b]	18.08[b]
5	Seed coat removed	10.84[b]	11.50[b]	11.93[b]	12.61	13.61	14.87	15.86[ab]	16.84[ab]
6	Control (Untreated)	11.41[b]	12.22[b]	12.89[b]	13.35	14.54	15.59	16.70[b]	17.80[b]
	F test	**	**	**	NS	NS	NS	*	*
	CD (0.05)	1.81	1.80	1.60	-	-	-	2.10	2.12
	SEm ±	0.85	0.84	0.75	0.9	0.97	1.00	0.98	1.00

NS –Non significant   * Significant at 5 per cent level   ** Significant at 1 per cent level

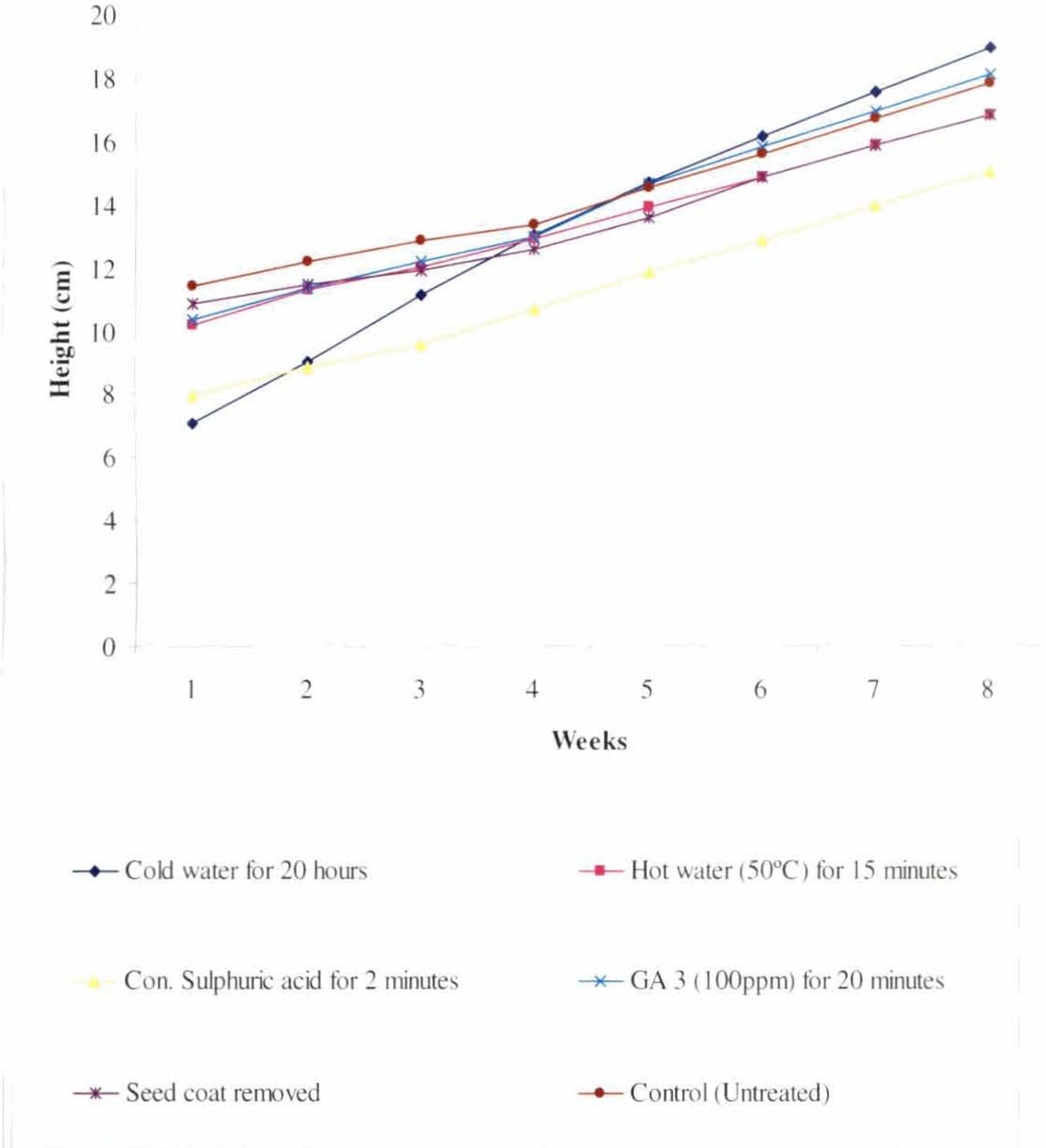

Figure 2. Effect of seed treatments on height (cm) of seedlings of *Pongamia pinnata*

4.2.2 Collar diameter

The observation with regard to this parameter is presented in Table 3 and Figure 3. Seed treatments showed significant difference for the collar diameter of the seedlings during the entire period of study. At the end of the study highest collar diameter (5.76 mm) was recorded by cold water for 20 hours treatment followed by hot water (50°C) for 15 minutes and control. The lowest collar diameter (4.22 mm) was recorded by seedlings obtained from seed coat removed treatment

4.2.3 Number of leaves

The data pertaining to effect of seed treatments on number of leaves is presented in Table 4. The seed treatments showed significant difference for number of leaves produced by the seedlings during first, second, third, fifth and eighth week of observation. During the end of study period maximum number of leaves (20.5) was produced by hot water (50°C) for 15 minutes treatment and there was significant difference with other treatments like Con. H_2SO_4 for 2 minutes, GA_3 (100 ppm) for 20 minutes, seed coat removed and control (untreated) seeds. The lowest value (16.15) was recorded by Con. H_2SO_4 for 2 minutes treatment.

4.2.4 Number of primary branches

The observation with regard to this parameter is presented in Table 5. The seed treatments showed significant difference for number of primary branches produced by the seedlings during first, second, third and eighth week of observation. At eighth week of observation the maximum value (5.64) was recorded by GA_3 (100 ppm) for 20 minutes and there was significant difference to other treatments like Con. H_2SO_4 for 2 minutes, seed coat removed and control. The lowest value (4.24) for number of primary branches recorded Con. H_2SO_4 for 2 minutes treatment.

4.2.5 Shoot fresh weight and dry weight

The data furnished in Table 6 indicates that the seed treatments did not show significant difference for shoot fresh weight and dry weight of the seedlings during the two months of study period.

Table 3. Effect of seed treatments on collar diameter (mm) of seedlings of *Pongamia pinnata* at weekly intervals

Sl. No.	Treatment details	Weeks							
		1	2	3	4	5	6	7	8
1	Cold water for 20 hours	3.01^{bc}	3.34^{b}	3.90^{b}	4.58^{c}	4.76^{b}	5.11^{c}	5.44^{c}	5.76^{c}
2	Hot water (50°C) for 15 minutes	2.69^{ab}	3.13^{b}	3.54^{b}	3.91^{b}	4.13^{a}	4.68^{bc}	4.89^{bc}	5.10^{b}
3	Con. H_2SO_4 for 2 minutes	2.27^{a}	2.6^{a}	3.04^{a}	3.34^{a}	3.61^{a}	3.89^{a}	4.16^{a}	4.42^{a}
4	GA_3 (100 ppm) for 20 minutes	3.01^{bc}	3.11^{b}	3.64^{b}	3.83^{ab}	4.02^{a}	4.37^{ab}	4.61^{ab}	4.84^{ab}
5	Seed coat removed	2.92^{bc}	2.92^{ab}	3.5^{b}	3.77^{ab}	3.64^{a}	3.90^{a}	4.2^{a}	4.22^{a}
6	Control (Untreated)	3.39^{c}	3.63^{b}	3.91^{b}	3.95^{b}	4.18^{a}	4.36^{ab}	4.63^{ab}	4.88^{ab}
	F test	**	**	**	**	**	*	**	**
	CD (0.05)	0.48	0.39	0.42	0.54	0.57	0.69	0.61	0.63
	SEm ±	0.23	0.18	0.20	0.25	0.27	0.32	0.28	0.29

* Significant at 5 per cent level ** Significant at 1 per cent level

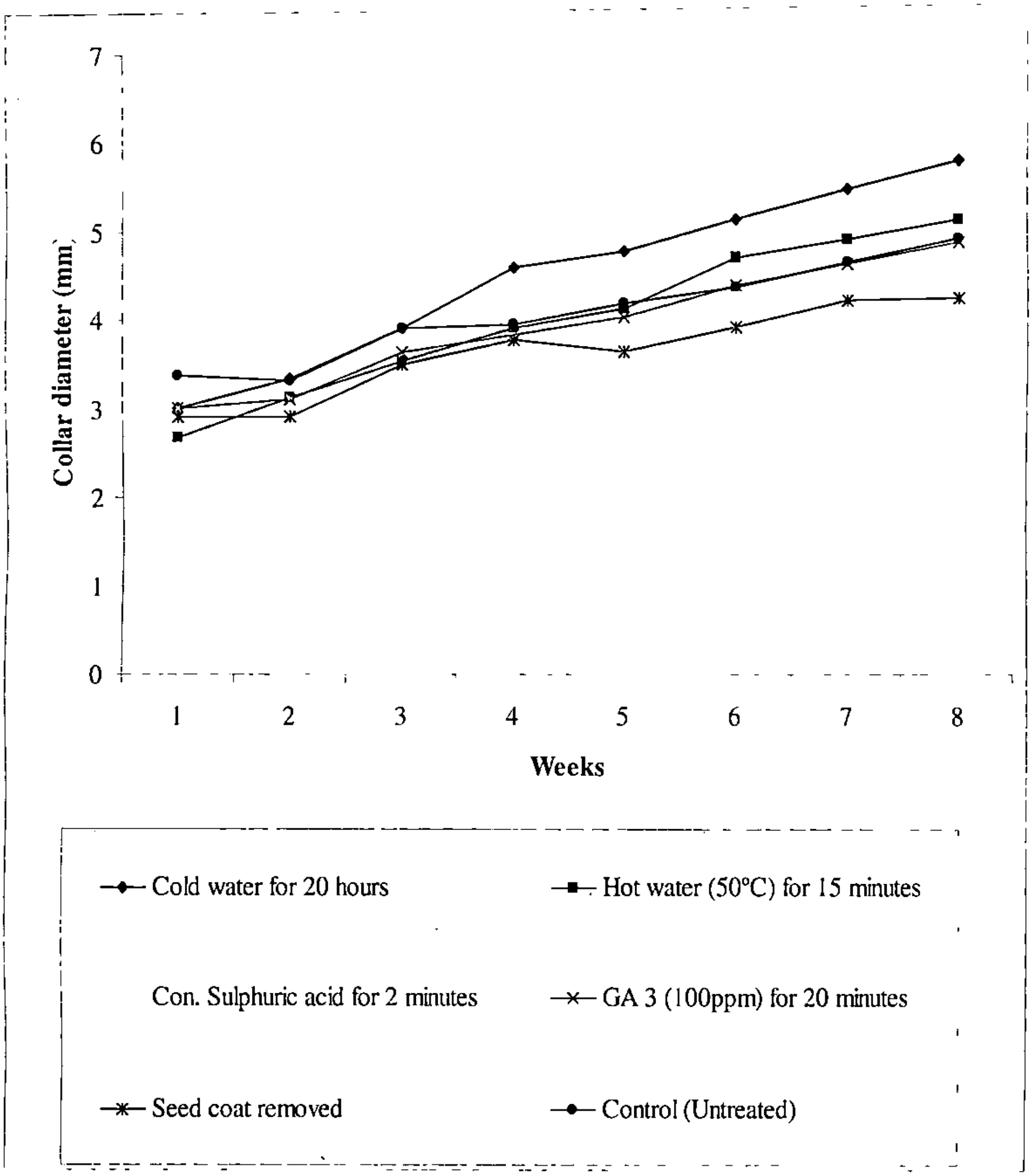

Figure 3. Effect of seed treatments on Collar diameter (mm) of seedlings of *Pongamia pinnata*

Table 4. Effect of seed treatments on number of leaves of seedlings of *Pongamia pinnata* at weekly intervals

Sl. No.	Treatment details	Weeks							
		1	2	3	4	5	6	7	8
1	Cold water for 20 hours	7.66^{b}	8.69^{bc}	10.47^{b}	14.89	14.00^{b}	16.80	18.64	20.47^{c}
2	Hot water (50°C) for 15 minutes	7.94^{b}	8.44^{bc}	9.86^{b}	11.83	13.50^{b}	15.69	18.1	20.50^{c}
3	Con. H_2SO_4 for 2 minutes	6.04^{a}	6.53^{a}	7.48^{a}	9.47	11.04^{a}	13.81	14.98	16.15^{a}
4	GA_3 (100 ppm) for 20 minutes	8.44^{b}	9.27^{bc}	10.50^{b}	12.30	14.05^{b}	16.14	18.06	19.97^{bc}
5	Seed coat removed	8.16^{b}	8.25^{b}	9.91^{b}	11.25	13.44^{b}	15.25	16.69	18.14^{abc}
6	Control (Untreated)	8.75^{b}	9.83^{c}	10.64^{b}	12.14	14.19^{b}	14.95	16.24	17.53^{ab}
	F test	*	**	**	NS	*	NS	NS	*
	CD (0.05)	1.49	1.40	1.33	-	1.79	-	-	2.73
	SEm ±	0.70	0.66	0.62	1.93	0.84	1.18	1.18	1.28

NS –Non significant * Significant at 5 per cent level ** Significant at 1 per cent level

Table 5. Effect of seed treatments on number of primary branches of seedlings of *Pongamia pinnata* at weekly intervals

Sl. No.	Treatment details	Weeks							
		1	2	3	4	5	6	7	8
1	Cold water for 20 hours	1.11[ab]	1.41[a]	1.92[b]	2.66	3.16	4.00	4.71	5.41[b]
2	Hot water (50°C) for 15 minutes	1.50[abc]	1.52[a]	1.97[b]	2.75	3.25	4.08	4.78	5.47[b]
3	Con. H_2SO_4 for 2 minutes	0.98[a]	0.94[a]	1.30[a]	2.26	2.48	3.24	4.49	4.24[a]
4	GA_3 (100 ppm) for 20 minutes	1.77[c]	2.00[a]	2.36[b]	3.00	3.42	3.85	4.75	5.64[b]
5	Seed coat removed	1.64[bc]	1.50[a]	2.08[b]	2.39	3.11	3.92	4.32	4.72[ab]
6	Control (Untreated)	1.55[bc]	1.69[a]	2.02[b]	2.39	3.14	3.51	3.96	4.41[a]
	F test	*	*	*	NS	NS	NS	NS	*
	CD (0.05)	0.50	0.52	0.60	-	-	-	-	0.98
	SEm ±	0.24	0.24	0.28	0.38	0.36	0.47	0.6	0.46

NS –Non significant   * Significant at 5 per cent level

Table 6. Effect of seed treatments on total biomass (g) of seedlings of *Pongamia pinnata* at monthly intervals

Sl. No.	Treatment details	Months				Months			
		1		2		1		2	
		Shoot fresh weight (g)	Shoot dry weight (g)	Shoot fresh weight (g)	Shoot dry weight (g)	Root fresh weight (g)	Root dry weight (g)	Root fresh weight (g)	Root dry weight (g)
1	Cold water for 20 hours	3.41	1.22	5.48	1.63	1.65	0.42	4.64	0.94
2	Hot water (50°C) for 15 minutes	3.76	1.14	7.02	1.96	1.68	0.43	3.87	0.82
3	Con. H_2SO_4 for 2 minutes	2.20	0.77	4.42	1.35	1.76	0.45	2.43	0.56
4	GA_3 (100 ppm) for 20 minutes	2.46	0.69	5.78	1.60	2.28	0.48	3.52	0.71
5	Seed coat removed	2.16	0.51	4.33	1.19	1.61	0.34	2.97	0.62
6	Control (Untreated)	4.90	1.49	6.70	1.60	2.67	0.58	3.04	0.78
	F test	NS	NS	NS	NS	NS	NS	NS	NS
	CD (0.05)	-	-	-	-	-	-	-	-
	SEm ±	0.99	0.31	1.4	0.47	0.46	0.12	1.21	0.30

NS- Non significant

4.2.6 Root fresh weight and dry weight

Data pertaining to effect of seed treatments on root fresh weight and dry weight is presented in Table 6. The observation revealed that seed treatments could not impose any significant effect on root fresh weight and dry weight during the study period.

4.2.7 Root growth parameters

The root growth parameters such as root length, root spread and number of secondary roots are tabulated in Table 7.

4.2.7.1 Root length, root spread and number of secondary roots

The observations recorded for root length, root spread and number of secondary roots revealed that there was no significant difference between the seed treatments. However, at the end of two months, the root length (Table 7) ranged between 11.38 cm to 17.03 cm, while the root spread and secondary root production ranged from 7.63 cm to 9.63 cm and 4.25 cm to 5.50 cm respectively.

4.3 Effect of shade on seedling growth

4.3.1 Height

The observations pertaining to the effect of shade on height of seedlings of *Pongamia pinnata* was recorded at fortnight intervals and are furnished in Table 8 and Figure 4. Effect of shade on seedling height was not evident in the present study. However, the total height increment ranged from 24.32 cm to 35.41 cm (Table 8). At the end of study, maximum (54.96 cm) height was recorded for seedlings raised under 50 per cent shade with an increment percent of 64.43. The least height was recorded by seedlings kept under 75 per cent shade (44.58 cm) with an increment of 54.55 percent.

Table 7. Effect of seed treatments on root parameters of seedlings of *Pongamia pinnata* at monthly intervals

Sl. No.	Treatment details	Root length (cm)		Root spread (cm)		Number of secondary roots	
		Months		Months		Months	
		1	2	1	2	1	2
1	Cold water for 20 hour	10.68	14.58	7.25	9.63	4.25	5.00
2	Hot water (50°C) for 15 minutes	9.63	11.38	7.63	9.63	4.25	4.50
3	Con. H_2SO_4 for 2 minutes	9.18	12.73	6.90	7.63	3.25	4.50
4	GA_3 (100 ppm) for 20 minutes	10.70	14.73	5.35	7.75	4.25	5.50
5	Seed coat removed	14.20	17.03	6.15	8.75	3.00	4.25
6	Control (Untreated)	12.25	14.55	6.88	9.00	4.25	4.75
	F test	NS	NS	NS	NS	NS	NS
	CD (0.05)	-	-	-	-	-	-
	SEm ±	1.73	2.67	1.56	2.08	1.23	0.80

NS –Non significant

Table 8. Effect of shade on height (cm) of seedlings of *Pongamia pinnata* at fortnightly intervals

Treatment details	Fortnight												Total increment (cm)	Increment percentage (%)
	1	2	3	4	5	6	7	8	9	10	11	12		
25 per cent shade	24.77	28.50	31.37	32.87	35.00	37.61	39.31	49.20	49.91	52.21	51.21	52.99	28.22	53.26
50 per cent shade	19.55	21.12	23.41	26.85	30.00	33.69	38.6	44.86	49.01	51.52	50.53	54.96	35.41	64.43
75 per cent shade	20.26	20.93	23.42	23.02	26.70	28.46	32.26	39.38	41.60	42.98	44.00	44.58	24.32	54.55
Full sunlight	20.67	22.91	24.86	28.27	32.41	34.00	35.56	43.60	46.71	47.71	48.38	50.30	29.63	58.91
F test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
CD (0.05)	-	-	-	-	-	-	-	-	-	-	-	-		
SEm ±	3.67	3.55	3.89	3.49	3.33	3.33	4.19	4.14	5.42	5.43	5.41	5.71		

NS - Non significant

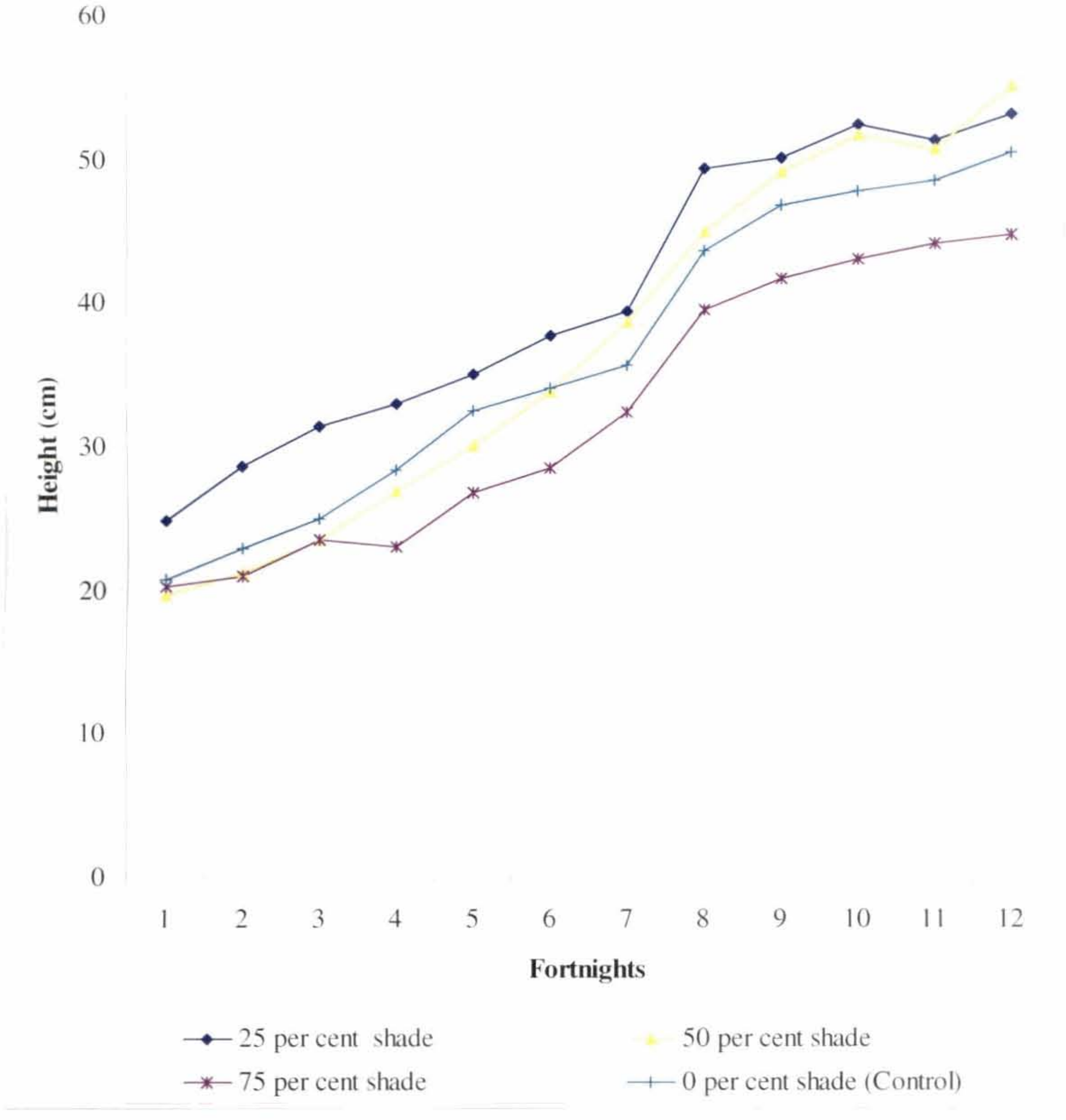

Figure 4. Effect of shade on height (cm) of seedlings of *Pongamia pinnata* at fortnightly intervals

4.3.2 Collar diameter

Data pertaining to the effect of shade on collar diameter of seedlings of *Pongamia pinnata* was recorded at fortnight intervals are furnished in Table 9.The observations revealed that shade could not impose any significant effect on the collar diameter of seedlings during the study period. However, during the end of study the total collar diameter increment ranged from 4.53 mm to 5.40 mm (Table 9). The highest (49.68 %) increment per cent was recoded by seedlings kept under 50 per cent shade and the lowest (44.25 %) increment per cent was recorded by seedlings under 25 per cent shade. The collar diameter trend for the seedlings is illustrated in Figure 5.

4.3.3 Leaf production

There exists significant difference between the shade treatments with regard to the number of leaves produced by the seedling (Table 10). For the first four fortnights there was no significant difference with respect to leaf production. However, during fifth, eighth and tenth fortnights there were significant difference in number of leaves produced by the seedlings. During the fifth fortnight, seedlings placed under full sunlight produced the maximum (33.06) number of leaves and there was significant difference to other treatments like 25 per cent, 50 per cent and 75 per cent shade treatment levels. The lowest number of leaves (24.26) was noticed in 75 per cent shade. At the eighth fortnight seedling grown under 50 per cent shade produced maximum number of leaves (32.26). The superiority of 50 per cent shade level with regard to other shade levels is clearly evident from the data. The lowest number of leaves (24.14) was recorded by seedlings kept under 75 per cent shade. At tenth fortnight the highest number of leaves were recorded in seedlings grown under full sunlight. The lowest number of leaves was recorded by seedlings grown under 50 per cent shade. During the end of study there was no significant effect of shade treatments on leaf production. However, data furnished in Table 10 indicates that the total increment in leaf production ranged from 6.70 to 12.64.

Table 9. Effect of shade on collar diameter (mm) of seedlings produced from seeds of *Pongamia pinnata* at fortnightly intervals

Treatment details	Fortnight												Total increment (mm)	Increment percentage (%)
	1	2	3	4	5	6	7	8	9	10	11	12		
25 per cent shade	5.71	6.54	7.25	7.81	8.08	8.30	8.51	8.94	9.19	9.70	9.88	10.24	4.53	44.24
50 per cent shade	5.47	6.07	7.37	7.97	8.24	8.74	8.97	8.85	9.41	9.67	10.25	10.87	5.40	49.68
75 per cent shade	5.65	6.09	6.92	7.69	7.91	8.22	8.59	8.63	9.29	9.54	9.87	10.48	4.83	46.09
Full sunlight	5.84	6.52	7.51	7.99	8.31	8.58	9.12	9.22	9.83	10.06	10.44	10.73	4.89	45.57
F test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
CD (0.05)	-	-	-	-	-	-	-	-	-	-	-	-		
SEm ±	0.32	0.38	0.49	0.51	0.48	0.57	0.60	0.51	0.58	0.52	0.48	0.57		

NS- Non significant

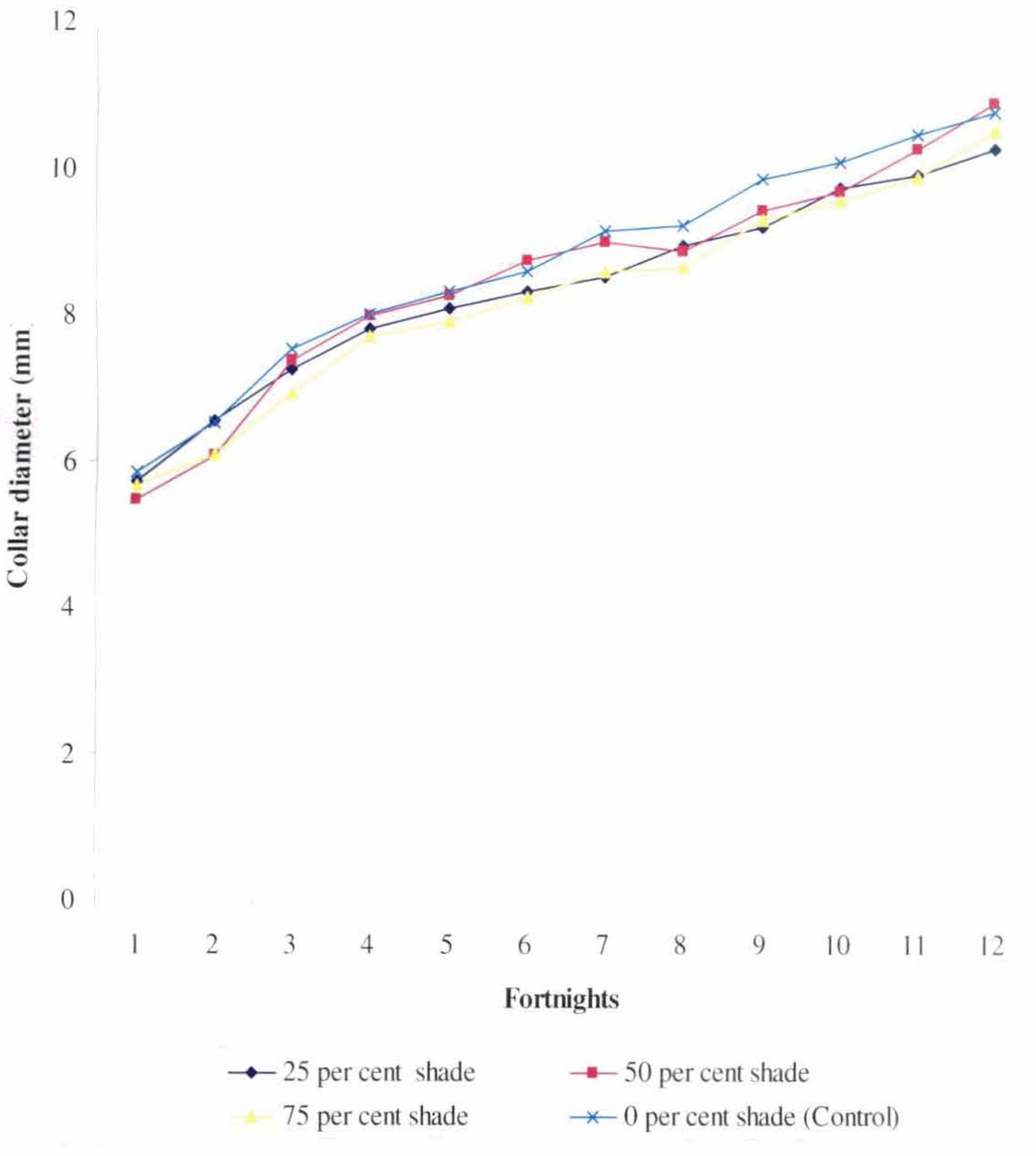

Figure 5. Effect of shade on collar diameter (mm) of seedlings produced from seeds of *Pongamia pinnata* at fortnightly intervals

Table 10. Effect of shade on leaf production (number) of seedlings of *Pongamia pinnata* at fortnightly intervals

Treatment details	Fortnight												Total increment	Increment percentage (%)
	1	2	3	4	5	6	7	8	9	10	11	12		
25 per cent shade	19.78	22.90	27.00	26.74	31.14^{ab}	30.40	29.30	30.22^{ab}	26.64	32.48^{b}	21.94	32.42	12.64	38.99
50 per cent shade	21.16	24.10	27.80	28.34	31.20^{ab}	30.10	32.18	32.26^{b}	27.14	23.28^{b}	23.20	29.90	8.74	29.23
75 per cent shade	18.90	20.04	23.14	22.22	24.26^{a}	26.16	25.26	24.14^{a}	20.86	23.56^{a}	21.38	25.60	6.70	26.17
Full sunlight	20.72	21.70	25.68	25.04	33.06^{b}	26.14	28.66	31.14^{ab}	28.50	33.00^{b}	15.82	28.80	8.08	28.06
F test	NS	NS	NS	NS	*	NS	NS	*	NS	**	NS	NS		
CD (0.05)	-	-	-	-	7.14	-	-	6.46	-	6.39	-	-		
SEm ±	2.84	1.83	2.76	2.96	3.28	3.40	2.90	2.96	3.30	2.93	4.60	3.90		

NS –Non significant * Significant at 5 per cent level ** Significant at 1 per cent level

4.3.4 Number of primary branches

The observation pertaining to the effect of shade on number of primary branches of seedlings of *Pongamia pinnata* are furnished in Table 11. From data it was evident that shade induced significant effect on number of primary branches production during fourth and seventh fortnight. There was no significant effect of shade treatment for the rest of study period. At fourth fortnight, the highest value (6.46) was recorded by seedlings grown under 50 per cent shade and there was significant difference with other treatments like 25 per cent, 75 per cent and full sunlight treatments. The lowest value (5.04) was recorded by seedlings kept under 75 per cent shade. Similar trend was observed during the seventh fortnight also. After seventh fortnight, shade treatments did not have significant difference with regard to number of primary branches. The data furnished in Table 11 indicates that the primary branch production ranged from 2.06 to 3.84.

4.4 Effect of shade on biomass production

4.4.1 Shoot fresh weight

Data on effect of shade on shoot fresh weight is furnished in Table 12. Significant difference between the shade treatments was recorded during third, fifth and sixth month of study period. At the end of study, seedlings kept under 75 per cent shade recorded the maximum shoot fresh weight of 45.74 g followed by those under full sunlight and 50 per cent shade. The lowest value (30.03 g) was recorded by seedlings under 25 per cent shade.

4.4.2 Shoot dry weight

The observation pertaining to the effect of shade on shoot dry weight is presented in Table 13. Shade induced significant effect on shoot dry weight during second, fifth and sixth month of study period. At the end of study, seedlings under 75 per cent shade recorded the maximum shoot dry weight (19.01 g) followed by those kept under full sunlight and 50 per cent shade. The lowest value (12.09 g) was recorded by seedlings kept under 25 per cent shade.

4.4.3 Root fresh weight

Data pertaining to effect of the effect of shade on root fresh weight is presented in Table 12. The observation revealed that the shade treatments did not have any significant effect except during the fifth month of study period. The maximum (21.98g) root fresh weight was recorded by seedlings under 75 per cent shade followed by those under 50 per cent shade.

4.4.4 Root dry weight

Data pertaining to effect of the effect of shade on root dry weight is presented in Table 13. Shade induced significant effect during only second and fifth month of study period. At second month, maximum (3.36 g) root dry weight was recorded by seedlings under 50 per cent shade and lowest value (1.69 g) was recorded in 75 per cent shade. At fifth month the maximum value (9.98g) was observed by seedlings under full sunlight and the lowest value (4.25 g) for seedlings grown under 25 per cent shade.

4.4.5 Shoot root ratio

The observation pertaining to the effect of shade on shoot root ratio is presented in Table 13. Shade treatment induced significant effect only during fifth and sixth month of study period. During the fifth month, the highest (1.96) shoot root ratio was recorded by seedlings under full sunlight. This was followed by seedlings under 75 per cent (1.76) and 25 per cent (1.71). The lowest value (1.27) was recorded by seedlings under 50 per cent shade. However, at the end of study the above trend was not observed. The seedlings under 75 per cent shade recorded the maximum shoot root ratio (1.88) followed by those 25 per cent and full sunlight. The lowest value (1.53) was recorded by seedlings under 50 per cent shade.

Table 11. Effect of shade on primary branches (number) produced by seedlings of *Pongamia pinnata* at fortnightly intervals

Treatment details	Fortnight												Total increment	Increment percentage (%)
	1	2	3	4	5	6	7	8	9	10	11	12		
25 per cent shade	4.60	5.26	5.28	5.68[ab]	5.66	6.04	6.16[a]	6.30	7.86	7.66	7.64	8.44	3.84	45.50
50 per cent shade	4.74	5.50	5.66	6.46[b]	5.92	7.04	7.40[b]	6.76	7.96	7.26	8.02	8.08	3.34	41.34
75 per cent shade	4.88	4.92	5.12	5.04[a]	5.12	6.16	5.62[a]	5.80	6.56	6.78	6.36	6.94	2.06	29.68
Full sunlight	4.42	5.02	5.36	5.64[ab]	5.70	5.86	6.04[a]	6.34	7.32	6.88	7.22	7.96	3.54	44.47
F test	NS	NS	NS	**	NS	NS	*	NS	NS	NS	NS	NS		
CD (0.05)	-	-	-	0.69	-	-	1.21	-	-	-	-	-		
SEm ±	0.70	0.62	0.73	0.32	0.86	0.55	0.56	0.76	0.94	0.81	0.83	0.86		

NS –Non significant * Significant at 5 per cent level ** Significant at 1 per cent level

Table 12. Effect of shade on shoot fresh weight (g) and root fresh weight (g) of seedlings of *Pongamia pinnata* at monthly intervals

Treatment details	Shoot dry weight (g)						Root dry weight (g)					
	1	2	3	4	5	6	1	2	3	4	5	6
25 per cent shade	3.14	4.01^{ab}	4.89	6.30	7.21^{a}	12.09^{a}	1.65	2.90^{bc}	3.76	4.00	4.25^{a}	7.97
50 per cent shade	2.16	4.66^{b}	6.39	6.79	8.68^{a}	14.99^{b}	1.96	3.36^{c}	3.53	4.56	7.17^{b}	9.87
75 per cent shade	2.22	2.73^{a}	4.57	6.47	14.18^{b}	19.01^{c}	0.98	1.69^{a}	3.00	4.30	8.11^{b}	10.08
Full sunlight	2.60	3.89^{ab}	5.93	8.63	15.50^{b}	16.69^{b}	1.41	2.23^{ab}	3.94	5.83	9.98^{b}	11.08
F test	NS	*	NS	NS	**	**	NS	**	NS	NS	**	NS
CD (0.05)	-	1.38	-	-	2.93	2.77	-	0.78	-	-	2.77	-
SEm ±	0.67	0.63	0.79	1.11	1.35	1.27	0.97	0.36	0.88	0.96	0.99	1.30

NS- Non significant * Significant at 5 per cent level ** Significant at 5 per cent level

Table 13. Effect of shade on shoot dry weight (g) and root dry weight (g) of seedlings of *Pongamia pinnata* at monthly intervals

Treatment details	Months																	
	Shoot dry weight (g)						Root dry weight (g)						Shoot root ratio					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
25 per cent shade	3.14	4.01[ab]	4.89	6.30	7.21[a]	12.09[a]	1.65	2.90[bc]	3.76	4.00	4.25[a]	7.97	3.33	1.37	1.43	1.69	1.71[b]	1.56[a]
50 per cent shade	2.16	4.66[b]	6.39	6.79	8.68[a]	14.99[b]	1.96	3.36[c]	3.53	4.56	7.17[b]	9.87	2.24	1.42	1.88	1.55	1.27[a]	1.53[a]
75 per cent shade	2.22	2.73[a]	4.57	6.47	14.18[b]	19.01[c]	0.98	1.69[a]	3.00	4.30	8.11[b]	10.08	4.44	1.7	1.54	1.52	1.76[b]	1.88[b]
Full sunlight	2.60	3.89[ab]	5.93	8.63	15.50[b]	16.69[b]	1.41	2.23[ab]	3.94	5.83	9.98[b]	11.08	2.53	1.76	1.65	1.58	1.96[b]	1.55[a]
F test	NS	*	NS	NS	**	**	NS	**	NS	NS	**	NS	NS	NS	NS	NS	*	*
CD (0.05)	-	1.38	-	-	2.93	2.77	-	0.78	-	-	2.77	-	-	-	-	-	0.48	0.31
SEm ±	0.67	0.63	0.79	1.11	1.35	1.27	0.97	0.36	0.88	0.96	0.99	1.30	2.19	0.24	0.35	0.36	0.22	0.14

NS- Non significant   * Significant at 5 per cent level   ** Significant at 5 per cent level

4.4.6 Total biomass

Data pertaining to the effect of shade on total biomass is presented in Table 14. Shade induced significant effect during second and fifth month of study period. At the end of study, seedlings under 75 per cent shade recorded the highest total biomass (29.09 g) followed by those under full sunlight (27.77 g) and 50 per cent shade (24.86 g) respectively. The lowest value (20.06 g) was recorded by seedlings under 25 per cent shade.

4.5 Effect of shade on root growth parameters

The observations on various root growth characters viz., root length, root spread and number of secondary roots as influenced by various shade levels are furnished in Table 15 to 17.

4.5.1 Root length

Shade treatments cast significant influence on length of roots during first month of study period (Table 15). However, root length was not influenced by shade during the rest of the observation period. The maximum (25.60 cm) root length was recorded by seedlings kept under 50 per cent shade followed by those under full sunlight (21.76 cm) and 25 per cent (18 cm). The minimum root length of 17.06 cm was recorded by seedlings under 75 per cent shade. At the end of study, the total increment in length of roots of seedlings of *Pongamia pinnata* ranged 32.90 cm to 40.20 cm.

4.5.2 Root spread

The spread of roots did not show significant difference between the treatments (Table 16) except during the end of study period. The maximum value (20.30 cm) was recorded by seedlings grown under 25 per cent shade and followed by those under 50 per cent shade. The lowest root spread was shown by seedlings grown under 75 per cent shade (16.30 cm) at the end of the study.

Table 14. Effect of shade on total biomass (g) of seedlings of *Pongamia pinnata* at monthly intervals

Treatment details	Months					
	1	2	3	4	5	6
25 per cent shade	4.79	6.91[bc]	8.64	10.30	11.45[a]	20.06[a]
50 per cent shade	4.12	8.02[c]	9.92	11.35	15.85[b]	24.86[b]
75 per cent shade	3.20	4.43[a]	8.16	10.78	22.29[c]	29.09[b]
Full sunlight	4.01	6.12[ab]	9.88	14.46	23.47[c]	27.77[b]
F test	NS	**	NS	NS	**	**
CD (0.05)	-	-	-	-	4.35	5.16
SEm ±	1.44	0.88	1.21	1.55	2.00	2.37

* Significant at 5 per cent level NS –Non significant

Table 15. Effect of shade on length (cm) of roots of seedlings of *Pongamia pinnata* at monthly intervals

Treatment details	Months						Total increment (cm)
	1	2	3	4	5	6	
25 per cent shade	18.00[b]	23.30	30.00	37.60	42.10	50.90	32.90
50 per cent shade	25.60[b]	30.40	37.30	42.50	49.40	65.80	40.20
75 per cent shade	17.06[a]	24.60	32.90	35.50	40.30	50.30	33.24
Full sunlight	21.76[ab]	26.70	35.60	37.40	45.50	58.70	36.94
F test	*	NS	NS	NS	NS	NS	
CD (0.05)	5.96	-	-	-	-	-	
SEm ±	2.73	3.19	6.29	6.32	7.24	6.66	

* Significant at 5 per cent level NS –Non significant

Table16. Effect of shade on spread (cm) of roots of seedlings of *Pongamia pinnata* at monthly intervals

Treatment details	Months					
	1	2	3	4	5	6
25 per cent shade	7.90	10.00	12.80	15.40	17.30	20.30 ^{b}
50 per cent shade	10.50	11.70	13.80	15.30	16.20	20.00 ^{b}
75 per cent shade	8.00	8.60	11.70	12.50	12.80	16.30 ^{a}
Full sunlight	9.40	11.10	11.90	13.80	15.90	19.30 ^{ab}
F test	NS	NS	NS	NS	NS	*
CD (0.05)	-	-	-	-	-	3.05
SEm ±	1.52	1.18	0.99	1.94	2.28	1.40

NS –Non significant * Significant at 5 per cent level

Table17. Effect of shade on number of secondary roots of seedlings of *Pongamia pinnata* at monthly intervals

Treatment details	Months					
	1	2	3	4	5	6
25 per cent shade	6.20	7.80	10.40	12.80	18.60	27.20
50 per cent shade	7.00	7.60	9.80	16.20	20.80	27.60
75 per cent shade	6.00	7.60	11.40	14.60	26.00	37.00
Full sunlight	5.80	9.80	12.40	15.80	21.60	31.20
F test	NS	NS	NS	NS	NS	NS
CD (0.05)	-	-	-	-	-	-
SEm ±	0.96	1.21	1.32	2.43	4.28	4.30

NS –Non significant

4.5.3 Number of secondary roots

Effect of shade on number of secondary roots is furnished in Table 17. The data revealed that there was no significant effect of shade treatments on the above parameter. However, at the end of study, the number of secondary root production ranged from 27.20 to 37.00.

4.6 Growth analysis

4.6.1 Relative growth rate

The data pertaining to Relative growth rate of seedlings of *Pongamia pinnata* is furnished in Table 18. The observation revealed that shade treatments had no significant effect on Relative growth rate. The Relative growth rate of seedlings at the end of study ranged from 0.005 $g.g^{-1}day^{-1}$ to 0.017 $g.g^{-1}day^{-1}$.

4.6.2 Leaf area

Data tabulated in Table 19 revealed that shade level had no significant effect on leaf area for the entire period of study. However, the leaf area production by seedlings ranged from 30.00 cm^2 to 38.82 cm^2 at the end of the study. The leaf area production trend is given in Figure 6.

4.6.3 Specific leaf area

Data with regard to specific leaf area (SLA) is furnished in Table 20. During the first four months shade treatments did not yield any significant effect on SLA. However, significant difference was observed during fifth month of the study. The maximum value (12.69 cm^2g^{-1}) was recorded for seedlings kept under 25 per cent followed by those under 50 per cent and 75 per cent respectively. The lowest value (4.19 cm^2g^{-1}) was recorded for seedlings under full sunlight.

Table 18. Effect of shade on relative growth rate ($g.g^{-1}day^{-1}$) of seedlings of *Pongamia pinnata* at monthly intervals

Treatment details	Months				
	1	2	3	4	5
25 per cent shade	0.014	0.007	0.006	0.006	0.017
50 per cent shade	0.023	0.011	0.004	0.012	0.015
75 per cent shade	0.014	0.018	0.012	0.02	0.014
Full sunlight	0.021	0.014	0.014	0.016	0.005
F test	NS	NS	NS	NS	NS
CD (0.05)	-	-	-	-	-
SEm ±	0.01	0.01	0.00	0.01	0.01

NS –Non significant

Table 19. Effect of shade on leaf area (cm^2) of seedlings of *Pongamia pinnata* at monthly intervals

Treatment details	Months						Total increment (cm^2)
	1	2	3	4	5	6	
25 per cent shade	15.12	19.69	21.5	23.88	30.94	36.39	21.27
50 per cent shade	17.60	21.05	23.60	25.83	28.99	38.82	21.22
75 per cent shade	13.63	20.22	23.69	25.09	28.33	35.11	21.48
Full sunlight	14.31	19.16	21.64	24.50	28.50	30.00	15.69
F test	NS	NS	NS	NS	NS	NS	
CD (0.05)	-	-	-	-	-	-	
SEm ±	3.70	3.42	2.41	1.83	3.20	5.76	

NS –Non significant

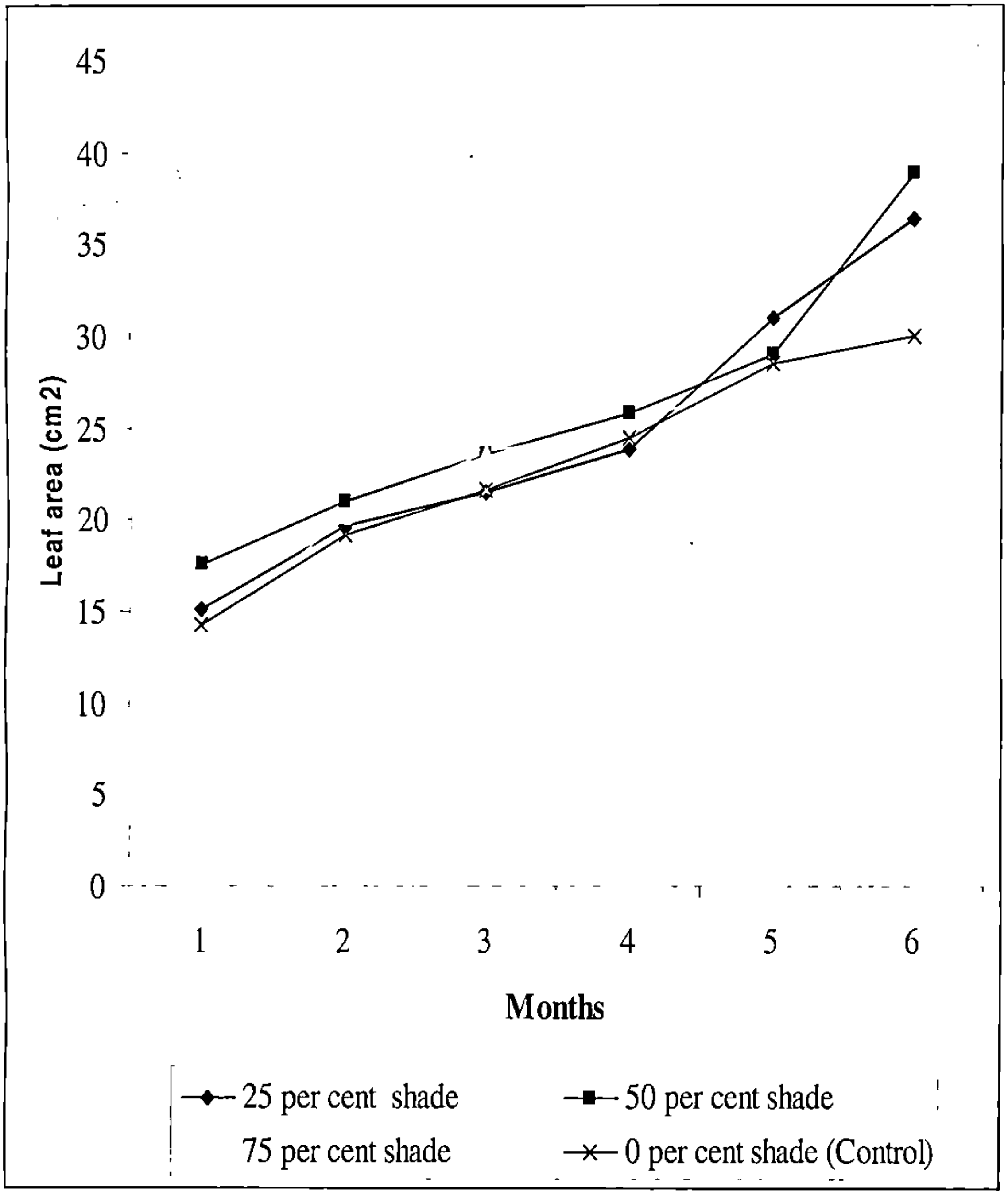

Figure 6. Effect of shade on leaf area (cm^2) of seedlings of *Pongamia pinnata* at monthly intervals

Table 20. Effect of shade on specific leaf area (cm^2g^{-1}) of seedlings of *Pongamia pinnata* at monthly intervals

Treatment details	Months					
	1	2	3	4	5	6
25 per cent shade	11.53	11.81	12.88	9.54	12.69^{c}	6.61
50 per cent shade	19.87	13.73	9.38	9.60	8.35^{b}	4.69
75 per cent shade	12.63	13.16	11.99	9.09	6.16^{ab}	4.49
Full sunlight	14.53	10.52	11.33	9.75	4.19^{a}	4.32
F test	NS	NS	NS	NS	**	NS
CD (0.05)	-	-	-	-	3.60	-
SEm ±	4.01	2.89	2.48	1.39	1.37	1.15

NS –Non significant ** Significant at 1 per cent level

4.6.4 Specific leaf weight

Data tabulated in Table 21 depict the effect of shade levels on Specific leaf weight (SLW) of *Pongamia pinnata* seedlings. There was no significant effect of shade on this parameter for the first four months. However, during fifth month of study shade treatment induced significant effect on SLW. The highest SLW was 0.25 $g.cm^{-2}$ seedlings under full sunlight followed by 75 per cent and 50 per cent shade. The lowest value (0.08 $g.cm^{-2}$) was observed under 25 per cent shade.

4.6.5 Leaf area ratio

Data furnished in Table 22 depict the effect of shade on leaf area ratio of seedlings of *Pongamia pinnata*. The data revealed that there was significant difference during second, fifth and sixth month of observation. During the end of study the maximum value (3.03 cm^2g^{-1}) was recorded by seedlings under 25 per cent shade followed by those under 50 and 75 per cent shade. The lowest value (1.80 cm^2g^{-1}) was recorded for seedlings under full sunlight.

4.6.6. Specific leaf weight ratio

Data tabulated in Table 23 shows the effect of shade on leaf weight ratio (LWR) on seedlings of *Pongamia pinnata*. The observation revealed that there was no significant effect of shade on the above said parameters. However, during the end of study, the leaf weight ratio ranged from 0.27 $g.g^{-1}$ to 0.33 $g.g^{-1}$.

4.6.7 Number of stomata

Data tabulated in Table 24 showed that there was significant effect of shade on number of stomata only during fourth month of study period. The maximum value (275.25) was for seedlings kept under 25 per cent shade followed by those under full sunlight (263.06 per mm^2) and 75 per cent shade (215.52 per mm^2). The lowest value (191.55 per mm^2) was recorded for the seedlings grown under 50 per cent per cent shade.

Table 21. Effect of shade on specific leaf weight (g. cm^{-2}) of seedlings of *Pongamia pinnata* at monthly intervals

Treatment details	Months					
	1	2	3	4	5	6
25 per cent shade	0.09	0.09	0.09	0.11	0.08^{a}	0.16
50 per cent shade	0.05	0.08	0.11	0.11	0.13^{a}	0.23
75 per cent shade	0.10	0.08	0.08	0.12	0.19^{b}	0.25
Full sunlight	0.08	0.11	0.10	0.11	0.25^{b}	0.24
F test	NS	NS	NS	NS	**	NS
CD (0.05)	-	-	-	-	0.07	-
SEm ±	0.02	0.02	0.02	0.02	0.03	0.04

NS –Non significant ** Significant at 1 per cent level

Table 22. Effect of shade on leaf area ratio (cm^2g^{-1}) of seedlings of *Pongamia pinnata* at monthly intervals

Treatment details	Months					
	1	2	3	4	5	6
25 per cent shade	4.36	5.03[a]	4.57	4.04	4.29[b]	3.03[b]
50 per cent shade	9.03	4.50[a]	3.75	3.80	3.46[b]	2.62[b]
75 per cent shade	6.52	7.93[b]	5.55	4.03	2.05[a]	1.85[a]
Full sunlight	5.58	5.15[a]	3.78	3:24	1.89[a]	1.80[a]
F test	NS	*	NS	NS	**	*
CD (0.05)	-	2.21	-	-	0.99	0.88
SEm ±	1.86	1.01	1.00	0.63	0.45	0.41

NS –Non significant * Significant at 5 per cent level ** Significant at 1 per cent level

Table 23. Effect of shade on specific leaf weight ratio ($g.g^{-1}$) of seedlings of *Pongamia pinnata* at monthly intervals

Treatment details	Months					
	1	2	3	4	5	6
25 per cent shade	0.23	0.26	0.22	0.28	0.21	0.29
50 per cent shade	0.27	0.22	0.25	0.24	0.23	0.33
75 per cent shade	0.41	0.37	0.29	0.27	0.28	0.29
Full sunlight	0.28	0.34	0.23	0.20	0.30	0.27
F test	NS	NS	NS	NS	NS	NS
CD (0.05)	-	-	-	-	-	-
SEm ±	0.09	0.08	0.06	0.04	0.05	0.04

NS –Non significant

Table 24. Effect of shade on number of stomata per mm^2 of seedlings of *Pongamia pinnata* at monthly intervals

Treatment details	Months					
	1	2	3	4	5	6
25 per cent shade	163.46	204.13	204.32	275.25^{b}	268.47	269.16
50 per cent shade	153.83	167.56	184.96	191.55^{a}	243.02	279.96
75 per cent shade	159.53	170.14	193.12	215.52^{ab}	228.46	246.17
Full sunlight	160.90	183.30	204.72	263.06^{b}	267.82	276.82
F test	NS	NS	NS	*	NS	NS
CD (0.05)	-	-	-	68.90	-	-
SEm ±	18.98	32.74	46.46	31.62	32.60	41.37

NS –Non significant * Significant at 5 per cent level

Discussion

DISCUSSION

Even after procuring good seeds, germination could be slow, unpredictable and difficult. Therefore, it is necessary to use some pre-treatments which could enhance the speed of germination. In forestry, various treatments are applied to seeds prior to sowing in order to increase the rapidity or completeness of germination which are the pre-requisites for obtaining a healthy planting stock. This information is very valuable in forestry programmes as seed propagation is still mainly resorted to in most of the tree species for their commercial propagation. In the succeeding paragraphs the findings of an investigation carried out to identify the most ideal pre-treatment for *Pongamia pinnata* seeds are discussed.

Light gradients are ubiquitous in nature, so all plants are exposed to some degree of shade during their lifetime. The minimum light required for survival and shade tolerance is a crucial life-history trait that plays a major role in plant community dynamics (Valladares and Niinemets, 2008). The present study also investigates the response of *Pongamia pinnata* seedlings to the various shade levels.

5.1 Effect of seed treatments on germination of seeds

The present study revealed that pre-treatments enhance the germination of *Pongamia pinnata* seeds. Among the seed treatments, seeds treated with GA_3 showed highest germination (Table 1). Bahuguna *et al.* (1988) reported that *Michelia champaca* seeds when treated with GA_3 enhanced both total germination and speed of germination while untreated seeds recorded poor germination. Chandra and Chauhan (1977) also recommended soaking of *Picea smithiana* seeds in 100 ppm GA for early and better germination. GA_3 soaking treatment is reported to enhance speed of germination percentage in *Bauhina vahlii* seeds (Upreti and and Dhar, 1997). Effectiveness of GA_3 treatment for enhancing seed germination is also reported in other species (Nagaveni and Srimathi, 1980; Singh and Murthy, 1987; Fox *et al.*, 1994). Gopikumar and Moktan (1994) also reported better gemination and vigour when seeds of *Albizia odoratissima* were treated with GA and IBA. Application of GA_3 is known to influence the enzymatic activity in tree seeds. In the present study GA_3 treated seeds had recorded lesser number of days (17.50) for germination which indicates the role of GA_3 in enhancing the speed of germination. GA_3 treated seeds also showed (Table 1) higher Final Mean Daily Germination (0.86), Germination Value (0.82) and Peak Value (0.93). In the present study, higher germination behaviour of seeds treated with GA_3 could be attributed to the mobilization of stored food reserves of the endosperm by stimulating enzyme amylase. Hence, GA_3 helps in the germination process.

In this study untreated seeds showed 26.87 per cent germination followed by seeds treated with hot water (50°C) for 15 minutes (26.36 %). Ramamoorthy *et al.* (1989) also found that hot water (50°C) treatment of fresh seeds of *Pongamia pinnata* for 15 minutes improved both speed and percentage of germination over that of untreated seeds. Mwang'Ingo *et al.* (2004) found that soaking in hot water enhanced seed germination (57.5%) and shortened the time to commence germination in *Osyris lanceolata*. The hot water and pre-soaking in water treatments shortened the germination period by 5-10 days along with uniformity of germination. The artificial softening of the seed coat reduced seed hardness in Fabaceae (Kumar *et al.*, 2007).

The next best treatment for *Pongamia pinnata* was seed coat removal followed by cold water treatment. Although sulphuric acid is found to be enhancing germination in many seeds, in the present study, soaking the seeds in Con. H_2SO_4 resulted in poor germination (15.19 %). In *Pongamia pinnata* treatment with sulphuric acid might have some detrimental effect on the seed tissue resulting in poor germination. The poor germination could also be probably attributed to the permeable seed coat and sensitivity of the embryos to sulphuric acid. Concentrated sulphuric acid can consequently desiccate tissues and eventually cause cell separation (Egley, 1989; Fu *et al.*, 1996).

5.2 Effect of seed treatments on growth characteristics of seedlings

Plant growth and development are influenced by earliness in germination and thereby influenced by seed treatments. The initial growth of tree seedlings is also affected by the earliness in germination. Growth of seedlings and subsequent survival in the field mainly depends on quality of seed and vigour of seedlings (Abideen *et al.*, 1993). In this study, seedlings produced from GA_3 treated seeds showed better height and collar diameter growth. Studies by Verma and Tandon (1988) in *Pinus kesiya and Schima khasiana* seedlings revealed that GA was effective in increasing the growth of shoot part of the seedlings in the nursery. Banker (1989) reported that seeds of *Carissa caronda* treated with 25 ppm GA resulted in vigrous seedling having 19.6 cm height compared to 12.2 cm in control. It is proved that seed germination influences the early seedling growth. Several other literature have also suggested that movement of GA_3 basipetally through stem could bring about shoot elongation (Kentzer and Libert, 1961 in *Helianthus*; Michniewicz and Lang, 1962; Cohen *et al.*, 1996 in *Pisum* and in herbaceous crops). Hence, in the present study also better height and collar diameter could be attributed to the advantages arising out of early seed germination. The highest number of primary branch production also was observed on seedlings produced from GA_3 treatment (Table 5). Considering the initial response of *Pongamia pinnata* seedlings, it can be concluded that GA_3 helped shoot elongation in this study. However, at the end of study seeds treated with cold water produced seedlings with maximum height (18.93 cm), highest collar diameter (5.76 mm) and more number of leaves (20.47) (Table 2,3 and 4). With regard to influence of cold water treatment on the seedling growth could not be ascribed which further needs better understanding of seedling response. Seed treatments did not induce significant effect on biomass production and on root growth parameters of *Pongamia pinnata* seedlings in the nursery (Table 6 and 7). Further investigation on the physiological and biochemical response of seedling to the pretreatments is required to confirm this probability.

5.3 Effect of shade on shoot growth parameters

5.3.1 Height and collar diameter

In the present study, it was observed that different shade treatments did not induce significant effect on height and collar diameter growth of *Pongamia pinnata* seedlings (Table 8 and 9). *Pongamia pinnata* is a shade bearer and can be grown under the shade of other trees. It also responds well when grown in full sunlight or partial shade (Gilman and Watson, 1994). Hence, it can be interplanted in existing tree stands. Due to shade bearing nature of the species, in this study the effect of different shade levels might not have manifested on the height and collar diameter.However, it can be observed that seedlings showed an incresing trend with respect to height when placed under 50 per cent shade with an incremnet of 64.43 per cent during the study period (Figure 4). Prasad (2002) reported that seedlings of *Terminalia tomentosa and Terminalia bellirica* recorded maximum heights when grown under 50 per cent shade. Height growth of seedlings of *Dalbergia sissoo* and *Acacia catechu* was found maximum when grown under 50 per cent shade conditions (Saxena *et al.,* 1995).

In the present study it was also observed that shade levels did not affect collar diameter of the seedlings. Barrett and Fox (1994) made a preliminary study on the response of sandal under different shade conditions viz. full sun, 32 per cent, 50 per cent, 70 per cent and 80 per cent shade and observed that plant height and collar diameter were not significantly infuenced by shade levels. However, the present study indicated better performance of the seedling for collar diameter when placed under 75 per cent shade (Figure 5). During the end of study, the total collar diameter increment ranged from 4.53 mm to 5.40 mm (Table 9). The sandal seedlings grown under 50 per cent shade had the highest collar diameter (2.21 mm) when compared with the seedlings grown under full sunlight, 25 and 75 per cent shade levels (Singh, 2008). Seedlings of *T.tomentosa* and *T.bellirica* grown under 50 per cent shade recorded maximum collar diameter of 7.46 cm and 6.95 cm respectively. The total collar diameter increment was also maximum when they were grown under 50 per cent shade. An earlier study conducted at College of Forestry, revealed that *Leucaena leucocephala* recorded maximum collar girth when grown under 25 per cent and 50 per cent shade levels (Vimal. 1993). Hence, in the present study, better performance of *Pongamia pinnata* under 50 per cent shade suggests that species require medium exposure to sunlight for their height and collar diameter growth.

5.3.2 Leaf and primary branch production

In the present study, full sunlight had a significant impact on the leaf production (Table 10). The maximum (33.00) number of leaves was observed in seedlings under full sunlight. The variation in response of species to shade with regard to leaf growth parameters was established by earlier workers. Bush and Auken (1987) reported that there was maximum leaf production in *Prosophis glandulosa,* when grown under full sunlight. Hazra (1989) reported that in pulses there was an increase in leaf production for plants exposed to sunlight when compared to those under tree canopy. Seedlings placed under 50 per cent shade (Table 11) produced maximum number of primary branches. Hence, it can be concluded that *Pongamia pinnata* produced more leaves under full sunlight condition, although primary branch production was higher under 50 per cent shade level. This could be due to more carbohydrate produced was not used for branch production. However, more studies are needed to confirm this conclusion.

5.4 Effect of shade on biomass production

Influence of shade on biomass production revealed that dry weight of shoot, dry weight of root, total biomass and shoot :root ratio(Table 13 and 14) were significantly influenced by the different levels of shades at the end of the study period. The highest (19.01 g) dry weight of shoot was observed in seedlings grown under 75 per cent shade (Table 13). The maximum shoot: root ratio (1.88 g/g) and highest (29.09 g) total biomass were observed in seedlings grown under 75 per cent shade (Table 13 and 14). The seedlings under 75 per cent was found to be the second best for root dry weight production (Table 13). The present study retreated that *Pongamia pinnata* seedlings performed better under shaded conditions (75 % shade) in nursery stage with regard to dry weight of shoot, root, total biomass and shoot: root ratio.

Role of varying levels of shade in improving biomass has been reported by many workers earlier. In *Cupressus sempervirens* the maximum weight was produced under 75 per cent shade (Cregg and Teskey, 1993). Saju *et al.* (2000) also found that seedlings of *Ailanthus triphysa* performed well under 75 per cent shade with regard to shoot dry weight which was attributed to the shade loving nature of the species. Sharma *et al.* (1994) also found that dry weight of *Enicostemma littorale* were found to be the best under shaded condition as compared to plants grown under full sunlight. *Ailanthus triphysa* was also recorded to produce more root weight when grown under shade (Saju *et al.*, 2000). Lyapova and Palashev (1982) reported that *Tilia tomentosa* produced greater aerial biomass under 50 per cent shade when it was grown under different shade conditions. Ravindra (2007) also reported that the highest root biomass in *Mucuna* seedlings when grown under 75 per cent shade followed by 50 per cent and 25 per cent shade levels. The higher biomass levels obtained for *Pongamia pinnata* seedlings under shade in the present study also can be attributed to the shade bearing nature of the species.

The shoot:root ratio is a morphological attribute that is commonly used for the evaluation of seedlings quality. In the present study, the highest shoot: root ratio was observed for seedlings under 75 per cent shade (Table 13). It is possible that the leaves growing under shade accumulated more nitrogen per unit leaf area and hence more supply of nitrogen to the leaf metabolism those in full sunlight and hence the higher shoot: root ratios under shade condition (Oguchi *et al.*, 2006). Kinyamario *et al.*, (2008) reported that the shoot:root ratios were highest (1.84) for *Polyscias fulva* and 6.42 for *Warburgia ugandensis* under 75 per cent shade. The high shoot: root ratios may be adaptive features to a certain range of light intensities. As light decreases, plants allocate more biomass to the above-ground structures and results in high shoot:root ratios under shade (Chen 1997; Robakowski *et al.*, 2004). Shoot: root ratios were greatest in the 55 per cent and 75 per cent shade treatments for all Pacific Northwest conifer species (Khan *et al.*, 2000). It shows that in a light-limited environment, photosynthate allocation patterns favor shoot elongation and chlorophyll production and hence, increase light harvesting capabilities (Wang *et al.*, 1994). In the present study, it can also be concluded that shade in nursery stage that is triggering higher biomass production with respect to *Pongamia pinnata* seedlings.

5.5 Effect of shade on root growth parameters

In *Pongamia pinnata* seedlings, the root growth parameters viz., root length and root spread recorded highest values when grown under 50 per cent shade (Table 16, 17 and 18). Root length was found to be significantly influenced by the use of different levels of shade during the first month of study. The highest (65.80 cm) root length (Table 16) was recorded in seedlings under 50 per cent shade while the root spread (Table 17) was found to be the maximum (20.30 cm) in seedlings under 25 per cent shade level. Similar conclusions were also drawn by Chathurvedi and Bajpai (1999) in seedlings of *Bridelia retusa* and *Holarrhena antidysenterica.* Production of secondary roots was not affected significantly by different shade levels in the present study (Table 18). The environmental factors such as temperature and soil moisture are modified to some extent in shady condition. In the present study, the higher root growth under shade could be attributed to shade bearing nature of *Pongamia pinnata* and due higher allocation of biomass due to stress or limiting light.

5.6 Effect of shade on growth indices

Shade levels could not influence any significant changes in *Pongamia pinnata* seedlings with respect to relative growth rate and leaf area (Table 19 and 20). However, shade had significant influence on other physiological attributes such as specific leaf area (SLA), Leaf area ratio (LAR) and stomatal number.

The maximum value (12.69 cm^2g^{-1}) for Specific leaf area (SLA) (Table 21) was recorded for 25 per cent shade during the fifth month of study. SLA describes the efficiency with which the leaf captures light relative to the biomass invested in the leaf. Groninger *et al.* (1996) reported that shade treatments increased specific leaf area of four Virginia Piedmont tree species. Specific leaf area was significantly higher in shade-grown foliage of Pacific yew than in sun-grown foliage and was diagnostic of the light environment in which the foliage grew (Mitchell, 1998). Specific leaf area of *Intsia palembanica* and *Hopea odorata* were largest under shade treatment (Kriebitzsch *et al.*, 1996). It seems major factor contributing to an increased SLA in response to shading is a reduction in several components of the photosynthetic system which governs the capacity at high quantum flux densities. In the present study, high SLA under 25 per cent shade reflects the ability of the *Pongamia pinnata* seedlings to grow under low light condition.

Specific leaf weight (SLW), the ratio of blade mass to blade area, is in general an indicator of leaf thickness. Leaves in shady environments typically have lower SLW than leaves grown in open conditions. In the present study, SLW was lower under shade condition and high under full sunlight (Table 22). The leaves with low SLW, maximize the exposure of the radiation harvesting apparatus to the limited number of usable photons. Low SLW represents a complement of leaf characteristics including decreased leaf thickness, decreased palisade cell developments, lesser photosynthesising cells per unit leaf area, decreased assimilatory apparatus per unit area, lower maximum rate of photosynthesis per unit leaf area and lower light saturation point. (Boardman, 1977; Chabot and Chabot, 1977). Even the maximum photosynthetic rate per unit leaf area is low under shade, total photosynthetic rate per plant is higher due to increased leaf area per plant. Therefore, SLW is a good indicator of photosynthetic capacity, growth and relative ability to shade adaptation. Hence, in the present study, lower SLW indicates the ability of *Pongamia pinnata* seedlings to perform well under shaded conditions.

LAR reflects the size of photosynthetic surface relative to the respiratory mass. During the end of study the maximum value (3.03 cm^2g^{-1}) for Leaf area ratio (LAR) was recorded by *Pongamia pinnata* seedlings placed under 25 per cent shade. There was a consistent trend for higher specific leaf area (SLA) and leaf area ratio (LAR) at lower growth light regimes in *Olea europaea* and *Podocarpus falcatus* (Fetene and Feleke, 2001). In the present study, seedlings of *Pongamia pinnata* allocate more resources to leaf production, giving rise to higher leaf area ratios (LAR).

Leaf weight ratio (LWR) is a reflection of the plant ability to maintain its normal developmental pattern and it will be found to be constant over a range of flux densities to which a plant is adapted. In the present study, shade levels had no significant effect on leaf weight ratio (LWR) of seedlings of *Pongamia pinnata* suggesting that under shade leaves are relatively thin. This is associated with relatively few and small palisade mesophyll cells per unit area. The increase in LAR with shading represents an adaptation to low Photosynthetic Active Radiation (PAR) because a greater LAR results from a greater allocation of plant material to the photosynthetic light harvesting structures. The increase in LAR under 25 per cent shade level was due to an increase in SLA. Considering increases in SLA and LAR and no significant changes in LWR under shade levels, it can be concluded that *Pongamia pinnata* seedlings could compensate the reduction in radiation and thus photosynthesize by increasing leaf growth parameters.

In the present study, shade levels induced significant effect on stomatal number. Seedlings grown under 25 per cent shade showed maximum number (275.25) of stomata per mm^2 followed by those under full sunlight (263.06 per mm^2) and 75 per cent shade (215.52 per mm^2) during fourth month of study. The stomatal frequency was reported to increase in sun grown plants of forest tree species (Lee *et al.*, 1996).

Similarly, plants grown under shade were reported to have fewer stomata per unit area of leaf. In the present study, the observations reveals that 25 per cent shade condition is required for high stomatal number in *Pongamia pinnata* seedlings.

Sunlight plays the key role in the physiology of plants, their growth and phenology. The requirement of sunlight varies according to species and their growing conditions. When shade is provided to the seedlings it reduces the irradiance predominantly in the photosynthetic active region of the spectrum (400 to 700 nm). The level of irradiance is a major ecological factor that influences plant growth. The present study reveals that optimum light condition is required for the good growth of *Pongamia pinnata* seedlings. It suggests that the selection of species to plant with respect to the light condition of a focal planting site needs to be considered for the successful end of a plantation programme.

Summary

SUMMARY

Seed treatments are known to enhance seed germination and seedling growth. They also improve speed and rate of germination and help to produce uniform seedlings. The use of seed treatments will thus help the farmers and other nursery men to produce healthy and even seedlings in the shortest time.

Sunlight is one of the primary factors influencing the growth and biomass production in green plants. The light requirement of each species varies widely and each species requires specific shade levels at various stages of their growth period. Light requirements of many annuals including vegetables have been studied well in India and abroad. However, information regarding the effect of shade on the growth of many important tree species including *Pongamia pinnata*, particularly in the nursery, is very meager. The wide potentialities of growing trees can be fully exploited, only if a good knowledge about their light requirements is available.

An investigation on effect of seed treatments and shade on seedling growth dynamics of *Pongamia pinnata* (Linn.) Pierre in the nursery was carried out at the College of Forestry, Vellanikkara, Thrissur, Kerala during 2007 to 2009. The salient findings of the study are as follows:

1. Significant difference was observed among the various seed treatments with regards to germination behaviour. Seeds treated with GA_3 (100 ppm) for 20 minutes showed highest germination and number of days taken for germination was minimum as compared to the other seed treatments. GA_3 treated seeds also showed higher Final Mean Daily Germination, Germination Value and Peak Value.

2. GA_3 treatment was also effective in promoting seedling height and collar diameter during the initial stages. However, at the end of study seedlings produced from seeds treated with cold water recorded good growth with respect to height, collar diameter and leaf production. However, highest primary branch production was observed under GA_3 treatment. Overall, in *Pongamia pinnata*

seed pretreatments could not cast significant effect on biomass production and root growth.

3. Shade treatments did not induce any significant effect on height and collar diameter of *Pongamia pinnata* seedlings in the nursery. However, at the end of study period seedlings raised under 50 per cent shade showed highest increment per cent. The maximum leaf production and primary branch production was observed in seedlings kept under full sunlight and 50 per cent shade levels respectively.

4. As far as dry weights of shoot, root, shoot: root ratio and total biomass production are concerned, *Pongamia pinnata* seedlings kept under 75 per cent shade conditions in the nursery stage performed better.

5. The root growth parameters viz., root length and root spread was highest for seedlings grown under 50 per cent shade. At the same time, shade had no significant effect on secondary root production.

6. Shade levels also did not influence any significant changes in *Pongamia pinnata* seedlings with respect to relative growth rate and leaf area. However, Specific leaf area and Leaf area ratio was higher under 25 per cent shade. Highest Specific leaf weight was recorded under full sunlight. At the same time, shade had no significant effect on leaf weight ratio of *Pongamia pinnata* seedlings. Stomatal number was highest in seedlings grown under 25 per cent shade.

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EFFECT OF SEED TREATMENTS AND SHADE ON SEEDLING GROWTH DYNAMICS OF *PONGAMIA PINNATA* (Linn.) Pierre IN THE NURSERY

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ABSTRACT OF THE THESIS

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ABSTRACT

The present study entitled "Effect of seed treatments and shade on seedling growth dynamics of *Pongamia pinnata* (Linn.) Pierre in the nursery" was carried out in College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur during the period of 2007-2009.

In the first phase, seeds were subjected to six pre-sowing treatments. GA_3 treated seeds recorded highest Germination percentage, Final Mean Daily Germination (FMDG), Germination Value (GV) and Peak Value (PV). The effect of seed treatments were observed on various biometric parameters like height, collar diameter, number of leaves and primary branch. GA_3 treated seeds recorded better height and collar diameter during the initial stage of seedling growth. At the end of study cold water seed treatment was found to be effective in enhancing seedling growth. However, none of the pretreatments was observed to cast a significant effect on biomass production and root growth parameters in *Pongamia pinnata* seedlings.

In the second phase, to evaluate seedling growth under different shade conditions, seedlings were placed under 25 per cent shade, 50 per cent shade, 75 per cent shade and full sunlight situations. Shade treatments did not significantly influence height and collar diameter growth of *Pongamia pinnata* seedlings in the nursery. The maximum leaf production and primary branch production was observed in seedlings kept under full sunlight and 50 per cent shade respectively. Under seventy five per cent shade seedlings produce maximum shoot and root dry weight. The shoot: root ratio and total biomass was also maximum for seedlings kept under 75 per cent shade. Root length and spread were maximum under 50 per cent shade. However, shade did not significantly effect secondary root production. Shade levels also did not influence *Pongamia pinnata* seedlings with respect to relative growth rate and leaf area. However, Specific leaf area and Leaf area ratio was higher under 25 per cent shade. Highest Specific leaf weight was observed for seedlings under full sunlight. Shade had no significant effect on leaf weight ratio of seedlings. Maximum stomatal number was recorded under 25 per cent shade. In the nursery stage shade is casting an overriding influence with regards to various growth parameters of *Pongamia pinnata*.