SCREENING OF SUPERIOR GENOTYPES OF *Ailanthus triphysa* (Dennst.) Alston. (MATTI) FOR MATCHWOOD QUALITY

By

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(2016-17-007)

THESIS

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DECLARATION

I, hereby declare that this thesis entitled "**Screening of superior genotypes of *Ailanthus triphysa* (Dennst.) Alston, (*Matti*) for matchwood quality**" is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship, associateship or other similar title, of any other university or society.

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CERTIFICATE

Certified that this thesis entitled **"SCREENING OF SUPERIOR GENOTYPES OF *Ailanthus triphysa* (Dennst.) Alston, (*MATTI*) FOR MATCHWOOD QUALITY"** is a record of research work done independently by Mr. Jagaddish Kumar Das (2016-17-007) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship and associateship to him.

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We, the undersigned members of the advisory committee of Mr. Jagaddish Kumar Das (2016-17-007) a candidate for the degree of **Masters of Science in Forestry** with major in wood science, agree that thesis entitled **"SCREENING OF SUPERIOR GENOTYPES OF *Ailanthus triphysa* (Dennst.) Alston, (*MATTI*) FOR MATCHWOOD QUALITY"** may be submitted by Mr. Jagaddish Kumar Das (2016-17-007). In partial fulfillment of the requirement for the degree.

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Introduction

1. INTRODUCTION

Bengal is the birth place of match industry in India. The first match industry was established in Saharanpur, West Bengal during 1920 and the second in Shivakashi, Tamil Nadu during 1923 (Sharesh *et al.*, 2011). Historically, the Indian match industry depended on imported wood including aspen (*Populus tremula* L.) from America, Canada, and Russia; linden (*Tilia japonica* (Maq.) Simonk.) from Japan and cotton wood (*Populus deltoids* Var. *deltoides*) from Canada. Indian government took a decisive move to strengthen the use of indigenously available wood and stopped importing foreign woods. This led to an increased search for indigenous species in particular, light colored wood (Sekhar *et al.*, 2015).

In India, the wooden match industries are classified into three sectors; large-scale mechanized sector, small-scale handmade sector, and cottage level handmade sector. The overall handmade sector contributes around 82 per cent of the total match splint production of the country; out of which small-scale sector contributes 67 per cent and cottage sector contributes 15 per cent. The small-scale industry therefore provides the largest employment in the match splint sector (Tandon, 1991). In the state of Tamil Nadu women shares around 74 per cent of total employment requirement (Singh, 2014). As per the recent data, the average demand for raw material for wooden match splint industries is about 16000 tonnes per month. Softwoods are imported from China to meet the demand. The cost of imported wood is 46 rupees per kilogram whereas the wood available in the local market is 30 rupees per kilogram. During shipment, the wooden logs get discolored and thus become unfit for wooden match splint production. Usually, the imported woods are not available on a regular basis, so the industry mainly dependent on locally available raw material (Anon., 2015).

With a rapidly growing population, there is a growing demand for various products in the country, which is an area of major concern. The situation is same in the case of wood-based products i.e. industrial round wood, pulpwood, match wood etc. In southern India *Ailanthus triphysa* (Dennst.) Alston, *Ailanthus excelsa* Roxb., *Melicope lunu-ankenda* (Gaertn.) T.G. Hartley, *Alstonia scholaris* (L.) R. Br., *Macaranga peltata* (Roxb.) Mull. Arg., *Bombax ceiba* L., and *Albizia falcataria* (L.) Fosberg. are commonly used for producing match splints. Among all species, *M. lunu-ankenda* which is endemic to India is considered best for match splint manufacturing however, this species is an endangered one (Anon., 1998). In Kerala, the match splint industries are mainly dependent on *A. triphysa*. There are approximately 500 match splint industries (small, medium, large scale) in Kerala, many of which are facing acute shortage of raw materials. Only ten per cent of the total raw material requirement of the industries is met through the forests of Kerala and hence the demand is very high (Nair *et al.*, 1984).

In this context, College of Forestry, Kerala Agricultural University, Vellanikkara had conducted a workshop on the topic "Homestead grown trees and match industry" on 12th July 2011. The main emphasis of the workshop was the need for research on wood quality improvement aspects of the major raw material species viz., *Ailanthus triphysa*. The workshop also made a recommendation to develop and supply quality planting stock by Kerala Agricultural University to the farmers as a part of farm forestry programmes. The workshop also resolved to create interest among farmers for growing match splint species in their homesteads.

Ailanthus triphysa is a fast growing tree species with short rotation period. The tree attains harvestable girth in six to eight year time period. It produces an aromatic resin called Halmaddi, used for making traditional incense sticks. A dye obtained from the plant leaves can be used for staining satin black. The leaves, roots, gum exudates and bark are having medicinal uses in India. In Kerala, it is found in natural forests, plantations, and homesteads. In homesteads, the young plants are used as a support for black pepper (*Piper nigrum* L.). Due to the narrow branching pattern, it takes less aerial space, which makes the species suitable to grow in homesteads. The presence of natural resin reduces the necessity for dipping the splints in wax and hence, this species has been counted as the best matchwood species. *Ailanthus triphysa* is also found performing well in both fertile land and degraded land whereas species like *Ailanthus integrifolia* failed to survive in degraded areas (Indira, 1996).

Tree improvement includes the enhancement of management and silvicultural operations as well as the genetic improvement (tree breeding) together to strengthen the use and benefits derived from a particular tree species (Burley, 2004). An effort towards breeding and producing quality planting material has not been taken up widely for *Ailanthus triphysa*, which have a high demand in match industries in Kerala. Based on the objective of workshop "Homestead grown trees and match industry", organized in College of Forestry, Kerala Agricultural University, Vellanikkara a tree improvement programme was started on *Ailanthus triphysa*. Twenty Candidate Plus Trees (CPTs) selected from the ten different panchayats of Thrissur and Palakkad district based on phenotypic characters. The seedlings of respective mother trees were field planted in October 2015. The experimental trial located in the KAU main campus at Vellanikkara, Thrissur (N 10° 55' 10'' latitude, E 76° 29' 63'' longitude) is laid out in RBD with 4 replications. These are a total of 320 plants planted in 4 plots. The objectives of the current study are given below.

- Screening of superior genotypes based on the growth performance in the field.
- To study the between tree variation of wood physical and anatomical properties of the Candidate Plus Trees (CPTs) of the progenies laid out in the trial.
- To develop a potential biocontrol agent against two major insect pest, *Eligma narcissus* Cramer and *Atteva fabriciella* Swederus.
- Evaluate the general combining ability and broad sense heritability.

Review of Literature

2. REVIEW OF LITERATURE

2.1 WOOD

Wood has evolved, over a period of hundreds of millions of years, to meet the mechanical and physiological needs of the tree. It is also one of the most remarkable structural material on the earth (Wilson and White, 1986). There are numerous definitions regarding what constitutes wood but the one by Webster and McKatchnie (1980) that wood is "the hard fibrous substances beneath the bark in the stems and branches of trees and shrubs: xylem" is good among all. Apart from above definition, wood is an outstanding material with a variability and flexibility which makes it usable for any kind of products. It composed of cellulose, hemicellulose, lignin, numerous extractives, sugars and other organic and inorganic substances produce a raw material which can be used for many things including papers, building material, chemicals, energy, and even food (Domino, 1984). Wood properties varies throughout the world, the rate and cause of change must be known (Zobel and Buijtenen, 2012).

2.2 *Ailanthus triphysa* (Dennst.) Alston. : AN OVERVIEW

2.2.1 Taxonomy and distribution

The genus *Ailanthus* belong to the family *simarubaceae* which is spread over the tropical and subtropical regions of both the hemisphere and several species are widely distributed over Asia and north Australia (Laskar, 2010). There are about four species and subspecies reported from India these are, *Ailanthus altissima* (Mill) Swingle [syn. *Ailanthus glandulosa* (Desf)], *Ailanthus excelsa* (Roxb.), *Ailanthus integrifolia* Lam., *Ailanthus integrifolia* (Lamk.) (ssp.) calysina (Pierre) Noot. [syn. *Ailanthus grandis* (Prain)] and *Ailanthus triphysa* (Dennst.) Alston [syn. *Ailanthus malabarica* (DC)] (Anon, 1985).

The generic name '*Ailanthus*' comes from 'ailanthos' (tree of heaven). The genus *Ailanthus* is having 5 tree species occurring in South Asia, Malaya, China and Australia (Indira, 1996). Earlier it was grown as mixed plantation along with *Evodia lunnu-ankenda* (Gaertn.) Merr., *Bombax ceiba* L., and *Tectona grandis* L.f.. However, since 1980 the species is being raised as pure plantations in Kerala (Anon., 1991). It is a prominent multipurpose tree (MPTs) in the traditional land use systems of Kerala (Kumar *et al.,* 1994).

In India, its natural range extends from Konkan through Karnataka to Kerala along Western Ghat (a north-south running mountain range along the western margin of Deccan plateau in peninsular India) up to 1500 m elevation (Anon, 1985). In Kerala, *A. triphysa* found in almost all physiographic provenance except the high altitude ranges and it can tolerate a wide range of soils (Kumar, 2000).

2.2.2 Botanic description

Ailanthus triphysa (Dennst.) Alston. is a single-stemmed tree with cylindrical bole, can attain a height of about 30 meter and diameter of 1.2 meter. Leaves pinnate, large 45-60 cm long, crowded at branch ends. leaflets 5-10 pairs, ovate, oblong, sickle-shaped, tapering from the base, 7.5-15 x2.5-5 cm thin, shining, glabrous and glaucous beneath, very oblique at the base, petioles 1 cm long. Flowers white, polygamous in lax axillary panicles, pedicels short, Calyx lobes minute, pubescent, triangular, acute. Petals about 0.4 cm long, glabrous, oblong-lanceolate. Fruit a samara, 5-7.5 cm long, reddish-brown, membranous and flat. Seed compressed, circular. Bark grey, rough, inner bark, 1.3 cm thick, yellow and fibrous. It is monoecious and deciduous. Flowering in India and Nepal is between February and March, fruiting follows in April-May (Orwa *et al.*, 2015).

2.3 Field growth

Indira (1996) studied the genetic improvement of *Ailanthus triphysa* (Dennst.) Alston. The study found that *A. triphysa* has a high family heritability for height at early ages and it decreases to moderately high at the age of 3 years whereas, for basal girth the family heritability is moderate. The single tree heritability was found to be moderately high for height, while it was low for basal girth and decreased with age. The phenotypic and genotypic coefficient of variation was found to be low for both height and basal girth. Strong positive genetic correlation between height and basal girth which makes the improvement programme easy. The genetic correlation (r_g) between height and basal girth was found to be high as 1.0, while phenotypic correlation (r_p) was 0.69 at the age of three years. The analysis of variance showed that there was significant differences among families for tree height at all ages observed. For girth, the difference was not significant.

Ginwal *et al.* (2004) investigated the seed source evaluation of *Jatropha curcas* Linn.. The seeds were collected from ten sources in central India. The seedlings were field planted in a randomized complete block design with three replication. The growth performance of nursery seedlings and field were evaluated. Two years after field planting the analysis showed that, there were significant difference for height, collar diameter, number of branches, and survival per cent. It was mentioned that the presence of such variations may induced by different intensities of natural selection action upon these traits in their natural habitat.

Singh and Pokhriyal (2000) studied on biomass distribution pattern of *Dalbergia sissoo* Roxb. seedlings with respect to the seed source variation. Seeds were collected from six provenances within the natural distribution range of India and Nepal. The result revealed significant difference between the seed sources for growth characters, viz, height, collar diameter, leaf number, root length, and biomass production. Among the six seed sources, Gonda seed source had the best performance with respect to growth and biomass production, followed by Nepal and Chiriyapur. Significant differences were observed during the 2nd year of growth among different seed sources. The study also indicated that multi-trait selection criteria and environmental parameters play an essential role in evaluating the seed sources in *D. sissoo*.

Twenty-one provenances of *Acacia nilotica* ssp. India collected from 11°N to 31°N Latitude and 19 m to 650 m altitude range in India were growing at Hisar (Krishan and Toky, 1995). The result revealed significant variation in stem height, branch, leaf and spine growth characters between the provenances at 6 month and the 23-month after field plantation. The provenances from North-Western and Central India were found to be superior to those from South India. Moreover, the variation in growth characters was random as they did not show any significant relationship with the latitude of origin seed source.

Baharudin *et al.* (1987) studied the performance of twenty one provenances of *Acacia mangium* Willd. planted in a multi-location trial. Parameters like survival, growth and stem form were observed at the age of two year. The average performance of survival percentage was found to be good, ranging from 83% to 95%. The mean height shows significant differences between provenances at all sites. There was a great variability found between sites. There are many possibility which might have contributed to that great variability. The provenances from Claudie River and Jullatan (Queensland) and from Ontario River and west of Morehead (Papua New Guinea) showed better performance than other provenances.

A provenance trial of *Gmelina arborea* Roxb. was established during the mid-seventies time by the joint effort between 20 countries, the trial was executed outside the natural distribution areas of *Gmelina arborea* (Lauridsen and Kjaer, 2002). From the study an interesting result obtained that, the trees originating from plantations often perform better than those grown in natural forest. The possible reason can be (1) A positive selection during the thinning in the plantation (2) As a result of the lower rate of inbreeding in plantation (3) a positive response to the adaption of local condition. The obtained result couldn't fully justify the relative importance of these factors, but all the three factors suggest that important gain can be acquired by tree improvement programmes in *Gmelina arborea*.

A study was conducted to compare the performance of three Australian–Papua New Guinean Acacia species/provenances (*A. mangium, A. auriculiformis, A. crassicarpa*) and *Acacia julifera* was conducted at Kongowe, Kibaha, Tanzania (Kindo *et al.,* 2010). The growth parameters like height, diameter and volume, survival per cent, wood basic density and wood biomass were evaluated. Field data for survival, diameter at breast height and height were collected at ages 2 and 4 years. Result was found to be significantly different in survival, height and diameter growth among species/provenances during analysis. Volume production and wood biomass found to be significantly different ($p < 0.001$) between species only. The difference in volume between the provenances found to be non-significant. It was mentioned that, the variation in survival might be due to the edaphic, environmental condition or the seed sources. *A. crassicarpa* found to be perform higher than that in Indonesia, these variation was probably due to differences in climatic and edaphic factor. Good performance of *Acacia crassicarpa* in volume production was attributed to its advantages in growth in height and diameter at the research site.

Shukor *et al.* (1994) conducted a provenance trail on *Acacia auriculiformis* Benth. Survival rate and growth were assessed at 12 months stage. Among the provenances, 7 were from Queensland, 15 from northern Australia and 6 from Papua New Guinea. The study found that all the provenance survived well (>92%) but they differed very significantly ($P < 0.001$) in their growth performance. The result showed the genetic diversity of the species and can be potentially used for tree improvement programme. Awang *et al.* (1994) studied twenty five provenances of three geographic regions of *A. auriculiformis.* Four trials China, Indonesia, Malaysia, and Thailand at 18 months were inspected for survival and growth. The provenance at each site as well as between site, interaction between the provenances and site were found to be significantly different.

A study was carried out by Kumar *et al.* (2016), to trace the superior genotypes for quality planting stock from an existing twelve-year-old plantation of some selected *Acacia* species. The prime objective of the study was to select the best performing tree species or provenance suitable for better timber yield in Malaysia. They screened four species and four provenances of acacia on the basis of growth performance and other characteristics to assess the genetic variation and growth performance of a base breeding population. The research trial was laid out in a randomized complete block design including four blocks as replication. Twenty progenies selected for each species and sixteen trees representing each progeny. After analysis, it was found that there were significantly different ($p < 0.05$) between species, provenance, and progenies for their growth performance. Altogether with regard to growth, *Acacia mangium* performed better compared to other acacia species. They also found significant differences between provenance within regions and progenies within provenances in all quantitative and qualitative traits tested in this study.

A provenance trial of *Cyclocarya paliurus* (Batalin) lljinsk. was carried out by (Deng *et al.,* 2014). *C. paliurus* is a highly valuable multipurpose tree species mainly used for plantation for timber production and medicinal use. Seeds are collected from six provenances of the natural range of the species. Growth and wood traits between the provenances were studied at the age of seven-year. The analysis of variance revealed that there was significant difference in growth and wood traits at seven year.

Lamichhane and Thapa (2011) conducted an international provenance trail of Neem (*Azadirachta indica*) was established at Butwal Research Station of western Terai region of Nepal in July 1996. The seed sources belong to 23 provenances of ten countries including Nepal. The research trial was carried out in a randomized complete block design with two replication and the total area about 1.5 hectares. The study focused on the survival rate, diameter at breast height (DBH), height, crown diameter and straightness of stem at age 5 and age 10. According to analyzed data, the average survival rates of the provenances in the two assessments were 69.74 and 63.5% respectively and the highest survival rate (92%) was observed for Ramannagudu, India. Moreover, Sunyani, Ban Bo, Yezin, Ramannagudu, and Doitao showed the best performance for DBH. The mean DBH of provenances was 8.74 cm (SD = 2.07). The five provenances namely, Sunyani, Yezin, Ban Bo, Ghaati, and Bandia were the best performer for height. The mean height and SD of provenances were 6.29 m and 0.79 respectively.

Meena *et al.* (2014) studied fifty-four progenies of *Melia azedarach* L. selected from 11 geographical locations in India. The plantation established at a seed farm of Punjab Agricultural University and growth parameters were studied for screening purpose. The variation between and within the progenies was found to be significantly different at the age of 8 years. The highest value for height was recorded 11.50 m and highest value for basal diameter was 23.40 cm. The highest variations were recorded in the number of branches (35.63%), followed by DBH (26.89%), basal diameter (25.25%), and MAI for DBH (25.07%). The lowest variation found in height (16.01%) among the progenies. The highest growth for all traits expressed by Progeny number 1 except a number of branches and clear bole height. The lowest variation showed by total height (16.01%) among the progenies.

Gera *et al.* (2016) investigated around 55 provenances/seed sources of *Dalbergia sissoo* Roxb. which were collected from different locations in India and Nepal as part of National Provenance Trial by ICFRE in 1994 – 1995. Forty seed sources were planted in Basantar Bela, Samba district of Jammu region of J&K in July 1995 in a randomized complete block design. The screening of seed sources was started during January 2010 by taking survival and growth parameter into consideration. The parameters like height, diameter, and volume over bark shows the significantly different result when compared to seed sources not between replications. The variation found in the trial may not because of the difference in the climate of the locations from where the seeds were collected. It was also found that the seeds from Mirzapur, Nepal, and Pratapgarh gave good result compared to the other sources, in terms of height, diameter, survival, and volume.

Sudrajat *et al.* (2016) studied Genetic parameters on initial growth of *Niolamarckia cadamba* (Roxb.) Bosser, an indigenous species with potential source of wood timber. The experiment was consist of 12 provenances and 105 families arranged in a randomized complete block design with 5 replication. It was an open-pollinated provenance-progeny test at two locations of West Java provenance, Indonesia. Collar diameter and total height were measured at 12 months after planting in the field. The analysis of variance showed a significant difference between the provenances and within the provenances. In one site the analysis revealed, the difference was not-significant for collar diameter.

2.4 WOOD PHYSICAL PROPERTIES

2.4.1 Basic density

Miranda *et al.* (2007) studied the impact of provenance and site on wood density *Eucalyptus globulus* Labill. Thirty seven provenances of *E. globulus* were used in this study. The analysis of variance revealed that, the variance in basic density between the provenances was highly significant ($P<0.001$). Variation between the sites within provenance also exhibited significant difference ($P= 0.004$), the interaction between site and provenance was found to be non-significant ($P= 0.355$). The study also revealed that, the wood density increased with the increase in age.

Cáceres *et al.* (2017) studied the wood variation in density and extractive contents of Japanese larch (*Larix kaempferi* (Lamb.) Carr.) in a provenance trial. Seven trees are selected for 20 provenances, total 140 trees are cross cut from a thinning operation. The result showed the basic density between the provenances were not significant. Whereas within-tree variation in basic density found to be significantly different. Thus, the density is more near to the base while comparing to the density at 4 meters height.

Kimberley *et al.* (2017) studied the basic density variation of *Pseudotsuga menziesii* (Mirb.) Franco grown in New Zealand. For an extensive study the increment core samples were collected from approximately 10,800 individual trees from 312 stands throughout the country, pith-to-bark radial density profiles from 515 trees from 47 stands and discs taken from multiple heights in 172 trees from 21 stands. The analysis of variance revealed that, the variation in density was significantly different between the sites and between trees within a stand.

Machado *et al.* (2014) studied the variation in basic density and mechanical property between trees (sites) and within trees (longitudinal and radial) for Blackwood (*Acacia melanoxylon* R. Br.). Twenty trees were selected randomly for the study (40 cm dbh class, 33–51 years of age), samples from different radial and longitudinal plane were collected. For measuring the air-dried density the moisture level reduced to 12%. The result showed that there was no significant difference in basic density, compression strength parallel to grain (CS), bending strength (MOR) and modulus of elasticity (MOE) between trees. All these properties showed significantly different result within the trees.

Yanchuk *et al.* (2007) investigated the intra-clonal wood density variation of aspen (*Populus tremuloides* Michx.). Four trees from each of three reputed clones are selected for the study. The result exhibited significant difference between the sampled clones. The longitudinal variation in density was significantly different, the density more at the base and decreases at mid-height and increases again near treetop. The variation along the radial direction was not significant within the trees

Gartner *et al.* (2007) studied six 40-year-old red alders (*Alnus rubra* Bong.) that were harvested from a mixed stand of *A. rubra* and big-leaf maple (*Acer macrophyllum* Pursh) in Oregon Coast Range to evaluate the variation in wood properties. The study revealed that the specific gravity varied significantly between the trees. The mean specific gravity ranges in between 0.45 to 0.51 between the trees.

2.4.2 Wood colour

Colour is also an important feature in wood like other physical properties, which determines final utilisation of wood in to various products. Wood colour has a significant effect on the aesthetic value of wood, hence it helps in increasing the market demand and price as well. Consumers always like to purchase superior quality wood along with attractive appearance. Heartwood colour variation between homesteads and plantation grown teak was assessed (Thulasidas *et al.*, 2006). Two methods were adopted to determine the wood colour i.e. CIE 1976 (L^* a^* b^*) system and Munsell system. According to the Munsell colour system hue, value, and chroma were considered for identification of colour. The result revealed, heartwood colour did not vary significantly between the homestead and plantation grown teak ($P < 0.05$)

Montes *et al.* (2008) studied the genetic variation in wood colour of *Calycophyllum spruceanum* (Benth.) Hook.f. ex K.Schum. at young stages. They also studied the correlation of tree growth and density of wood with colour. To study the variation and correlation a provenance/progeny trial was established and the colour variations in the wood were studied after 39 months. CIELab technique was used to study the colour. The variation in wood colour found to be significantly different between the provenances, also significant difference found between families within the provenance. Some colour characteristics varied significantly due to the planting zones. The genetic correlation exposed that the selection of denser wood species or the species with faster growth rate had less effect on wood colour and its uniformity.

Grekin (2007) studied the colour variation of scot pine wood (*Pinus sylvestris* L.) in the air dry condition. Wood samples were collected randomly from sixty different scot pine dominated stand, Finland. Wood samples were extracted from the different height of log with the desired dimensions. The wood lightness differed significantly between the heartwood and sapwood, even more difference found with the increase in height. Lightness was significantly higher in sapwood than heartwood. With the increase in height the sapwood percentage increases which add the difference in the lightness of wood. For individual colour parameters L*, a* and b* within-tree variation found between 43 to 77 per cent. Tree to tree variation within a stand was found to be significant between 17 to 40 per cent. The variation between stand within a region even less significant between 5-15 per cent.

2.4.3 Grain

The word grain technically known as the arrangement of wood cell fibres along the main axis of the stem (Tsehaye and Walker, 1995). From the craftsmen's point of view grain is one among few criteria for selecting wood. In *Pinus radiata* D. Don Spiral grain angle was found to be increase with increase in stem height whereas, the angle was decreases with gradual increase in distance from pith towards bark. The variation in spiral grain was significantly different among the trees and within the trees as well. The spiral grain arrangement was predominant in all the trees irrespective in site (Cown *et al.*, 1991).

2.5 WOOD ANATOMICAL PROPERTIES

Anoop *et al.* (2012) studied the wood anatomical properties of the different provenance of selected *Acacia* species. Wood anatomical parameters like ray height, ray width, tissue proportion, vessel frequency, vessel element diameter and heartwood percentage as physical properties were studied. Between the provenances, variation in vessel diameter found to be significantly different. The remaining anatomical properties are found to be non-significant between the provenances.

Sahoo *et al.* (2017) investigated between zones variation in vessel morphology of *Artocarpus hirsutus* LAM. Thrissur, Kerala. Core wood samples were collected from three agro-ecological zones and also from three girth classes for the study. The analysis of variance revealed that, there was no significant variation in vessel frequency between the zones as well as girth classes. The value for vessel frequency found to be 2-3 no/mm^2 between the zones. Vessel diameter and vessel area did not show any significant variation between the zones as well as girth classes. Moreover vessel length exhibited significant difference between the zones, but between girth classes no significant variation was founded. The value for vessel length ranges between 248.47 µm to 289.43 µm for coastal sandy, 126.86 µm to 171.31 µm for central midland, and 192.71 µm to 330.27 µm for Malayoram.

Gartner *et al.* (2007) observed within and between trees variation in wood physical and anatomical parameters of Red Alder (*Alnus rubra* Bong.). Wood samples were collected from a mixed stand of *A. rubra* and big-leaf maple (*Acer macrophyllum*), Oregon coast range to study the variation. The result revealed, significant difference in the specific gravity and vessel diameter between the trees. The mean vessel diameter varied from 43 to 71 µm between the six trees. Kouba *et al.* (2007) studied the variation pattern in fibre length of within clones, between clones and within the stem of hybrid poplar. The result exhibited significant difference in fibre length between ten hybrid clones.

Jorge *et al.* (2000) studied the fibre length variation in wood and bark of *Eucalyptus globulus* Labill.. Wood samples were collected from three different locations of Portugal, 10 trees selected from each location. The result showed fibres from both wood and bark are morphologically similar but generally longer in the bark. The bark fibre length increases with the increase in height, whereas the wood fibre length decreases with increase in height. Fibre length in wood increases significantly from pith to bark.

Leal *et al.* (2006) studied between and within tree difference in the biometry of wood fibres and rays in cork oak (*Quercus suber* L.). They studied the variation in three radial positions in five cork oak trees of age about 40 years. As the tree species contained both uniseriate and multiseriate rays, the height and width were measured from the tangential plane. Fibre anatomical features (height and width) are studied after the maceration. They found the average multiseriate ray height 5.16 mm and width 0.48 mm, and average uniseriate ray height were 227 μm. The analysis revealed that, the variation in rays dimension non-significant in radial plane and they also found little variation between-tree. Fibre dimension increased with increase in radial length but little difference found between the trees, on average fibre length 960–1,220 μm, width 18.40–21.49 μm and wall thickness 6.66–8.07 μm.

2.6 BIO-CONTROL OF TWO MAJOR INSECT/PEST

Eligma narcissus Cramer considered as the serious pest of *Ailanthus triphysa* in South India (Chatterjee and Sen Sarma, 1968). Two major insect pest for the genus *Ailanthus* were *Eligma narcissus* Cramer and *Atteva fabriciella* Swederus (Chaterjee *et al.*, 1969). Ailanthus webworm *Atteva fabriciella* Swederus is considered as a major insect pest for *Ailanthus excelsa* causes wide spread defoliation in plantations and nurseries (Brown, 1968). The major species of bacterial bio pesticides belong to the genus *Bacillus* were *Bacillus thuringiensis*, *Bacillus lentimorbus*, *Bacillus papillae* and *Bacillus cereus* (Hogodson, 1990). Among them *B. thuringiensis* gets much attention due to its long range of host killing ability and its higher potency. In most cases, the effect started after 10-15 hr and clearly seen after 24 hr of feeding by the insect larvae (Dhaliwal *et al.*, 2014). After feed on *B. thuringiensis* treated leaves, the larva becomes lethargic and inactive and seizes feeding due to the loss of appetite. At first stage the larva becomes light brown color, gradually shrinks in size and becomes dark brown finally death (Heimpel and Angus, 1963).

Shamila and Lall (2000) studied the efficacy of three varietal toxins of *Bacillus thuringiensis* (thuringiensis (BTB) and 2 products of kurstaki, LDC, and Dipel) on some important forest insect pest. The bio pesticides were tested at different concentrations (2.0

%, 1.5 %, 1.0 %, 0.5 %, 0.25 %, and 0.10%) against ten important insect pest at nursery and plantation level. They found that all the defoliators were controlled effectively by spraying 1.5 % concentration of *B. thuringiensis*. The pest tested and their host plants were, *Pongamia pinnata* (*Hasora chromus*), *Dalbergia sissoo* (*Plecoptera reflexa*), *Tectona grandis* (*Hyblaea puera*, *Eutectona machaeralis*), *Dendrocalamus strictus* (*Pyrausta bambucivora*), *Albizia procera* (*Rhesala imparata*), *Populus deltoids* (*Phalantha phalantha*),

Joshi *et al*. (1996) investigated the effectiveness of three varietal toxins of *Bacillus thuringiensis* against ailanthus leaf defoliator *atteva fabriciella* Swederus (ailanthus webworm). The toxins were (var. dendrolimus endotoxin, var. thuringiensis and its exotoxin and var .kurstaki endotoxin) applied by spraying on larva and host plant *Ailanthus excelsa* Roxb. The result found that, the defoliators were controlled significantly by spraying the Bt on host plant than on the target pest. Among the three toxin var. dendrolimus endotoxin found to be highly effective against both the larval and host plant application at 2.0% and 1.5% level of concentration.

Roychoudhury and Joshi (2009) studied the toxicity of Ivermectin and larval mortality of Ailanthus webworm *Atteva fabriciella* Swederus. Ivermectin (Ivecop-12) is a derived avermectin B produce from a soil actinomycete *Streptomyces avermitilis*. The last instar larvae of *A. fabriciella* were collected and starved for one hour prior to the bio-assay. Eight different concentrations of Ivermectin prepared, sprayed on fresh leaves and given to the starved larvae and one treatment kept under control. Three replications kept for each concentration and the process repeated for three times. The observations were recorded after 24, 48 and 72 hours of treatment. The result revealed that, four concentrations of Ivermectin cause hundred percent mortality of *A. fabriciella* i.e. 1.2, 0.6, 0.3, 0.15% and significantly different from other lower concentration including control. Moreover, there was a gradual decline in mortality rate with the decrease in concentration of insecticide.

Bai *et al*. (2015) studied the effect of *Metarhizium anisopliae* Metschn. against *Eligma narcissus* Cramer. This fungi was also known as one of most effective biocontrol agent against the insect. In this study, the bio efficacy of 25 isolates of *Metarhizium anisopliae* was determined to evaluate the toxicity against *E. narcissus* in the laboratory and field condition. They found MIS7 and MIS13 were more effective against *E. narcissus*. The toxicity of isolates MIS7, MIS13, and 0.5% *Pongamia pinnata* L. Pierre seed oil in different concentration increases the larval mortality rate. Formulation of "MIS7 + MIS13" and "MIS7 + MIS13 + 0.5% *Pongamia* seed oil" proved to be superior against E. narcissus, causing 93.93% and 76.30% mortality. In a field trial, MIS7 + MIS13 showed 53.76% reduction of infestation with 6.56 larvae per plant, whereas MIS7 + MIS13 + 0.5% *Pongamia* seed oil showed 60.53% reduction of infestation with 5.79 larvae per plant, respectively.

Govindachari *et al.* (1996) investigated the insect growth regulatory and antifeedant activity of neem (*Azadirachta indica*) seed oil. They found significant mortality against *Spodoptera litura* due to azadirachtine. Nathan *et al.* (2005) studied the effect of neem (*Azadirachta indica* A. Juss) limonoids on *Anopheles stephensi* Liston (Diptera: Culicidae). The reported Azadirachtin was the most potent in all experiments and induced almost 100 per cent larval mortality at 1 ppm concentration level, first to third instars larvae were more susceptible to the neem limonoids.

2.6.1 Scoring pest incidence

A study was carried out to evaluate the inter-provenance variation in resistance of blue gum (*Eucalyptus globulus* Labill.) against *Mnesampela private* Guenée insect-pest in early stage of growth (Farrow *et al.*, 1994). After six months of planting insecticide (0.1% Carbaryl) was sprayed to ensure the survival of seedlings, no spraying was carried out after that. Total eight provenances distributed in three blocks. They found the resistant of different provenances against *M. private* was inconsistent. Shujauddin and Kumar (2003) in *Ailanthus triphysa* (Dennst.) Alston. tried to score the incidence of two lepidopteran insect pest *Eligma narcissus* Cramer and *Atteva fabriciella* Swederus. They notice the extent of defoliation was moderate throughout the plantation.

Materials and Methods

3. MATERIALS AND METHODS

3.1 MATERIALS

The present study on "Screening of superior genotypes of *Ailanthus triphysa* (Dennst.) Alston, (*Matti*) for matchwood quality" was conducted to evaluate the variations in growth and wood traits between the seed source of *Ailanthus triphysa*, collected from different locations of Thrissur and Palakkad district. The study aimed at screening the superior genotypes of *A. triphysa* through an assessment of the genetic worth of their parent and to develop a possible biocontrol method against two major insect pest (*Eligma narcissus* Cramer) and *Atteva fabriciella* Swederus). The experiment comprises of 20 half-sib families of *A. triphysa* laid out in RBD (Randomized Block Design) with 4 replications grown under a tree improvement trial.

3.1.1 Species studied

Species : *Ailanthus triphysa* (Dennst.) Alston.

Family : Simaroubaceae

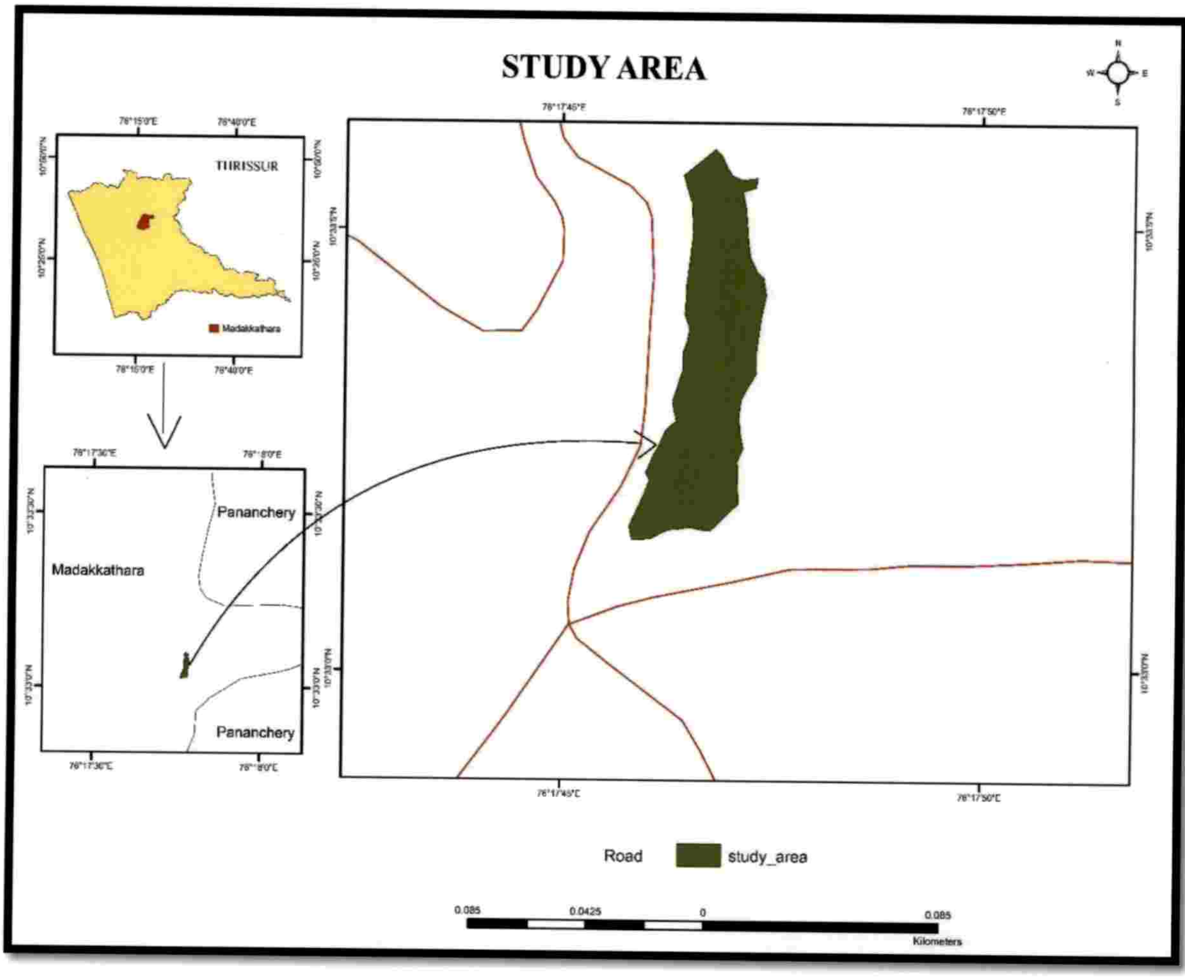
Order : Sapindales

Synonyms : *Ailanthus malabarica* DC.

3.1.2 Location

The research plot (experimental site) of the present study was located at the Kerala Agricultural University (KAU) main campus near Aramkal, Thrissur district (N 10° 55' 10'' latitude, E 76° 29' 63'' longitude and elevation 42 m above mean sea level) of central Kerala, India. The total area of the plantation was about 2 acres. The trees were field planted during October 2015 with a spacing of 3m×3m. The treatments were arranged in a Randomized Block Design (RBD) with 4 replications. Each half-sib family consist of 16 trees (4 trees × 4 replication), and total 20 CPTs × 16 = 320 trees were present in the plot.

Plate 1. Map showing the location of the experimental trial at Vellanikkara Thrissur, Kerala



3.1.2.1 Candidate Plus Trees

The seeds were collected from two districts in Kerala (Thrissur and Palakkad). Five panchayats each were selected from Thrissur and Palakkad districts. Total of twenty Candidate Plus Trees (CPTs) were identified from Madakkathara, Nadathara, Kolazhi, Pananchery, Mulakkunathukavu panchayats of Thrissur district and Cherupulashery, Vilayur, Koppam, Pattambi and Ongallur panchayats of Palakkad district. Two CPTs from each panchayats which recorded seed set were included in the study. Selected CPTs were assigned with the accession number as FCV AT (FORESTRY COLLEGE VELLANIKKARA AILANTHUS TRIPHYSA).

3.1.3 Wood samples

Out of total twenty Candidate Plus Trees (CPTs) ten trees were felled and the samples were collected from the remaining ten trees. Collected samples of ten candidate plus trees (CPTs) were from Madakkathara, Nadathara, and Pananchery panchayats of Thrissur district and Koppam, and Pattambi panchayats of Palakkad district respectively (Table 1.). From these trees, both core and cube samples (3 cm ×3 cm×2 cm) were taken. Core samples were collected using Haglof increment borer from the breast height. Cubes were collected using chisel and hammer from the breast height.

3.1.4 Insect larva

The insect larvae for the bioassay were collected from the research plot.

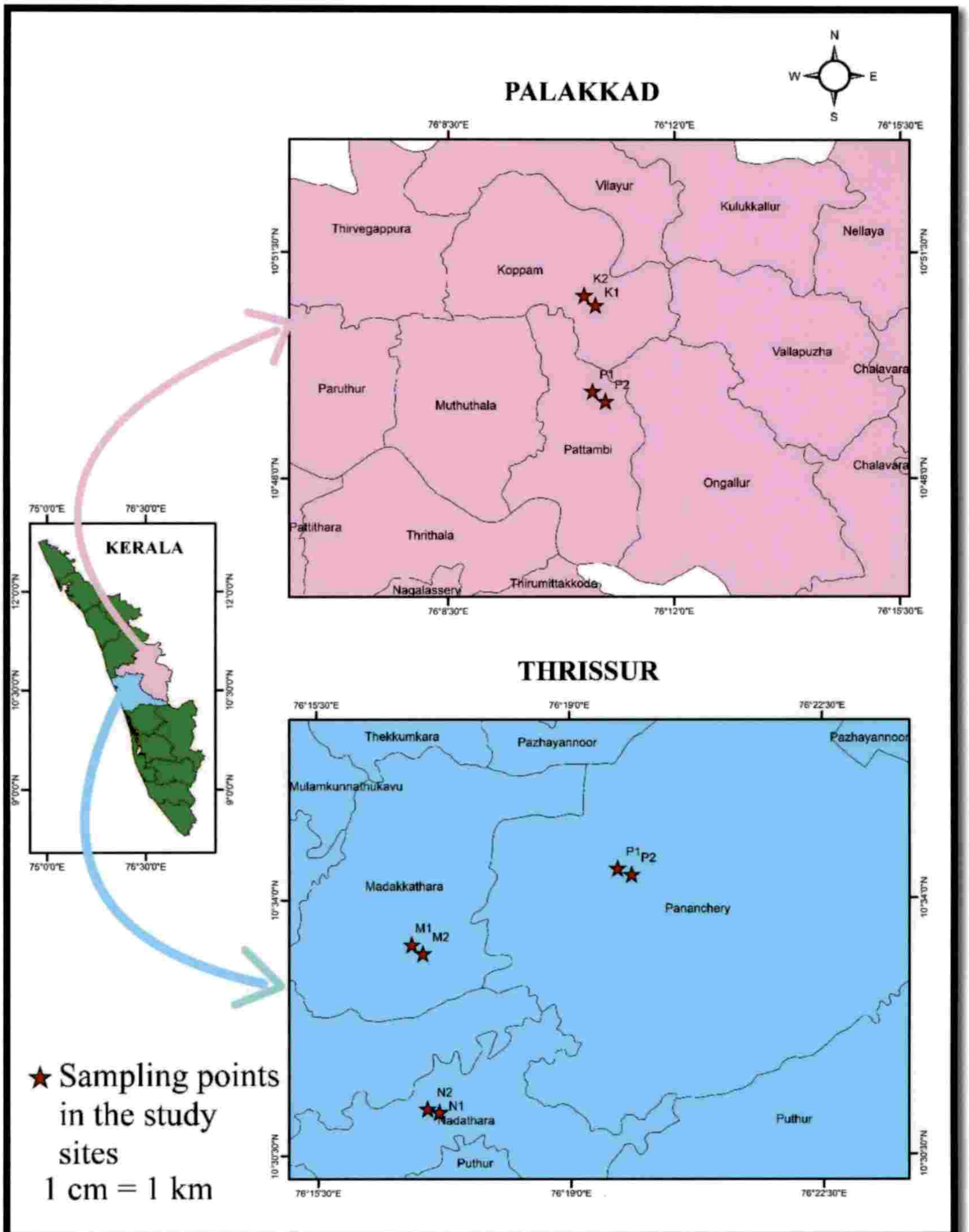
3.1.4.1 *Eligma narcissus* Cramer

First and second instar larvae of *Eligma narcissus* Cramer were collected from the field.

3.1.4.2 *Atteva fabriciella* Swederus

Healthy larvae of *Atteva fabriciella* Swederus were collected from the field.

Plate 2. Map showing sample collection sites in various panchayats of Thrissur and Palakkad district, Kerala



3.1.5 *Bacillus thuringiensis*

Bacillus thuringiensis popularly known as (Bt) is a gram positive bacteria. Liquid *Bacillus thuringiensis* (10% active ingredient) was used as a biocontrol agent in the bioassay.

3.1.6 Neem oil

Neem oil (*Azadirachta indica* A. Juss.) a plant origin eco-friendly pest repellent (Azadirachtin= 400-500 ppm) was used in the bioassay.

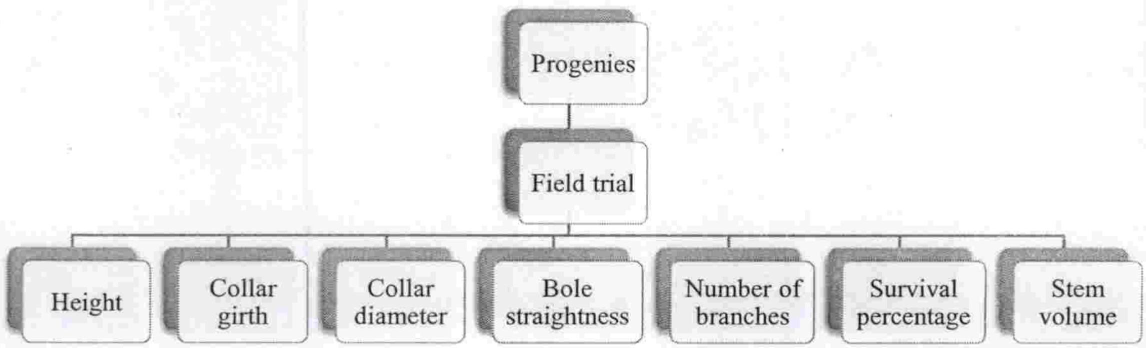


Figure 1. Work carried out based on the progenies of Candidate Plus Trees (CPTs) of *Ailanthus triphysa* laid out in the experimental trial

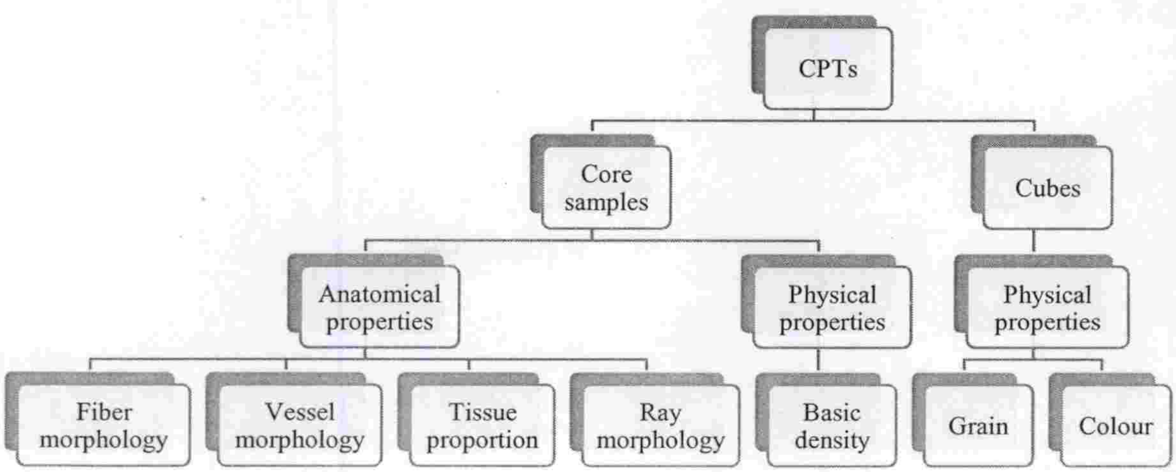


Figure 2. Wood physical and anatomical studies carried out based on the Candidate Plus Trees (CPTs) of *Ailanthus triphysa*

3.2 METHODS

The methods which were carried out in the studies summarised below.

3.2.1 Field trial

3.2.1.1 Height

The height of the progenies from ground level to the tip were measured with the help of a calibrated measuring stick and expressed in meter. The readings were taken in a bimonthly interval for one year.

3.2.1.2 Collar girth

The collar girth was measured in centimetre with the help of a measuring tape at the collar region of the progeny trees. The observations were taken in a bimonthly interval.

3.2.1.3 Collar diameter

The collar diameter was measured in millimetre, using a vernier calliper at the collar region of the progeny trees. The readings were taken in a bimonthly interval.

3.2.1.4 Number of branches

Number of branches of the progenies were taken through simple counting method.

Plate 3. Biometric data and core wood samples collection from the mother trees of *Ailanthus triphysa*

Height measurement of progeny trees

Collar diameter measurement

Collection of wood sample using increment borer

Core samples taken out using the increment borer

Table 1. Details of the Candidate Plus Trees (CPTs) of *Ailanthus triphysa* included for wood physical and anatomical study

location	Trees	Height (m)	Girth at Breast Height (cm)	Latitude	Longitude
Madakathara (Thrissur)	FCV AT 1	24	152	10 ° 54’ 75’’	76° 27’ 74’’
	FCV AT 2	19	156	10° 54’ 82’’	76° 28’ 04’’
Nadathara (Thrissur)	FCV AT 3	23	117	10° 51’ 66’’	76° 26’ 57’’
	FCV AT 4	22	110	10° 51’ 75’’	76° 26’ 48’’
Pananchery (Thrissur)	FCV AT 7	18	118	10° 55’ 46’’	76° 32’ 38’’
	FCV AT 8	19	112	10° 55’ 42’’	76° 32’ 39’’
Koppam (Palakkad)	FCV AT 15	22	131	10° 52’ 19’’	76° 11’ 30’’
	FCV AT 16	21	119	10° 52’ 18’’	76° 11’ 32’’
Pattambi (Palakkad)	FCV AT 17	19	132	10° 87’ 80’’	76° 12’ 96’’
	FCV AT 18	22	120	10° 87’ 37’’	76° 11’ 85’’

3.2.1.5 Bole straightness

Bole straightness was measured by the scoring method, where the score is divided into four categories given below (Hegde *et al*, 2009).

Score	Description
1	Very crooked with 2 serious bends
2	Slightly crooked with 2 small bends or less than 2 serious bends
3	Almost straight with 1 or 2 small bends
4	Completely straight

3.2.1.6 Survival percentage

The survival percentage was calculated by using the formula given below (Mohamed *et al*., 2015).

$$\text{Survival percentage} = \frac{\text{Number of survived seedlings}}{\text{Seedlings present initially}} \times 100$$

3.2.1.7 Stem volume

Stem volume of the progenies were calculated using quarter the girth formula (Deka *et al*., 2015).

$$V = (g/4)^2 \times l$$

Where,

V= Volume (m^3)

g= Middle girth

l= Length

3.2.2 Wood physical properties

Wood physical properties like grain, colour, and basic density were done for Candidate Plus Trees (CPTs) only.

3.2.2.1 Grain

Cube samples (3 cm × 3 cm × 2 cm) were studied using visual method to know the grain structure.

3.2.2.2 Colour

Munsell colour chart was used to study the colour difference in the collected wood samples (Anon., 1971). Colour difference is considered for visual elucidation as influenced by personal judgment of colour. Wood samples were converted into powder form and placed in the round opening present below each colour chart, which provides easy comparison with the rectangular colour chips. Collected samples were air dried prior to the study. The colour is then distinguished by its hue, value, and chroma. Hue ranges from 9.9 R to 1.0 Y, from red to yellow. Value ranges from 0 for pure black to 10 for pure white, which indicates the lightness/darkness of colour. Chroma is otherwise called the purity of colour. Colour of low chroma is sometimes called weak, while those with high chroma is said to be highly saturated, strong or vivid.

3.2.2.3 Basic density

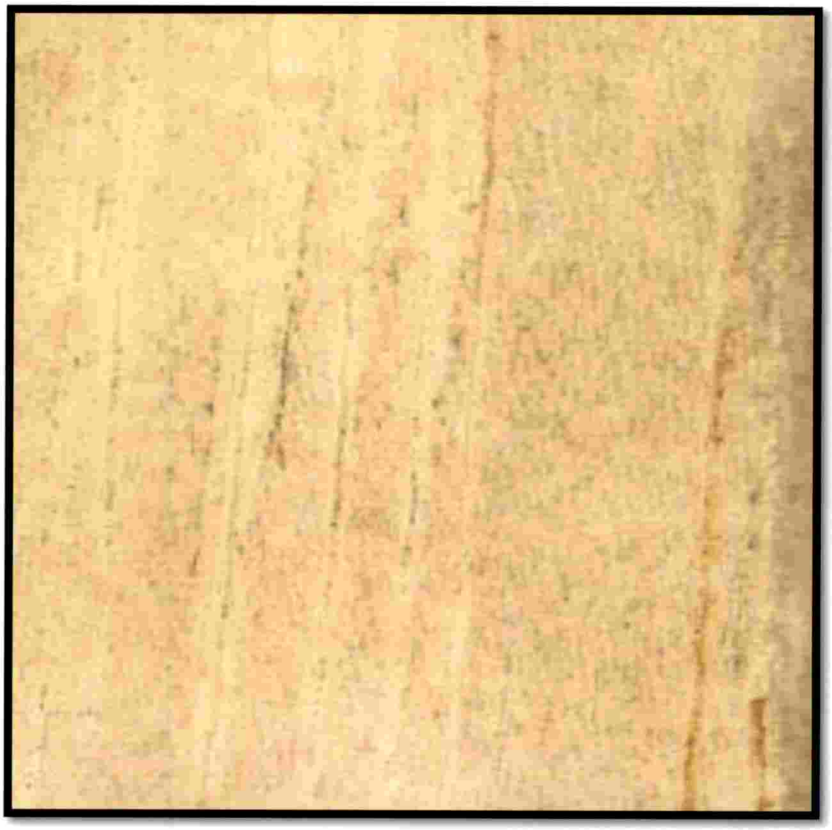
The green volume of core sample was estimated using the immersion method. The samples were kept in oven dried condition 103°C ± 2°C for 24 hours and determination of oven dry weight using a precision electronic balance (Shimadzu AUY 220) and were weighed correct to 0.001g.

Basic density (standard specific gravity) of wood specimens were calculated by the following formula,

$$\text{Basic density (g cm}^{-3}\text{)} = \frac{\text{Oven dry weight}}{\text{Green volume}}$$

Plate 4. Wood color and grain structure studies

Colour comparison using Munsell color chart



Grain structure

3.2.3 Wood anatomical properties

Wood anatomical properties like fibre morphology, vessel morphology, vessel frequency, tissue proportion, and ray morphology were studied.

3.2.3.1 Fibre morphology

Fibre morphological characters (length, width, wall thickness) was studied using temporary slides prepared from the macerated wood samples of CPTs of *Ailanthus triphys*. Fibre length was observed under 4X magnification, fibre width was observed in 10X lance, and fibre wall thickness observed in 40X lance. Ten observations were taken for each sample.

3.2.3.2 Vessel morphology

Vessel length was studied using temporary slides prepared from the macerated wood samples of CPTs. Vessel length was assessed under 4X magnification, five observations were taken per sample. Vessel area and vessel diameter were studied using permeant slides (Transverse section). Vessel area and diameter were measured under 10X magnification, ten observations were taken per sample. To estimate the vessel frequency, a square of dimension 1 mm^2 was drawn using digi-pro software, observations were taken under 4X magnification. Number of vessels came inside the square was counted, if more than half of a vessel area came inside the square was also counted as one. Five observations were taken per sample.

3.2.3.3 Tissue proportion

Tissue proportion was studied using permanent slides (Transverse section), a straight line of 1000 μm length was drawn randomly using digi-pro software under 4X magnification. Number of cells of respective tissues were counted and the proportion was calculated using the formula given below. Tissue proportion includes fibre proportion, parenchyma proportion (axial and ray), and vessel proportion, five observations were taken per sample. Transverse sections were used to study vessel area, vessel diameter, vessel frequency, and tissue proportion.

$$\text{Fibre proportion} = \frac{\text{Number of fibre cells}}{\text{Number of total cells counted}} \times 100$$

$$\text{Parenchyma proportion} = \frac{\text{Number of parenchyma cells}}{\text{Number of total cells counted}} \times 100$$

$$\text{Vessel proportion} = \frac{\text{Number of vessel cells}}{\text{Number of total cells counted}} \times 100$$

3.2.3.4 Ray morphology

Ray morphology was studied using tangential sections, ten readings were taken per sample. This species contained both multiseriated and uniseriated rays. Multiseriated rays were studied under 4X magnification whereas, uniseriate ray studied under 10X magnification separately. Ten observations were taken per sample for each character.

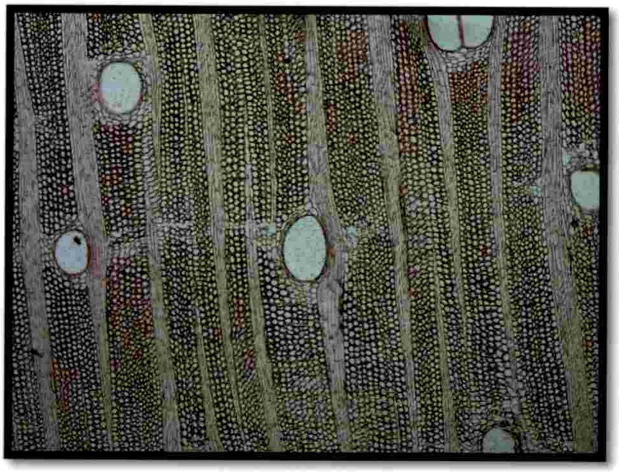
3.2.4 Microtomy

Wood core samples size of 3 cm were taken out from each Candidate Plus Trees (CPTs) by using a Haglof increment borer and anatomical properties were studied. To obtain good sections the collected specimens were kept in a water bath (Rotek water bath) at 100°C for 15 to 20 minutes. Transverse section (TS) and longitudinal section (TLS) were prepared using a sliding wood microtome (Leica SM 2000R) of thickness around 10-15 µm. The sections were kept in saffranin for 6-8 minutes for staining and later the sections were passed through a series of alcohol (70%, 90%, and 95%) for 3 minutes each to ensure complete dehydration. They were subsequently kept in acetone followed by xylene and finally mounted in DPX mountant to prepare permanent slides (Johansen, 1940).

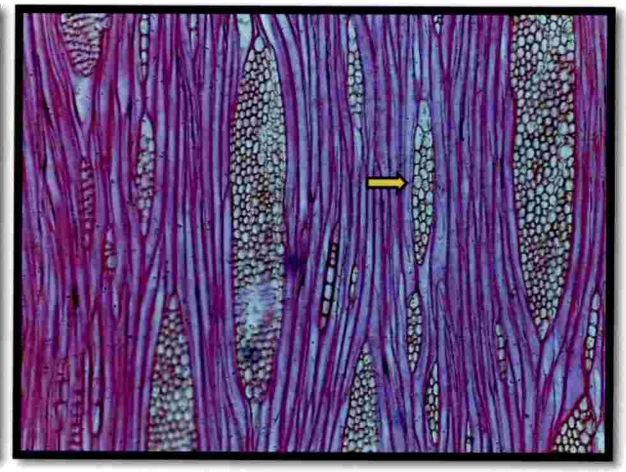
3.2.5 Maceration

Maceration of the collected wood samples was done through Jeffrey's method (Jeffrey, 1917). The Jeffrey solution was prepared with 10 per cent nitric acid and 10 per cent potassium dichromate and by mixing with an equal volume of water. Radial shavings was collected from the specimen. The Jeffrey solution

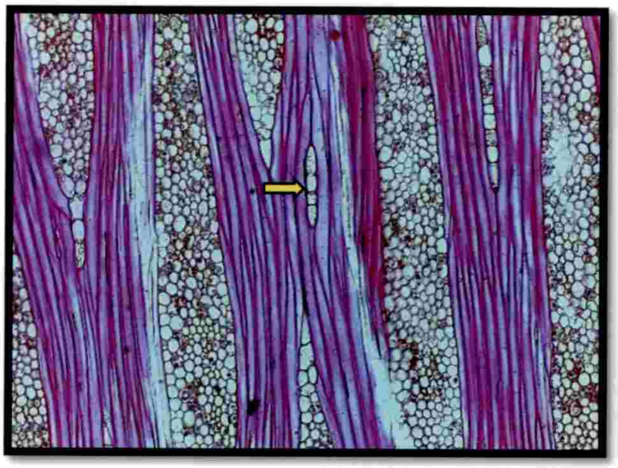
Plate 5. Profiling of wood anatomical properties



5a



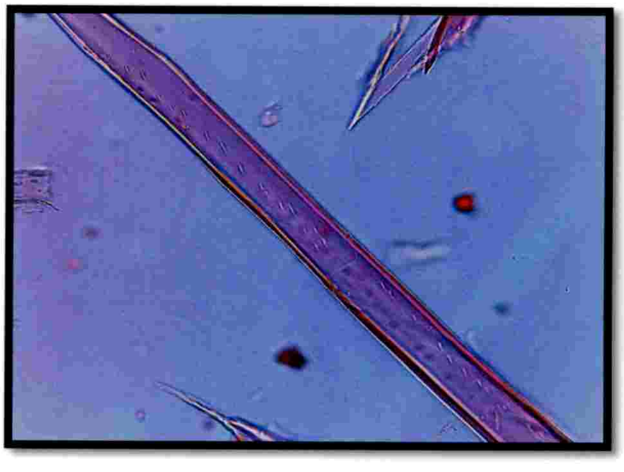
5b



5c

5d

5e



5f

Plate 5. Anatomy of (*Ailanthus triphysa* (Dennst.) Alston.) wood a. Diffuse porous wood (TS 4X) b. Multiserated ray cells (arrow head) TLS 4X c. Uniseriated ray cells (arrow head) TLS 4X d. Vessel (Maceration 4X) e. Fibre (Maceration 4X) f. Fibre wall thickness (Maceration 10X)

containing shavings were taken in a glass tube and boiled for 15-20 minutes, which helped to separate individual fibres. The solution was discarded and the resultant material was washed repeatedly with distilled water until the traces of acid were removed. The samples were stained using saffranin. Temporary slides were prepared using glycerin as the mountant.

3.2.6 Image analysis

Quantitative analysis of prepared wood micro-sections were carried out using an Image Analyzer (Labomed-Digi 4). It constitutes a PC (Personal Computer) and a microscope and digital camera. The image analyser provides quick and authentic data. The software provides facilities for a variety of measurements like length, width, diameter, area, proportions, and frequency.

3.2.7 Bioassay

There are two lepidopteran species *Eligma narcissus* Cramer and *Atteva fabriciella* Swederus that causes vast damage to the plant and stabilize the growth.

3.2.7.1 Bacillus thuringiensis

3.2.7.1.1 Eligma narcissus Cramer

The first and second instar larvae were collected prior to the laboratory experiment. The larvae were kept overnight under staved condition. Four different concentrations of Bt solution (1%, 5%, 10% and 15%) were used. Fresh leaves were collected and cut into approximately 1 cm^2 size and treated with different concentrations of Bt by using hand sprayer and kept for drying. After drying, the leaf samples were given to each larva in a custom-made plastic tube, specially made for bioassay. The observations were taken at different time intervals (24, 48 and 72 hours).

3.2.7.1.2 Atteva fabriciella Swederus

Healthy larvae were collected from the field and kept under starved condition overnight. Three different concentrations of Bt solution (1%, 2.5%, and

5%) were prepared. The fresh leaves collected were cut into 1 cm^2 dimension and treated with Bt solution using a hand sprayer and kept a while for drying. After drying the leaf samples were given to each larva in a custom-made plastic tube, specially made for bioassay. The observations were taken at different time intervals (24, 48, and 72 hours).

3.2.7.2 Neem oil

3.2.7.2.1 Eligma narcissus Cramer

Healthy larva were collected from the field and kept under starved condition for four hours. Two different concentrations (1%, 2%) of neem oil solution were prepared. Fresh leaves of *A. triphysa* were collected prior to the experiment. The leaves were then treated with the prepared solutions using a hand sprayer and kept for drying. After drying completely the treated leaves were given to the larvae in a glass bottle. Ten larvae were taken for each concentration. Three replication were taken for each concentration and a control was kept.

3.2.7.2.2 Feeding rate

The initial and final leaf area was measured using Digimizer image analysis software and observations were taken after 24 hours of treatment. Feeding rate was calculated using the formula given below and expressed as percentage.

$$\text{Feeding rate (\%)} = \frac{\text{Initial leaf area} - \text{Final leaf area}}{\text{Initial leaf area}} \times 100$$

3.2.8 Scoring of pest incidence

The incidence of attack by the two lepidopteran insect pest (*Atteva fabriciella* Swederus and *Eligma narcissus* Cramer were observed in the trial plot. The trees were left to recover naturally and no insecticide was applied till the scoring of the trees were finished. To evaluate the impact of pest incidence, a one-time visual scoring of all trees was done in the second year. The scoring was done using a visual scale from '0' to '9', where 0 stands for 'not infected' and 9 stands for 'severely infected'. This was done by observing the extent of defoliation and

Plate 6. Stages of development of *Eligma narcissus* Cramer and *Atteva fabriciella* Swedrus

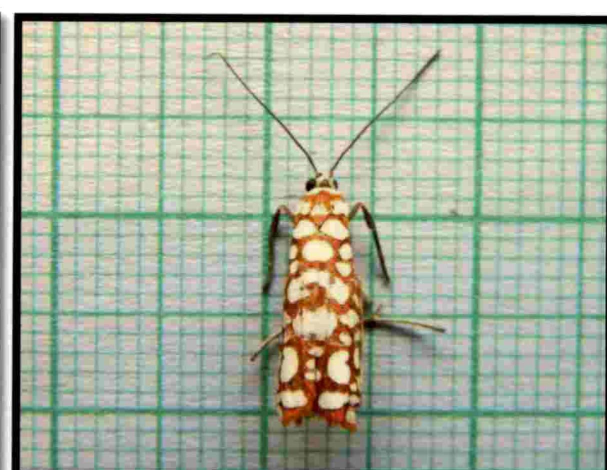
6a

6b

6c

6d

6e

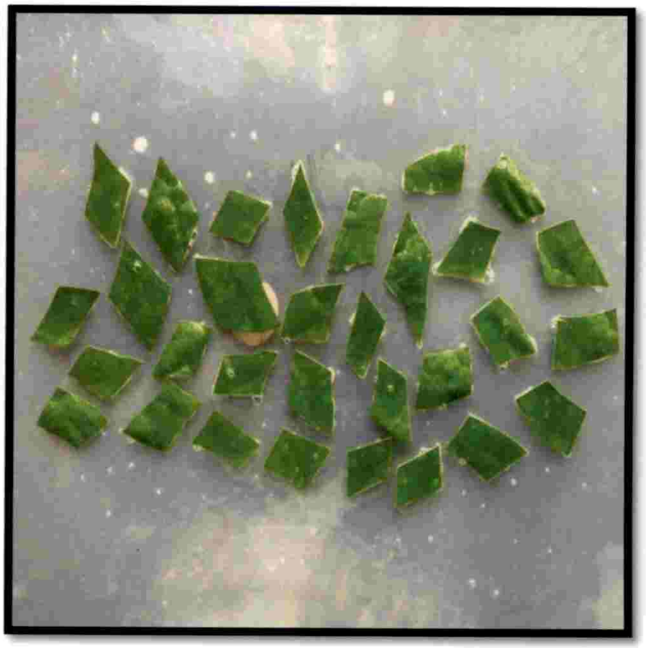


6f

Plate 6. *Eligma narcissus* (Cram.) (6a. Larvae 6c. Pupa 6e. Adult moth), *Atteva fabriciella* Swedrus (6b. Larvae 6d. Pupa (Arrow head) 6f. Adult moth)

Plate 7. Bioassay

Collection of insect larvae from the field



Leaf samples treated with *Bacillus thuringiensis*

Treated leaf samples kept for drying

Treated leaf samples fed to the larvae

growth retardation. Observations were taken during the peak season of attack, during April for *A. fabriciella* and for *E. nscissus* during August (Shujauddin and Kumar, 2003).

3.2.9 Genetic studies

3.2.9.1 General combining ability

General combining ability (GCA) is the average performance of the progeny of an individual when it mated to a number of other individuals (Falconer, 1960). The value representing GCA is also called as deviations from the total mean value. The parents with positive GCA indicates above average performances, GCA equal to zero indicates average performance, negative GCA indicates below average performance.

GCA_x = Mean of Parent X – Test mean

3.2.9.2 Broad sense heritability (H^2)

Broad sense heritability (H^2) is the ratio between total genetic and phenotypic variation in a population. It ranges between 0 to 1, if all the variation was due to genetics the H^2 would be equal to 1. A lower value of 0 would occur if none of the variation in a population was attributable to genetics (Zobel and Talbert, 1984).

$$\sigma^2_G = \frac{MSt - MSe}{r}$$

$$MS_t = \sigma^2_e + r\,\sigma^2_G$$

$$MS_e = \sigma^2_e$$

$$\sigma^2_P = \sigma^2_G + \sigma^2_e$$

$$H^2 = \sigma^2_G / \sigma^2_P$$

Where,

σ^2_G = Genetic variation

σ^2_P = Phenotypic variation

σ^2_e = Environmental variation

MSt = Mean sum of square of Candidate Plus Trees

MSe = Mean sum of squares of error

r = Number of replication

3.2.10 Statistical analysis

The data were analysed using the statistical package IBM SPSS version-21.0 for windows. Wherever the F-values were found to be significantly different, the mean value were compared with the help of Least Significant Difference (LSD) method.

3.2.10.1 Missing plot RBD analysis

While interpreting the field data into excel sheet, it was found that there were total eleven missing values present. In order to find out the missing values, missing plot RBD analysis was carried out using statistical package IBM SPSS version- 21.0 for windows.

3.2.10.2 Analysis of ordinal variables

The ordinal variables such as number of branches, bole straightness, and scoring of trees against pest incidence were analysed by Friedmen's test method.

3.2.10.3 Analysis of bioassay

The data obtained from bioassay did not follow normality, so it was transformed to arcsine value. The factorial CRD analysis was done to find out the variation, based on the transformed arcsine value.

Results

4. RESULTS

4.1 FIELD TRIAL

4.1.1 Height

The height data were analysed for variation among the progenies of different Candidate Plus Trees (CPTs). The result found there was no significant difference among the progenies over time (Table 2, Table 3, and Figure 3). After 16 months of planting, average height of the progenies were found to be 1.82 m. The highest value was found to be 2.18 m (FCV AT 20) and the lowest was 1.45 m (FCV AT 16). After 18 months of planting, the average height was 1.90 m. The highest value was 2.26 m (FCV AT 20) and lowest was 1.50 m (FCV AT 16). After 20 months of planting, the average height was found to be 1.97 m. The highest value was 2.33 m (FCV AT 20) and the lowest was 1.58 m (FCV AT 16). After 22 months of planting, the average height was found to be 2.11 m. The highest value was 2.48 m (FCV AT 20) and lowest was 1.71 m (FCV AT 16). After 24 months of planting, the average height was found to be 2.40 m. The highest value was 2.77 m (FCV AT 6) and lowest 1.94 m (FCV AT 16). After 26 months of planting, the average height was 2.61 m. The highest value was 2.97 m (FCV AT 20) and lowest 2.13 m (FCV AT 16). After 28 months of planting, the average height was found to be 2.79 m. The highest value was 3.14 m (FCV AT 6) and the lowest was 2.27 m (FCV AT 16).

4.1.2 Collar girth

Collar girth did not show any significant difference among the progenies of different Candidate Plus Trees (CPTs) (Table 4 and Figure 4). After 16 months of planting the mean collar girth was found to be 12.80 cm, the value ranged between 10.63 cm to 14.63 cm. After 18 months of planting the mean collar girth was found to be 13.89 cm, the value ranges between 11.43 cm to 15.80 cm. After 20 months of planting the mean collar girth was found to be 15.61 cm, the value ranges between 12.98 cm to 17.70 cm. For all the above observations the highest value was obtained from progenies belongs to FCV AT 20 CPTs and the lowest in FCV

AT 16 CPTs. After 22 months of planting the average collar girth was found to be 17.50 cm, the progenies of FCV AT 20 CPTs exhibited the highest value 19.34 cm whereas, the progenies of FCV AT 12 CPTs exhibited lowest value 15.08 cm.

4.1.3 Collar diameter

Collar diameter was analysed for variation among the progenies of different Candidate Plus Trees (CPTs). The result found there were no significant difference among the progenies over time (Table 5 and Figure 5). After 24 months of planting the average collar diameter for all the progenies was found to be 58.28 mm, the progenies belongs to FCV AT 20 CPTs exhibited the highest value 65.49 mm whereas, the progenies of FCV AT 16 CPTs exhibited lowest value 50.16 mm. After 26 months of planting the average collar diameter for all the progenies were found to be 65.48 mm, the progenies of FCV AT 3 CPTs exhibited the highest value 69.86 mm and the progenies of FCV AT 16 CPTs exhibited the lowest value56.70 mm. After 28 months of planting, the average value for all the progenies were 69.11 mm, the progenies of FCV AT 8 CPTs exhibited the highest collar diameter 74.69 mm and the progenies of FCV AT 16 CPTs exhibited the lowest collar diameter 59.90 mm.

4.1.4 Number of branches

Number of branches parameter came under ordinal variable, so the analysis was carried out using non-parametric Friedmen's test. The result revealed that there was no significant difference among the progenies of different Candidate Plus Trees (CPTs). The overall mode for number of branches was found to be zero. Result revealed that the number of branches was zero for all the progenies except the progenies of FCV AT 3 CPTs, which was found to be one.

4.1.5 Bole straightness

Friedmen's test of bole straightness revealed that there was significant difference among the progenies of different Candidate Plus Trees (CPTs) (Table 7). The overall mode of bole straightness was found to be 3 (almost straight with 1 or 2 small bends). All the progenies scored 3 except the progenies of FCV AT 8 and

FCV AT 14 CPTs scored 2 (Slightly crooked with 2 small bends or less than 2 serious bends). Progenies of FCV AT 7 and FCV AT 13 CPTs shown significantly higher Friedmen's value (14.88) during the analysis, which had a score 3.

4.1.6 Survival percentage

Survival percentage was calculated and did not show any considerable difference (Table 6 and Figure 6). The average survival percent observed was 94.98 %, which ranges between 83.61 % to 100.00 %.

4.1.7 Stem volume

Stem volume was analysed for variation among the progenies. The result was found to be non-significant among the progenies of different Candidate Plus Trees (CPTs) (Table 6 Figure 7). The overall mean volume was found to be 0.004 m^3. Progenies of FCV AT 11 CPTs (0.006 m^3) showed highest volume and the progenies of FCV AT 12 (0.002 m^3) showed the lowest value.

Table 2. Variation in height (m) of the progenies of different Candidate Plus Trees (CPTs) of *Ailanthus triphysa* over time

CPTs	Height (m)		
	16 Month	18 Month	20 Month
FCV AT 1	2.02 (0.12)	2.06 (0.41)	2.12 (0.21)
FCV AT 2	1.86 (0.46)	1.98 (0.24)	2.05 (0.43)
FCV AT 3	1.78 (0.86)	2.05 (0.48)	2.14 (0.57)
FCV AT 4	1.56 (0.26)	1.59 (0.42)	1.66 (0.25)
FCV AT 5	2.10 (0.20)	2.21 (0.07)	2.26 (0.20)
FCV AT 6	2.08 (0.15)	2.13 (0.33)	2.19 (0.18)
FCV AT 7	1.79 (0.08)	1.86 (0.34)	1.92 (0.06)
FCV AT 8	1.82 (0.26)	1.88 (0.36)	1.97 (0.28)
FCV AT 9	1.98 (0.28)	2.06 (0.23)	2.16 (0.29)
FCV AT 10	1.71 (0.30)	1.78 (0.48)	1.87 (0.29)
FCV AT 11	1.94 (0.37)	2.03 (0.21)	2.12 ()0.35
FCV AT 12	1.59 (0.21)	1.61 (0.32)	1.70 (0.24)
FCV AT 13	1.87 (0.24)	1.93 (0.30)	1.99 (0.20)
FCV AT 14	1.62 (0.55)	1.71 (0.72)	1.81 (0.52)
FCV AT 15	1.82 (0.24)	1.90 (0.39)	1.97 (0.28)
FCV AT 16	1.45 (0.55)	1.50 (0.69)	1.58 (0.56)
FCV AT 17	1.73 (0.22)	1.78 (0.48)	1.85 (0.25)
FCV AT 18	1.85 (0.34)	1.93 (0.11)	1.99 (0.32)
FCV AT 19	1.91 (0.56)	1.97 (0.70)	2.07 (0.59)
FCV AT 20	2.18 (0.15)	2.26 (0.59)	2.33 (0.19)
Mean	1.82 (0.36)	1.90 (0.41)	1.97 (0.35)
P	0.696^{ns}	0.405^{ns}	0.428^{ns}

Superscript "ns" indicates not-significant

Values within parenthesis is Standard Deviation (SD)

Table 3. Variation in height (m) of the progenies of different Candidate Plus Trees (CPTs) of *Ailanthus triphysa* over time

CPTs	Height (m)			
	22 Month	24 Month	26 Month	28 Month
FCV AT 1	2.17 (0.18)	2.71 (0.30)	2.94 (0.24)	3.12 (0.19)
FCV AT 2	2.20 (0.31)	2.45 (0.28)	2.66 (0.26)	2.81 (0.29)
FCV AT 3	2.25 (0.62)	2.60 (0.59)	2.90 (0.75)	2.99 (0.77)
FCV AT 4	1.76 (0.19)	2.07 (0.19)	2.38 (0.27)	2.62 (0.38)
FCV AT 5	2.36 (0.22)	2.66 (0.20)	2.90 (0.24)	3.10 (0.26)
FCV AT 6	2.42 (0.23)	2.77 (0.41)	2.79 (0.36)	3.14 (0.64)
FCV AT 7	2.06 (0.07)	2.38 (0.09)	2.61 (0.18)	2.87 (0.10)
FCV AT 8	2.12 (0.29)	2.44 (0.29)	2.69 (0.38)	2.93 (0.42)
FCV AT 9	2.26 (0.33)	2.63 (0.32)	2.75 (0.37)	2.89 (0.38)
FCV AT 10	1.97 (0.28)	2.24 (0.29)	2.44 (0.29)	2.63 (0.36)
FCV AT 11	2.25 (0.33)	2.57 (0.36)	2.85 (0.38)	3.11 (0.43)
FCV AT 12	1.88 (0.16)	2.10 (0.29)	2.31 (0.29)	2.45 (0.26)
FCV AT 13	2.19 (0.23)	2.46 (0.27)	2.70 (0.29)	2.86 (0.34)
FCV AT 14	1.91 (0.54)	2.18 (0.64)	2.33 (0.69)	2.49 (0.82)
FCV AT 15	2.08 (0.24)	2.31 (0.28)	2.51 (0.34)	2.70 (0.42)
FCV AT 16	1.71 (0.54)	1.94 (0.56)	2.13 (0.60)	2.27 (0.60)
FCV AT 17	1.98 (0.33)	2.28 (0.46)	2.47 (0.58)	2.62 (0.63)
FCV AT 18	2.13 (0.37)	2.41 (0.38)	2.61 (0.43)	2.76 (0.53)
FCV AT 19	2.22 (0.65)	2.47 (0.67)	2.71 (0.75)	2.74 (0.74)
FCV AT 20	2.48 (0.22)	2.71 (0.31)	2.97 (0.42)	3.12 (0.52)
Mean	2.11 (0.36)	2.40 (0.40)	2.61 (0.44)	2.79 (0.48)
P	0.362^{ns}	0.288^{ns}	0.477^{ns}	0.563^{ns}

Superscript "ns" indicate not-significant

Values within parenthesis is Standard Deviation (SD)

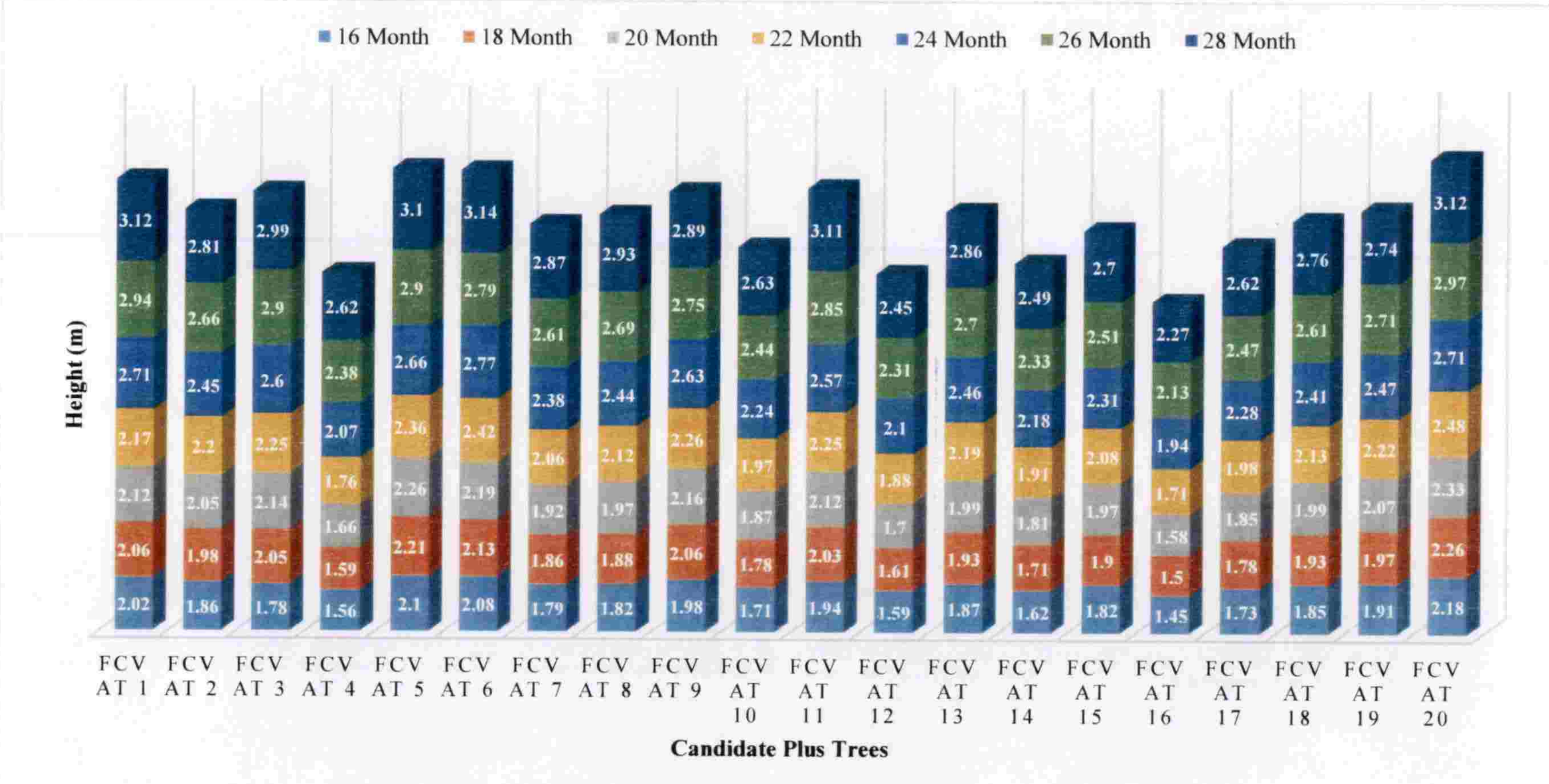


Figure 3. Bimonthly variation in height (m) of the progenies of different Candidate Plus Trees (CPTs) of *Ailanthus triphysa*

Table 4. Variation in collar girth (cm) of the progenies of different Candidate Plus Trees (CPTs) of *Ailanthus triphysa* over time

CPTs	Collar girth(cm)			
	16 Month	18 Month	20 Month	22 Month
FCV AT 1	13.12 (0.34)	14.34 (0.36)	16.48 (0.25)	18.25 (0.54)
FCV AT 2	13.50 (2.06)	15.54 (2.76)	17.13 (2.69)	18.75 (2.09)
FCV AT 3	13.91 (4.11)	15.40 (2.55)	16.92 (3.21)	18.20 (3.92)
FCV AT 4	11.62 (1.13)	12.48 (1.41)	14.13 (1.08)	16.06 (1.05)
FCV AT 5	13.43 (1.04)	15.18 (0.70)	16.70 (0.76)	18.52 (1.36)
FCV AT 6	13.52 (2.03)	14.23 (2.76)	15.76 (2.80)	17.91 (3.90)
FCV AT 7	12.63 (1.20)	14.04 (1.78)	15.60 (1.64)	17.55 (1.29)
FCV AT 8	12.55 (0.75)	13.59 (1.36)	15.65 (1.75)	17.80 (1.93)
FCV AT 9	13.47 (1.22)	14.27 (1.32)	15.85 (1.44)	17.87 (1.26)
FCV AT 10	12.61 (2.31)	13.56 (2.48)	15.71 (2.56)	17.77 (2.13)
FCV AT 11	13.36 (2.73)	14.39 (3.04)	16.52 (2.81)	18.60 (2.62)
FCV AT 12	11.69 (1.32)	12.20 (1.47)	13.53 (1.28)	15.08 (1.39)
FCV AT 13	13.73 (1.43)	14.47 (1.35)	15.68 (1.66)	17.87 (1.78)
FCV AT 14	11.27 (2.84)	12.22 (3.03)	13.56 (3.88)	15.36 (4.65)
FCV AT 15	12.65 (3.53)	14.18 (3.66)	16.13 (3.70)	18.08 (3.98)
FCV AT 16	10.63 (3.07)	11.43 (3.32)	12.98 (2.99)	15.13 (3.33)
FCV AT 17	12.17 (1.97)	12.90 (2.16)	14.81 (3.01)	16.61 (4.11)
FCV AT 18	13.00 (1.96)	13.84 (2.34)	16.00 (2.21)	17.96 (2.13)
FCV AT 19	12.58 (3.51)	13.57 (4.22)	15.41 (4.78)	17.28 (5.22)
FCV AT 20	14.63 (1.82)	15.80 (2.88)	18.40 (3.44)	19.34 (3.76)
Mean	12.80 (2.19)	13.88 (2.47)	15.61 (2.64)	17.50 (2.80)
P	0.603^{ns}	0.354^{ns}	0.389^{ns}	0.615^{ns}

Superscript "ns" indicate not-significant

Values within parenthesis is Standard Deviation (SD)

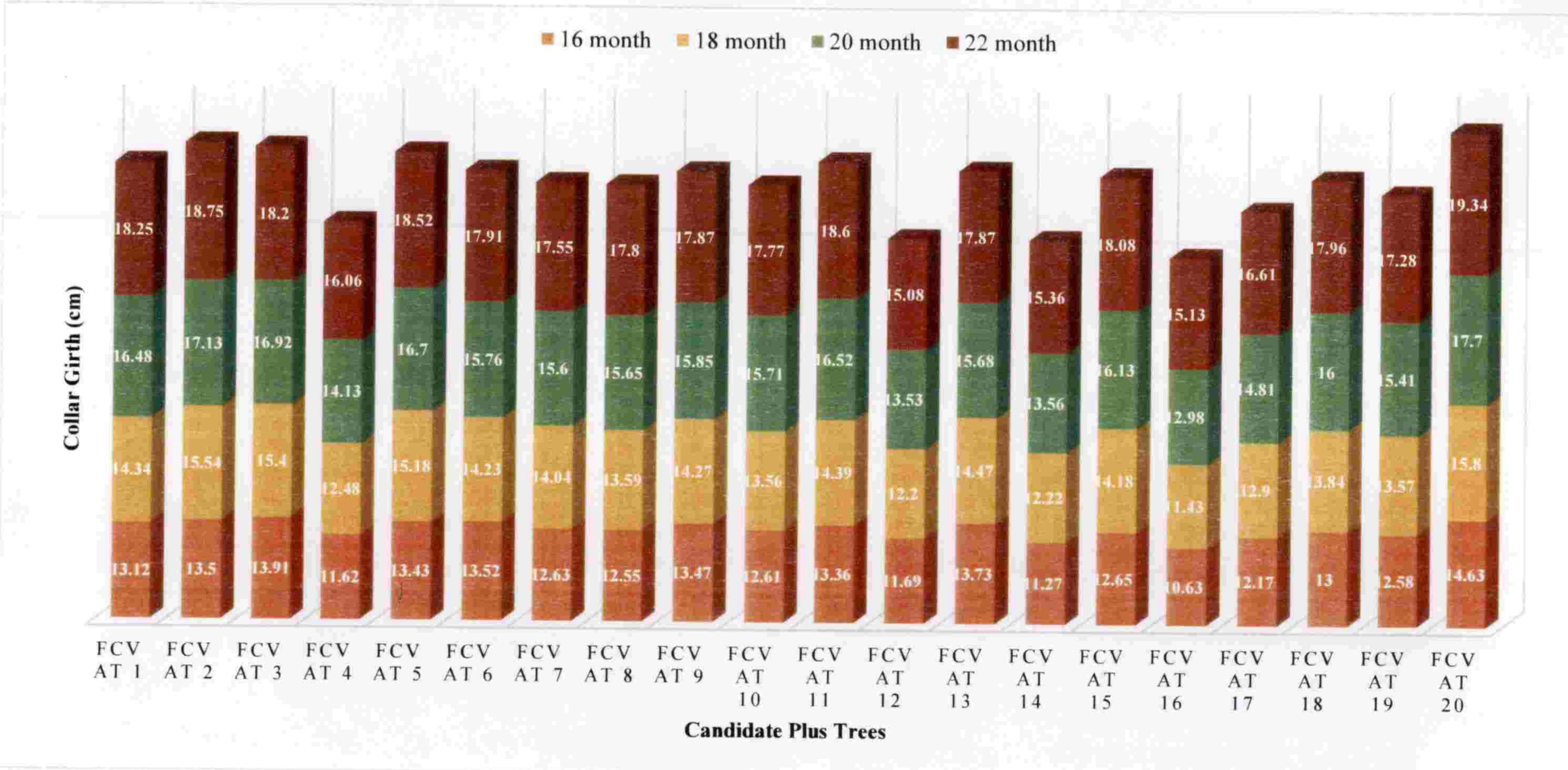


Figure 4. Bimonthly variation in collar girth (cm) of the progenies of different Candidate Plus Trees of *Ailanthus triphysa*

Table 5. Variation in collar diameter (mm) of the progenies of different Candidate Plus Trees (CPTs) of *Ailanthus triphysa* over time

CPTs	Collar diameter(mm)		
	24 Month	26 Month	28 Month
FCV AT 1	56.70 (2.07)	67.42 (2.95)	71.77 (2.46)
FCV AT 2	62.57 (4.61)	68.50 (5.17)	71.65 (6.16)
FCV AT 3	60.66 (15.40)	69.85 (11.30)	73.36 (11.75)
FCV AT 4	53.68 (4.27)	59.23 (4.56)	62.23 (5.02)
FCV AT 5	60.95 (6.68)	68.61 (7.05)	71.86 (5.96)
FCV AT 6	57.36 (11.67)	67.72 (15.00)	70.81 (16.03)
FCV AT 7	58.84 (3.57)	65.78 (1.03)	68.44 (1.49)
FCV AT 8	61.36 (5.11)	67.84 (6.44)	74.69 (9.69)
FCV AT 9	61.68 (5.17)	67.40 (5.01)	71.24 (5.75)
FCV AT 10	61.37 (9.55)	67.36 (9.43)	72.36 (10.41)
FCV AT 11	63.54 (7.57)	68.85 (8.64)	72.56 (8.51)
FCV AT 12	54.29 (5.59)	60.19 (4.25)	65.04 (4.84)
FCV AT 13	54.86 (11.90)	66.97 (9.23)	69.72 (9.63)
FCV AT 14	52.36 (13.24)	58.88 (15.67)	61.27 (16.97)
FCV AT 15	55.06 (11.31)	64.58 (13.00)	67.60 (13.99)
FCV AT 16	50.16 (15.91)	56.70 (18.61)	59.90 (19.95)
FCV AT 17	60.39 (8.18)	66.53 (10.30)	69.68 (10.74)
FCV AT 18	57.17 (9.58)	65.74 (6.49)	68.76 (7.03)
FCV AT 19	59.48 (17.94)	65.27 (18.28)	68.32 (19.84)
FCV AT 20	65.49 (15.33)	68.92 (14.34)	72.91 (16.08)
Mean	58.28 (9.60)	65.48 (9.74)	69.11 (10.59)
P	0.909^{ns}	0.938^{ns}	0.933^{ns}

Superscript "ns" indicate not-significant

Values within parenthesis is Standard Deviation (SD)

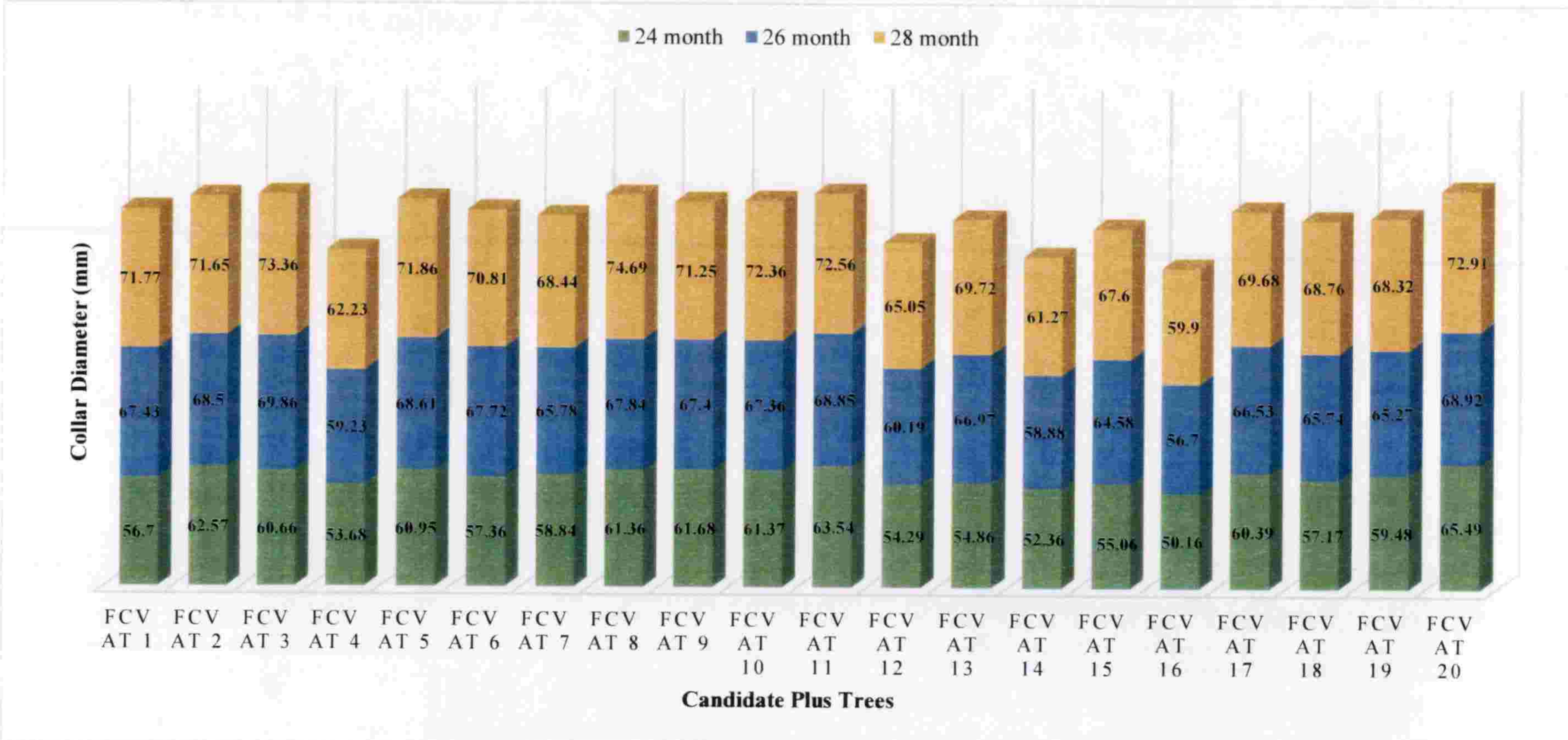


Figure 5. Bimonthly variation in collar diameter of the progenies of different Candidate Plus Trees of *Ailanthus triphysa*

Table 6. Stem volume and survival percentage of the progenies of different Candidate Plus Trees (CPTs) of *Ailanthus triphysa* at 28 months after planting

CPTs	Stem volume (m^3)	Survival percentage (%)
FCV AT 1	0.004 (0.0005)	100.00
FCV AT 2	0.003 (0.0018)	100.00
FCV AT 3	0.004 (0.0022)	100.00
FCV AT 4	0.003 (0.0005)	100.00
FCV AT 5	0.004 (0.0005)	84.61
FCV AT 6	0.004 (0.0020)	100.00
FCV AT 7	0.003 (0.0005)	88.88
FCV AT 8	0.004 (0.0022)	100.00
FCV AT 9	0.004 (0.0015)	90.90
FCV AT 10	0.003 (0.0012)	100.00
FCV AT 11	0.006 (0.0042)	84.61
FCV AT 12	0.002 (0.0005)	100.00
FCV AT 13	0.003 (0.0014)	92.30
FCV AT 14	0.004 (0.0012)	84.61
FCV AT 15	0.003 (0.0017)	88.88
FCV AT 16	0.003 (0.0012)	100.00
FCV AT 17	0.004 (0.0010)	100.00
FCV AT 18	0.004 (0.0009)	93.33
FCV AT 19	0.004 (0.0009)	91.66
FCV AT 20	0.004 (0.0025)	100.00
Mean	0.003 (0.0017)	94.98
P	0.295^{ns}	

Superscript "ns" indicate not-significant

Values within parenthesis is Standard Deviation (SD)

Table 7. Bole straightness of the progenies of different Candidate Plus Trees (CPTs) of *Ailanthus triphysa*

CPTs	Score	Friedmen's value
FCV AT 1	3 (0.00)	10.13
FCV AT 2	3 (0.50)	12.00
FCV AT 3	3 (0.50)	12.50
FCV AT 4	3 (0.00)	10.13
FCV AT 5	3 (0.50)	12.50
FCV AT 6	3 (0.00)	10.13
FCV AT 7	3 (0.57)	14.88
FCV AT 8	2 (0.57)	5.88
FCV AT 9	3 (0.00)	10.13
FCV AT 10	3 (0.50)	8.00
FCV AT 11	3 (0.50)	12.00
FCV AT 12	3 (0.50)	12.50
FCV AT 13	3 (0.57)	14.88
FCV AT 14	2 (0.57)	6.13
FCV AT 15	3 (0.00)	10.13
FCV AT 16	3 (0.00)	10.13
FCV AT 17	3 (1.00)	7.38
FCV AT 18	3 (0.50)	8.00
FCV AT 19	3 (0.00)	10.13
FCV AT 20	3 (0.50)	12.50
Mode	3 (0.50)	
P	0.048*	

**Significant at 5 per cent level*

Values within parenthesis is Standard Deviation (SD)

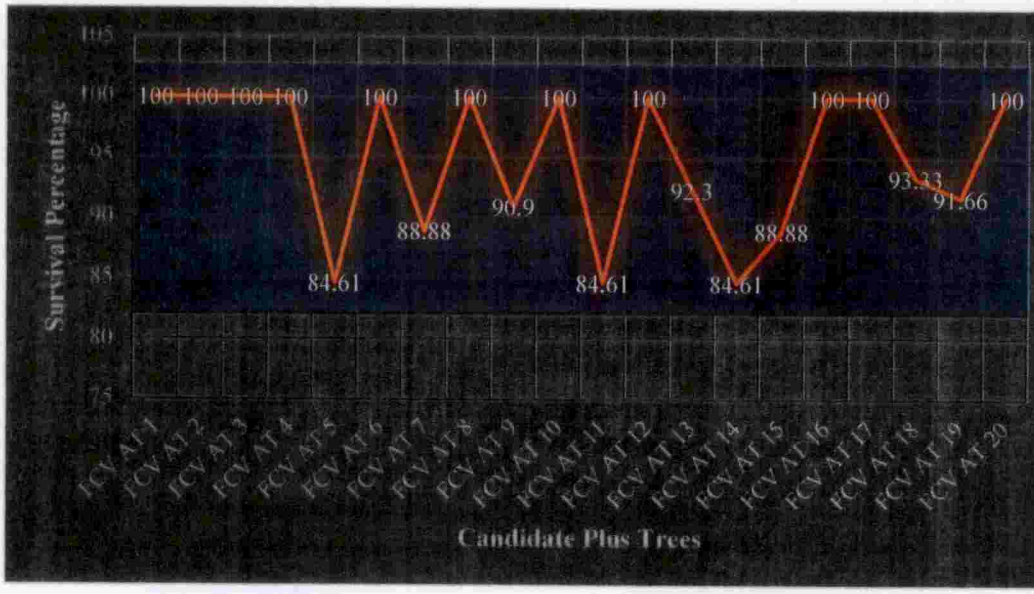


Figure 6. Survival percentage of the progenies of different Candidate Plus Trees of *Ailanthus triphysa* at 28 months after planting

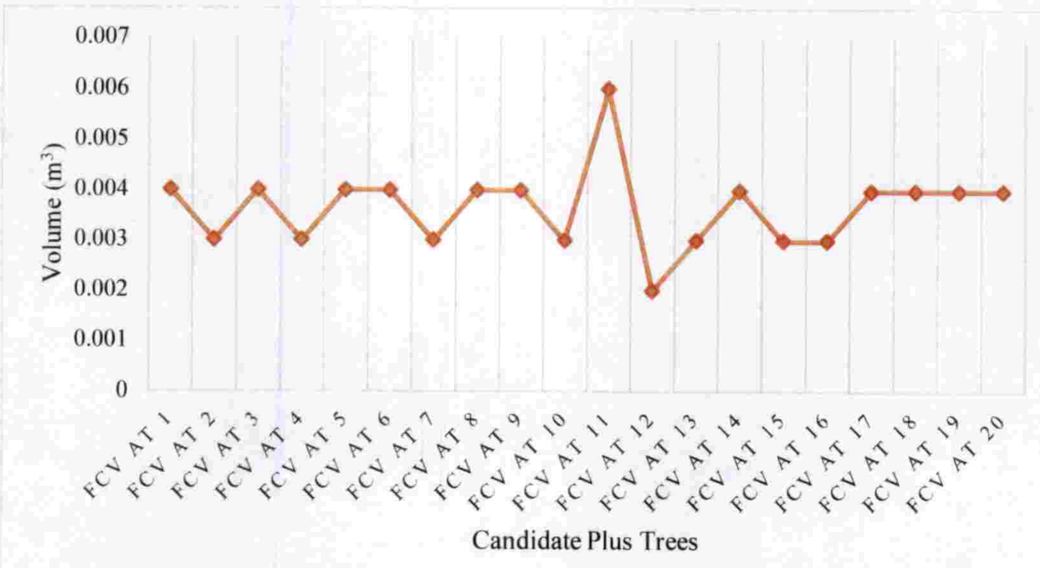


Figure 7. Stem volume (m^3) of the progenies of different Candidate Plus Trees of *Ailanthus triphysa* at 28 months after planting

4.2 WOOD PHYSICAL PROPERTIES

4.2.1 Basic density

Basic density was analysed for variation among the different Candidate Plus Trees (CPTs) of *Ailanthus triphysa.* The result was found to be significantly different (Table 8 and Figure 8). The average basic density for all the CPTs was found to be 0.37 g cm^{-3}, the highest value was 0.41 g cm^{-3} exhibited by FCV AT 15 CPTs and the lowest was 0.35 g cm^{-3} exhibited by FCV AT 2, 3, and 17 CPTs respectively.

4.2.2 Colour

The study of wood colour revealed that, one colour was predominant in all the CPTs. According to the Munsell colour system the predominant colour was 2.5 Y 8/4 (pale yellow).

4.2.3 Grain

The grain structure was found to be straight and it follows similar type of arrangement for all the CPTs, while analysed under a high resolution laser scanner.

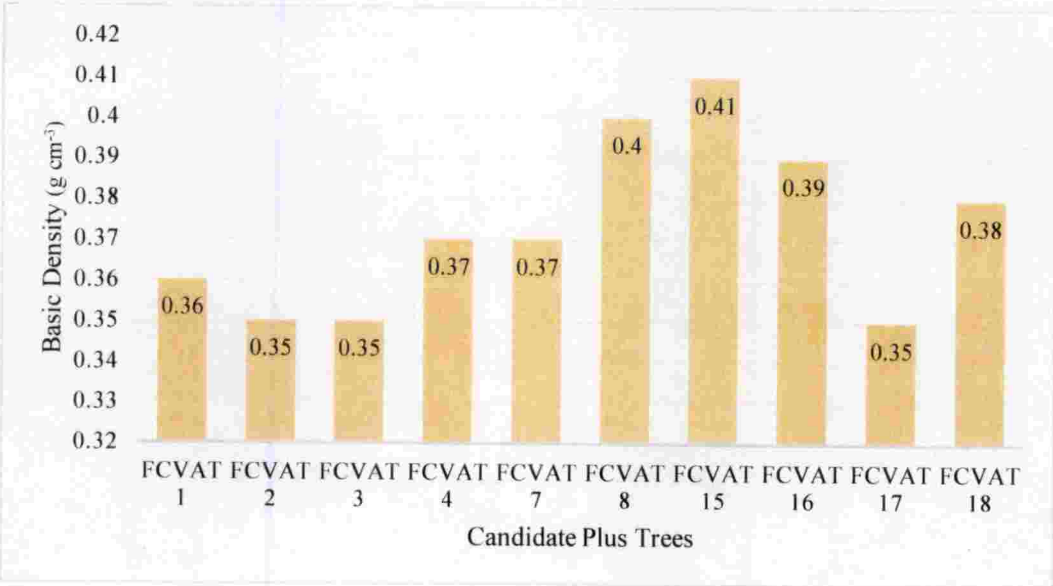


Figure 8. Basic density (g cm^{-3}) of the different Candidate Plus Trees (CPTs) of *Ailanthus triphysa*

Table 8. Basic density (g cm^{-3}) of the different Candidate Plus Trees (CPTs) of *Ailanthus triphysa*

Candidate Plus Trees	Basic density (g cm^{-3})
FCV AT 1	0.36^{d} (0.02)
FCV AT 2	0.35^{d} (0.01)
FCV AT 3	0.35^{d} (0.01)
FCV AT 4	0.37^{cd} (0.005)
FCV AT 7	0.37^{cd} (0.005)
FCV AT 8	0.40^{ab} (0.01)
FCV AT 15	0.41^{a} (0.00)
FCV AT 16	0.39^{abc} (0.01)
FCV AT 17	0.35^{d} (0.02)
FCV AT 18	0.38^{bcd} (0.01)
Mean	0.37 (0.02)
P	0.001^{*}
C.D.	0.02

**Significant at 5 per cent level*

Values with the same superscript along the column are homogeneous

Values within parenthesis is Standard Deviation (SD)

4.3 WOOD ANATOMICAL PROPERTIES

4.3.1 Fibre morphology

4.3.1.1 Fibre length

Fibre length ranged between 1076.48 µm to 1269.16 µm among the Candidate Plus Trees (CPTs) (Table 9 and Figure 9). The average fibre length of the CPTs was found to be 1163.83 µm. Analysis of variance revealed significant difference in fibre length among the CPTs. The fibre length was found to be highest in FCV AT 1 CPTs (1269.16 µm) and lowest in FCV AT 3 CPTs (1076.48 µm) respectively.

4.3.1.2 Fibre width

The average fibre width was 29.84 µm with the value ranged between 26.46 µm to 36.15 µm. The highest fibre width was found in FCV AT 1 CPTs (36.15 µm) and the lowest in FCV AT 15 CPTs (26.46 µm) respectively. Analysis of variance revealed significant difference in fibre width among the Candidate Plus Trees (CPTs) (Table 9 and Figure 10).

4.3.1.3 Fibre wall thickness

Analysis of variance revealed significant difference in fibre wall thickness among different Candidate Plus Trees (CPTs) (Table 9 and Figure 15). The average fibre wall thickness was found to be 4.25 µm. The highest fibre wall thickness was 4.88 m µm of FCV AT 1 CPTs and the lowest was 3.77 µm of FCV AT 3 CPTs respectively.

Table 9. Variation in fibre morphology of the different Candidate Plus Trees (CPTs) of *Ailanthus triphysa*

CPTs	FL (µm)	FW (µm)	FWT (µm)
FCV AT 1	1269.16[a] (214.08)	36.15[a] (3.31)	4.88[a] (0.48)
FCV AT 2	1163.00[abc] (126.63)	30.74[bc] (3.00)	4.30[abc] (0.64)
FCV AT 3	1076.48[c] (148.58)	26.72[c] (9.28)	3.77[c] (0.77)
FCV AT 4	1240.18[ab] (163.95)	33.11[ab] (4.49)	4.63[ab] (0.68)
FCV AT 7	1235.58[ab] (146.41)	32.87[ab] (3.20)	4.15[bc] (0.58)
FCV AT 8	1196.65[abc] (162.31)	26.50[c] (2.62)	4.32[abc] (0.47)
FCV AT 15	1094.41[bc] (79.42)	26.46[c] (3.83)	3.94[c] (0.67)
FCV AT 16	1111.41[bc] (125.24)	27.62[c] (3.35)	4.03[bc] (0.79)
FCV AT 17	1141.28[abc] (144.44)	29.49[bc] (4.16)	4.08[bc] (0.48)
FCV AT 18	1110.14[bc] (109.03)	28.69[bc] (4.05)	4.32[bc] (0.50)
Mean	1163.83 (153.66)	29.84 (5.39)	4.25 (0.66)
P	0.040*	<0.001**	0.007*
C.D.	132.70	4.02	0.54

FL= Fibre Length; FW= Fibre Width; FWT= Fibre Wall Thickness

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

Values with the same superscript along the column are homogeneous

Values within parenthesis is Standard Deviation (SD)

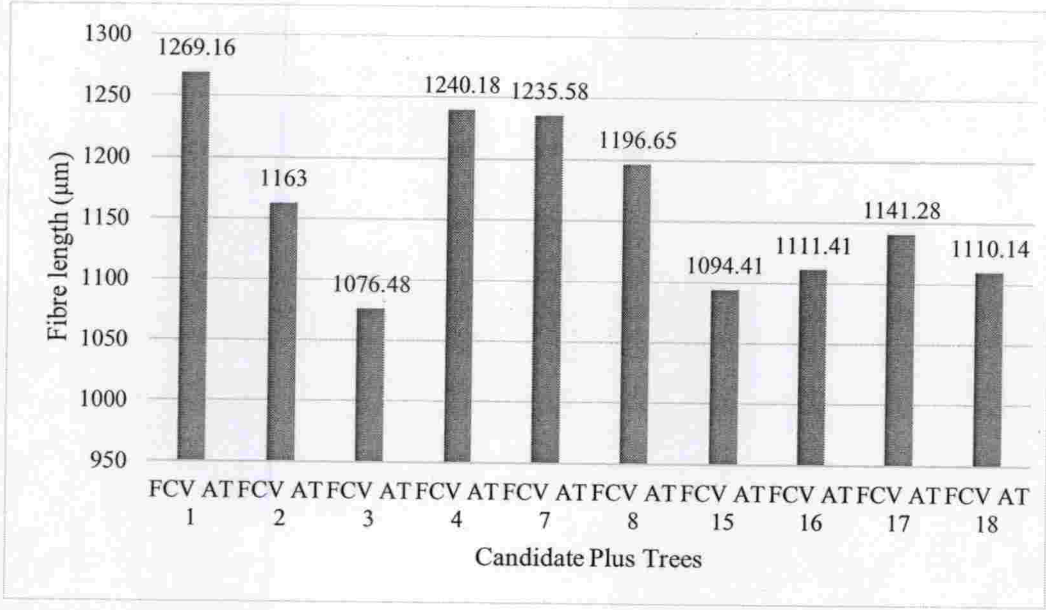


Figure 9. Fibre length (µm) of the different Candidate Plus Trees (CPTs) of *Ailanthus triphysa*

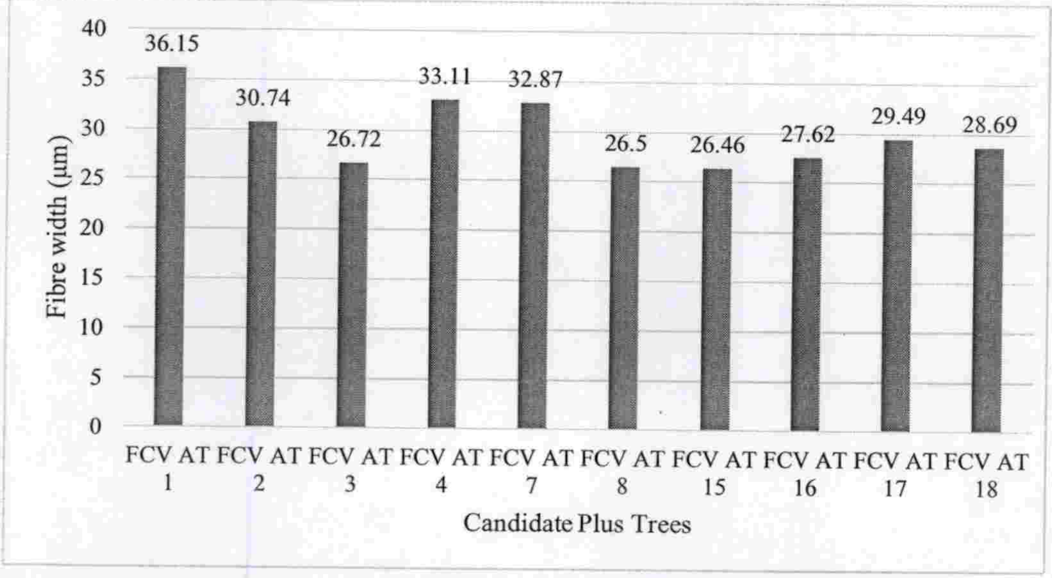


Figure 10. Fibre width (µm) of the different Candidate Plus Trees (CPTs) of *Ailanthus triphysa*

4.3.2 Vessel morphology

4.3.2.1 Vessel length

Vessel length was analysed for variation among the different Candidate Plus Trees (CPTs) (Table 10 and Figure 11). The average vessel length was found to be 618.9 µm, the highest vessel length was 720.91 µm shown by FCV AT 17 CPTs and the lowest was 541.50 µm shown by FCV AT 03 CPTs respectively. The analysis revealed that there was significant difference among the Candidate Plus Trees at 5 % level.

4.3.2.2 Vessel area

Vessel area was analysed for variation among the different Candidate Plus Trees (CPTs) (Table 10 and Figure 12). The average vessel area for all the CPTs was 48351.41 μm^2, with the highest vessel area 62419.82 μm^2 shown by FCV AT 17 CPTs and the lowest vessel area 37496.02 μm^2 shown by FCV AT 08 CPTs respectively. The analysis revealed that there was significant difference among the Candidate Plus Trees at 1 % level.

4.3.2.3 Vessel diameter

Vessel diameter ranged between 245.99 µm to 330.10 µm among the Candidate Plus Trees (CPTs) (Table 10 and Figure 13). The average vessel diameter of the CPTs was found to be 289.71 µm. Analysis of variance revealed significant difference in vessel diameter among different Candidate Plus Trees. The vessel diameter was found to be highest in FCV AT 17 CPTs and lowest in FCV AT 08 CPTs respectively.

4.3.2.4 Vessel frequency

Analysis of variance revealed significant difference in vessel frequency among different Candidate Plus Trees (CPTs), at 1 % level (Table 10 and Figure 14). The average vessel frequency was found to be 2/mm^2. The highest vessel frequency was 3 vessel/mm^2 shown by FCV AT 02 CPTs and the lowest 1/mm^2 shown by FCV AT 18 CPTs respectively.

Table 10. Variation in vessel morphology of the different Candidate Plus Trees (CPTs) of *Ailanthus triphysa*

CPTs	VL (μm)	VA (μm^2)	VD (μm)	VF (no./mm^2)
FCV AT 1	624.82^{abc} (128.33)	47553.71^{bcde} (11882.95)	310.32^{abc} (26.59)	1^{de} (0.44)
FCV AT 2	597.50^{bc} (43.34)	41779.54^{de} (8817.92)	286.44^{de} (19.36)	3^{a} (0.44)
FCV AT 3	626.76^{abc} (43.34)	56814.14^{abc} (10149.87)	319.23^{ab} (29.35)	2^{bc} (0.70)
FCV AT 4	647.46^{ab} (38.51)	52210.45^{abcd} (22418.37)	292.52^{cde} (33.90)	2^{cd} (0.44)
FCV AT 7	590.82^{bc} (77.11)	45877.53^{cbe} (8400.32)	271.31^{e} (16.59)	2^{cd} (0.44)
FCV AT 8	541.50^{c} (65.84)	37496.02^{e} (11810.73)	245.99^{f} (13.73)	1^{de} (0.44)
FCV AT 15	570.23^{bc} (54.11)	37902.17^{e} (9495.30)	268.41^{e} (17.63)	3^{ab} (0.54)
FCV AT 16	603.06^{bc} (52.37)	42416.48^{de} (9661.49)	269.20^{e} (19.92)	2^{bc} (0.00)
FCV AT 17	720.91^{a} (51.84)	62419.82^{a} (11637.71)	330.10^{a} (35.39)	1^{de} (0.44)
FCV AT 18	665.83^{ab} (45.87)	59044.25^{ab} (8956.04)	303.57^{bcd} (25.98)	1^{e} (0.00)
Mean	618.9 (76.66)	48351.41 (14036.82)	289.71 (34.55)	2 (0.71)
P	0.012*	<0.001**	<0.001**	<0.001**
C.D.	86.80	10837.60	21.77	0.21

VL= Vessel Length; VA= Vessel Area; VD= Vessel diameter; VF= Vessel Frequency

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

Values with the same superscript along the column are homogeneous

Values within parenthesis is Standard Deviation (SD)

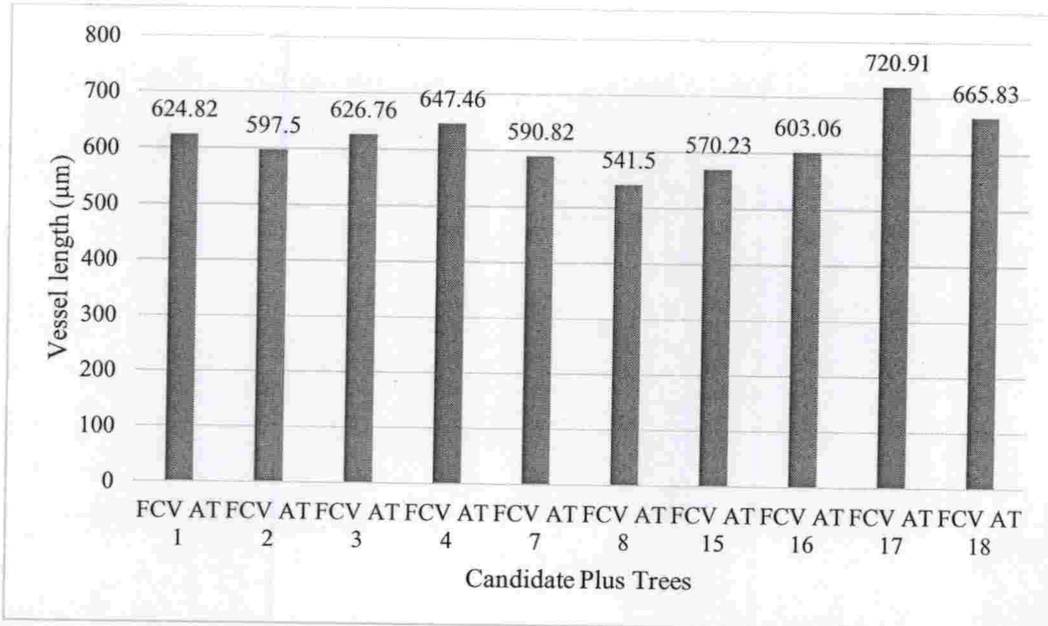


Figure 11. Vessel length (µm) of the different Candidate Plus Trees (CPTs) of *Ailanthus triphysa*

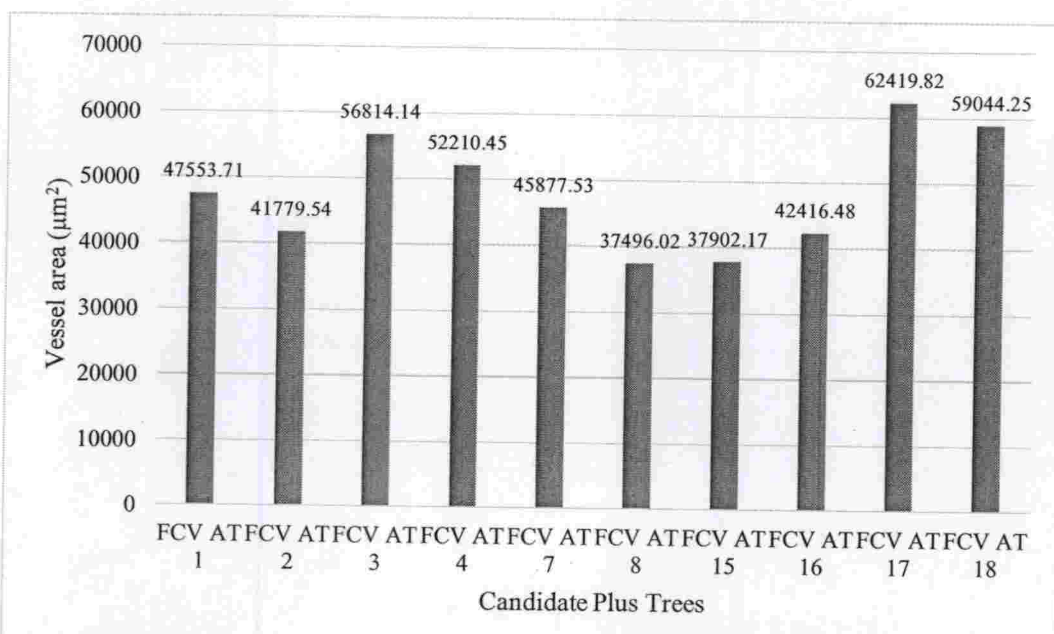


Figure 12. Vessel area (μm^2) of the different Candidate Plus Trees (CPTs) of *Ailanthus triphysa*

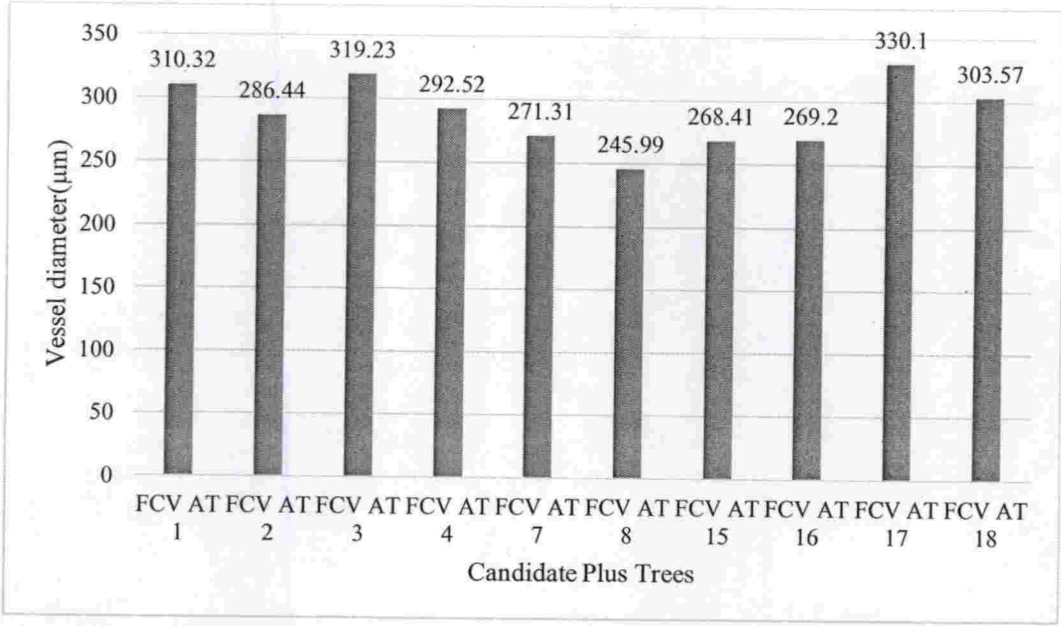


Figure 13. Vessel diameter (µm^2) of the different Candidate Plus Trees (CPTs) of *Ailanthus triphysa*

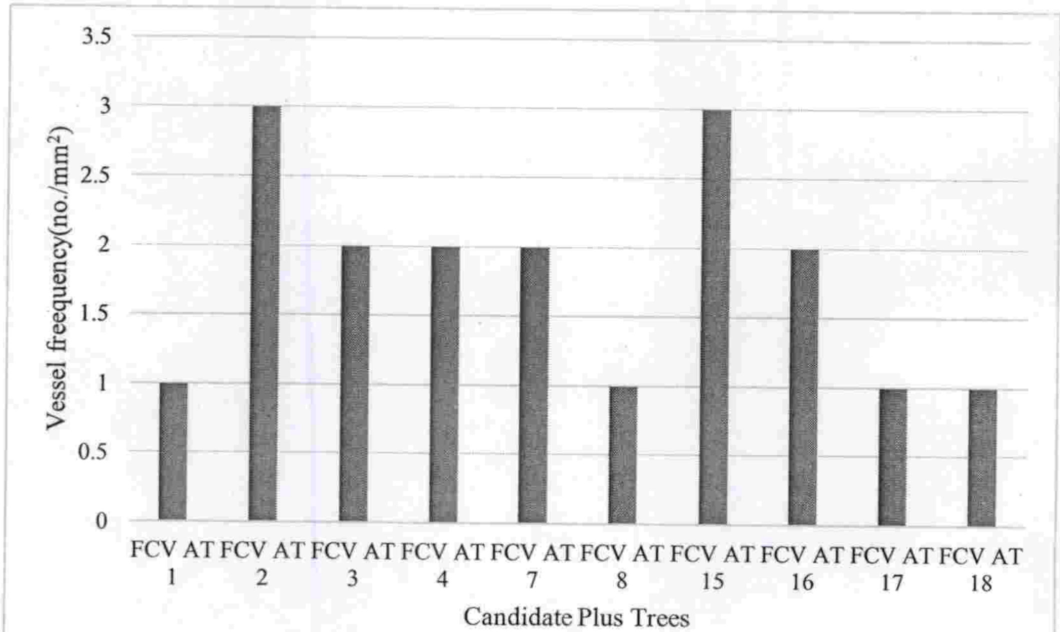


Figure 14. Vessel frequency (no. /mm^2) of the different Candidate Plus Trees (CPTs) of *Ailanthus triphysa*

4.3.3 Tissue proportion

4.3.3.1 Fibre

Fibre proportion was analysed for variation among the different Candidate Plus Trees (CPTs) (Table 11 and Figure 16). Result revealed there was no significant difference among the CPTs. The average fibre proportion for all the CPTs was found to be 61.84 per cent, the highest fibre proportion was 67.65 per cent shown by FCV AT 1 CPTs and the lowest was 55.98 per cent shown by FCV AT 16 CPTs respectively.

4.3.3.2 Parenchyma

Parenchyma proportion was analysed for variation between the different Candidate Plus Trees (CPTs) (Table 11 and Figure 16). The result found, there was no significant difference in parenchyma proportion among the CPTs. The average parenchyma proportion for all the CPTs was found to be 34.72 per cent, the highest proportion was 41.07 per cent shown by FCV AT 8 CPTs and the lowest was 28.11 per cent shown by FCV AT 2 CPTs respectively.

4.3.3.3 Vessel

Vessel proportion was analysed for variation among the different Candidate Plus Trees (CPTs) (Table 11 and Figure 16). The vessel proportion among the CPTs was found to be non-significant. The average vessel proportion for all the CPTs was found to be 3.41 per cent, the highest proportion was 4.76 per cent shown by FCV AT 2 CPTs and the lowest proportion was 2.41 per cent shown by FCV AT 8 CPTs respectively.

Table 11. Variation in tissue proportion of the different Candidate Plus Trees (CPTs) of *Ailanthus triphysa*

CPTs	FP	PP	VP
FCV AT 1	67.65 (6.12)	28.88 (5.26)	3.45 (1.95)
FCV AT 2	67.11 (2.90)	28.11 (3.99)	4.76 (1.51)
FCV AT 3	60.60 (7.28)	35.91 (7.03)	3.46 (2.03)
FCV AT 4	60.56 (10.35)	36.79 (9.76)	2.57 (2.35)
FCV AT 7	66.50 (10.71)	29.96 (8.16)	3.51 (3.64)
FCV AT 8	56.49 (12.08)	41.07 (10.18)	2.41 (2.22)
FCV AT 15	62.47 (12.93)	34.35 (13.62)	3.15 (1.80)
FCV AT 16	55.98 (3.23)	40.12 (3.00)	3.87 (0.41)
FCV AT 17	56.69 (8.05)	39.88 (7.73)	3.70 (1.91)
FCV AT 18	64.33 (7.93)	32.17 (7.57)	3.47 (2.04)
Mean	61.84 (9.03)	34.72 (8.72)	3.43 (2.02)
P	0.263^{ns}	0.134^{ns}	0.855^{ns}
C.D.	11.21	10.70	2.60

FP= Fibre Proportion; PP= Parenchyma Proportion; VP= Vessel Proportion

Superscript "ns" indicate not-significant

Values with the same superscript along the column are homogeneous

Values within parenthesis is Standard Deviation (SD)

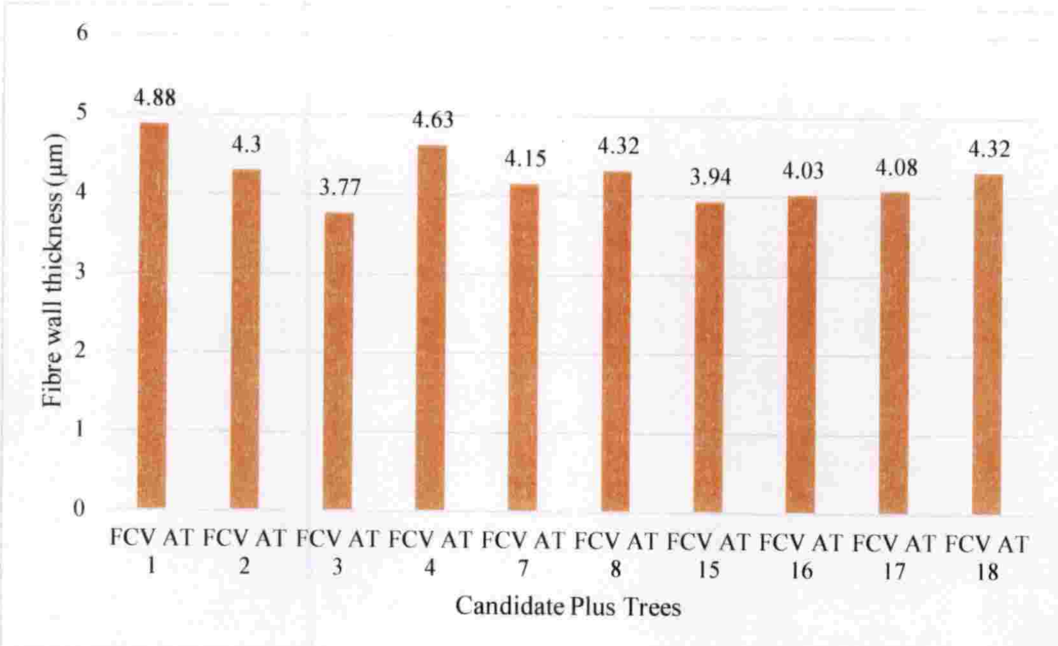


Figure 15. Fibre wall thickness (µm) of the different Candidate Plus Trees (CPTs) of *Ailanthus triphysa*

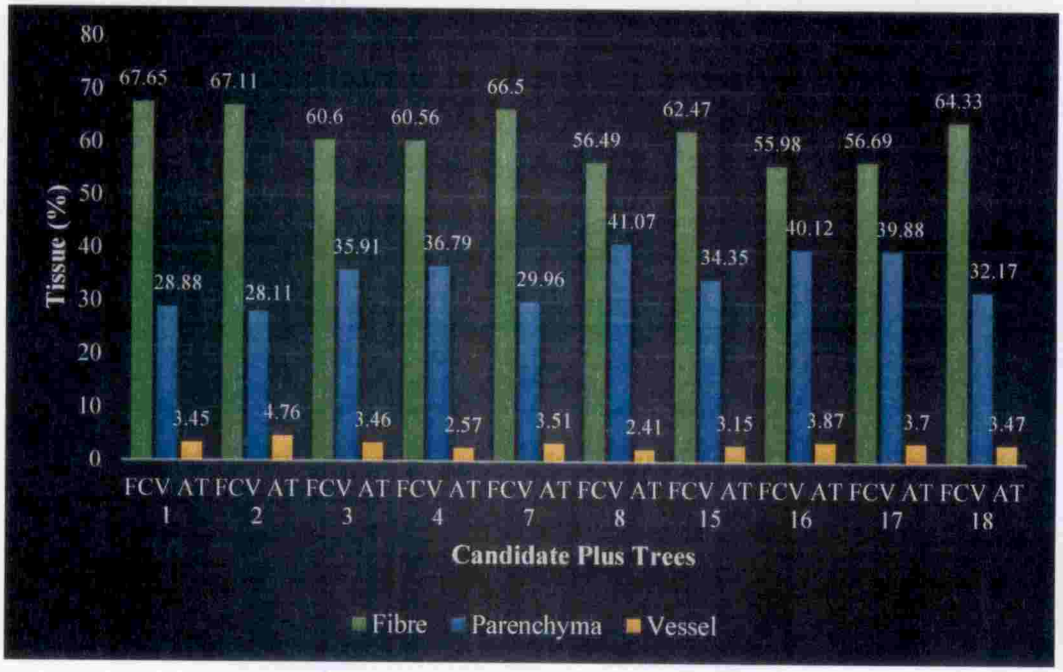


Figure 16. Tissue proportion (%) of the different Candidate Plus Trees (CPTs) of *Ailanthus triphysa*

4.3.4 Ray morphology

4.3.4.1 Ray height of multiseriate rays

Multiseriate ray height ranged between 1022.81 μm to 1397.61 μm among the Candidate Plus Trees (CPTs) (Table 12 and Figure 17). The average ray height of the CPTs was found to be 1262.89 μm. Analysis of variance revealed significant difference in multiseriate ray height among the different CPTs. The multiseriate ray height was found to be highest in FCV AT 4 CPTs (1397.61 μm) and lowest in FCV AT 2 CPTs (1022.81 μm) respectively.

4.3.4.2 Ray width of multiseriate rays

Multiseriate ray width was analysed for variation among the different Candidate Plus Trees (CPTs). Result revealed significant difference among CPTs (Table 12 and Figure 18). The average multiseriate ray width for all the CPTs was found to be 112.42 μm, with the highest value 142.44 μm shown by FCV AT 8 CPTs and the lowest was 82.69 μm shown by FCV AT 17 CPTs respectively.

4.3.4.3 Ray height of uniseriate rays

Uniseriate ray height ranged between 264.27 μm to 425.39 μm among the Candidate Plus Trees (CPTs) (Table 12 and Figure 19). The average ray height of the Candidate Plus Trees was found to be 346.60 μm. Analysis of variance revealed significant difference in uniseriate ray height among the different CPTs. Uniseriate ray height was found to be highest in FCV AT 8 CPTs (425.39 μm) and lowest in FCV AT 16 (264.27 μm) CPTs.

4.3.4.4 Ray width of uniseriate rays

Uniseriate ray width was analysed for variation among the different Candidate Plus Trees (CPTs). The result revealed significant difference among CPTs (Table 12 and Figure 20). The average uniseriate ray width for all the CPTs was found to be 27.75 μm, with the highest value 33.79 μm shown by FCV AT 8 CPTs and the lowest value was 20.65 μm shown by FCV AT 4 CPTs respectively.

Table 12. Variation in ray morphology of the different Candidate Plus Trees (CPTs) of *Ailanthus triphysa*

CPTs	MRH (μm)	MRW (μm)	URH (μm)	URW (μm)
FCV AT 1	1358.57[a] (245.02)	111.20[bc] (18.21)	378.58[abc] (65.53)	26.33[b] (4.96)
FCV AT 2	1022.81[c] (135.96)	99.57[cde] (24.16)	274.57[ef] (67.91)	25.78[b] (33.37)
FCV AT 3	1346.79[a] (148.97)	134.25[a] (21.83)	328.91[cde] (85.12)	30.82[ab] (7.24)
FCV AT 4	1397.61[a] (250.03)	93.50[de] (17.97)	387.01[abc] (64.06)	20.65[c] (2.94)
FCV AT 7	1366.79[a] (119.60)	92.92[de] (12.54)	412.22[ab] (72.42)	31.10[ab] (7.02)
FCV AT 8	1349.32[a] (216.85)	142.44[a] (21.34)	425.39[a] (83.93)	33.79[a] (5.09)
FCV AT 15	1253.85[ab] (221.75)	137.86[a] (22.03)	355.28[bce] (42.33)	29.47[ab] (6.05)
FCV AT 16	1097.62[bc] (185.98)	126.34[ab] (18.21)	264.27[f] (38.18)	26.05[b] (4.04)
FCV AT 17	1076.45[c] (130.37)	82.69[e] (15.04)	327.41[cde] (48.59)	27.50[b] (5.52)
FCV AT 18	1359.04[a] (89.24)	103.41[cd] (12.09)	312.33[def] (32.50)	26.09[b] (4.81)
Mean	1262.89 (220.19)	112.42 (26.71)	346.60 (79.36)	27.75 (6.14)
P	<0.001**	<0.001**	<0.001**	<0.001**
C.D.	159.03	15.69	54.10	4.84

MRH= Multiseriate Ray Height; MRW= Multiseriate Ray Width; URH= Uniseriate Ray Height; URW= Uniseriate Ray Width

***Significant at 1 per cent level.*

Values with the same superscript along the column are homogeneous

Values within parenthesis is Standard Deviation (SD)

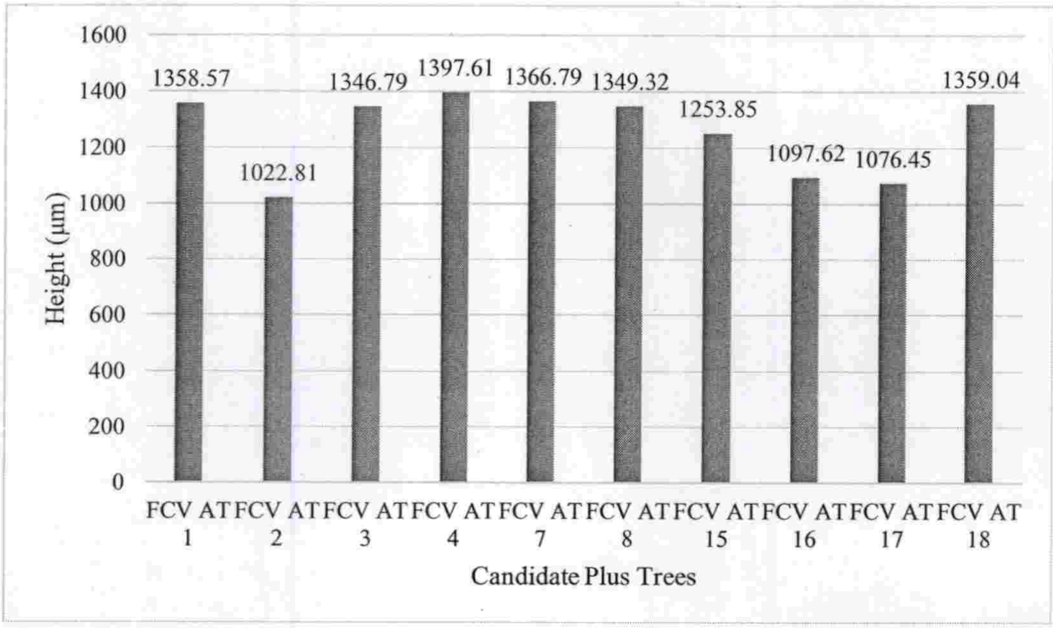


Figure 17. Multiseriate ray height (µm) of the different Candidate Plus Trees (CPTs) of *Ailanthus triphysa*

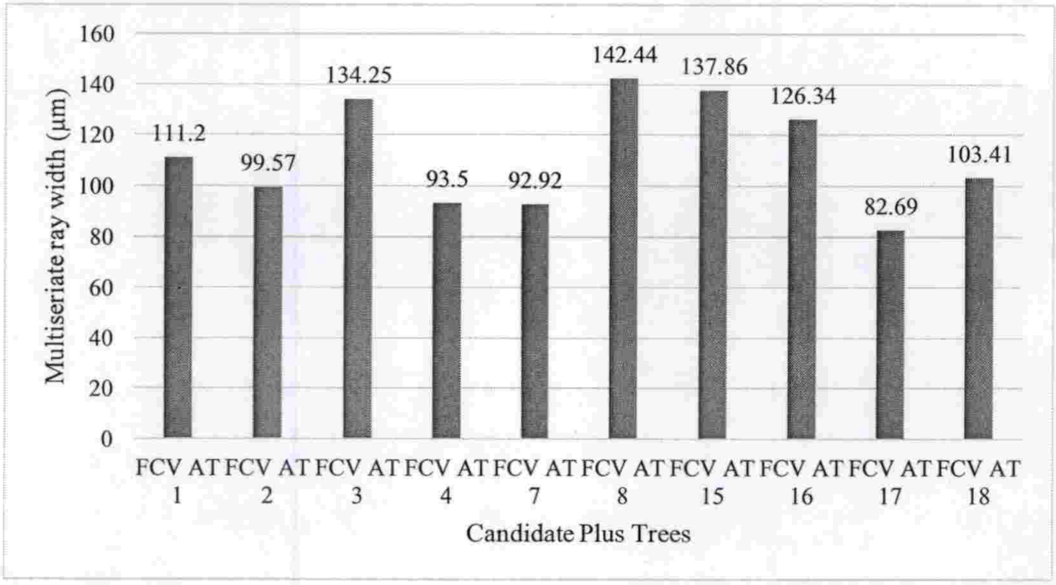


Figure 18. Multiseriate ray width (µm) of the different Candidate Plus Trees (CPTs) of *Ailanthus triphysa*

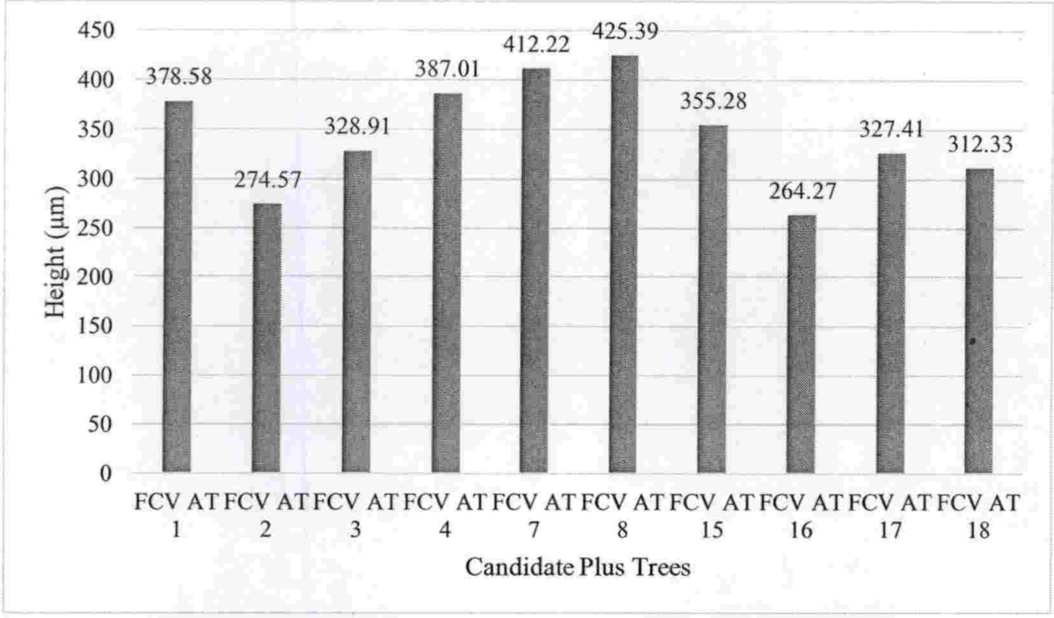


Figure 19. Uniseriate ray height (µm) of the different Candidate Plus Trees (CPTs) of *Ailanthus triphysa*

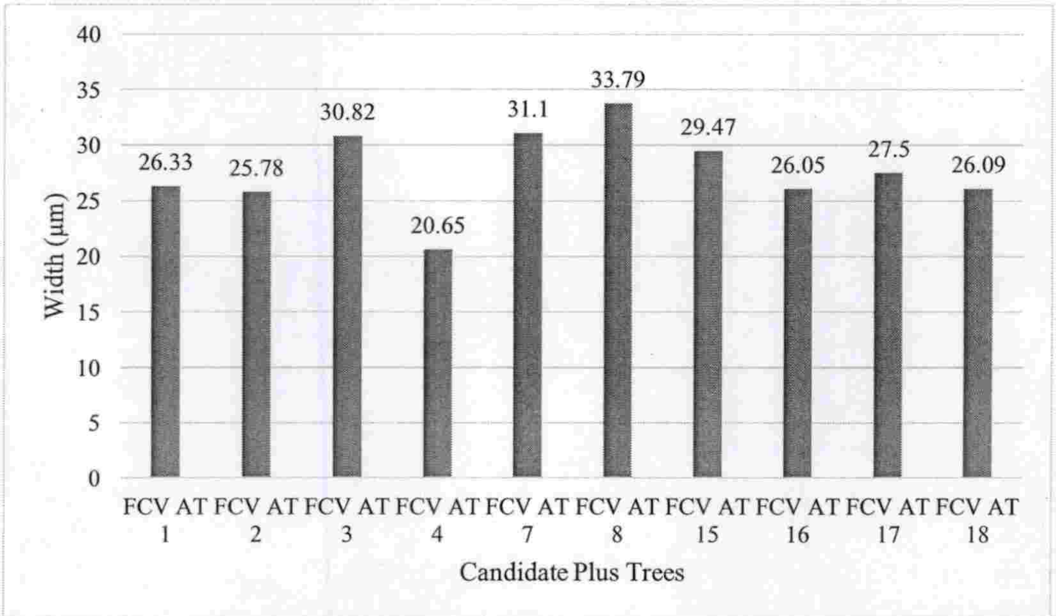


Figure 20. Uniseriate ray width (µm) of the different Candidate Plus Trees (CPTs) of *Ailanthus triphysa*

4.4 BIOASSAY

4.4.1 *Bacillus thuringiensis*

4.4.1.1 Eligma narcissus Cramer

The original data of bioassay did not follow the normality, hence it transformed in to arcsine value. Analysis was carried out by using factorial CRD method. The result revealed, the effect of different concentrations of Bt was found to be significantly different at 1 % level (Table 13 and Figure 21). The average mortality (%) after 72 hours was found to be 44.7 % (Arcsine value= 0.36), the highest mortality (%) was 86.5% (Arsine value= 0.64) exhibited by 15% Bt concentration and the lowest mortality rate was 0% (Arsine value= 0.00) exhibited by control.

4.4.1.2 Atteva fabriciella Swederus

The data of bioassay was analysed to find out the variation in effectiveness of three different concentrations of *Bacillus thuringiensis* (10% a.i.), a control was kept. The analysis of variance revealed, the effect of different concentrations of (Bt) were significantly different (Table 14 and Figure 22). The average mortality (%) after 72 hours was found to be 49.1 % (Arsine value= 0.34), the highest mortality (%) was 86.6% (Arsine value= 0.56) exhibited by 5% Bt concentration and lowest effect was 0% (Arsin value= 0.00) exhibited by control.

4.4.2 Neem oil

4.4.2.1 Eligma narcissus Cramer

Result did not show any larval mortality of *E. narcissus* due to the neem oil (Azadirachtin= 400-500 ppm) after 24 hours, but a marked difference was found in the feeding rate between two different concentrations of neem oil and control (Figure 23). The feeding rate was decreases with the increase in concentration. For 2% concentration of neem oil the feeding rate was 3.58 per cent, 1% concentration the feeding rate was 5.42 per cent, and for control the feeding rate was 30.91 per cent.

Table 13. Mortality rate (%) of *E. narcissus* under different concentrations of *Bacillus thuringiensis* (10% a.i.) after 72 hours

Concentration (%)	Mortality rate (%)
1	19.99^{b} (0.24)
5	33.20^{b} (0.30)
10	79.90^{a} (0.63)
15	89.99^{a} (0.64)
Control	0.00^{c} (0.00)
Mean	44.72
P	<0.001**
CD	0.16

***Significant at 1 per cent level*

Value within parenthesis is arcsine value

Table 14. Mortality rate (%) of *A. fabriciella* under different concentrations of *Bacillus thuringiensis* (10% a.i.) after 72 hours

Concentration (%)	Mortality rate (%)
1	29.90^{b} (0.27)
2.5	79.90^{a} (0.56)
5	83.32^{a} (0.56)
Control	0.00^{b} (0.00)
Mean	49.1
P	0.002*
CD	0.29

**Significant at 5 per cent level*

Value within parenthesis is arcsine value

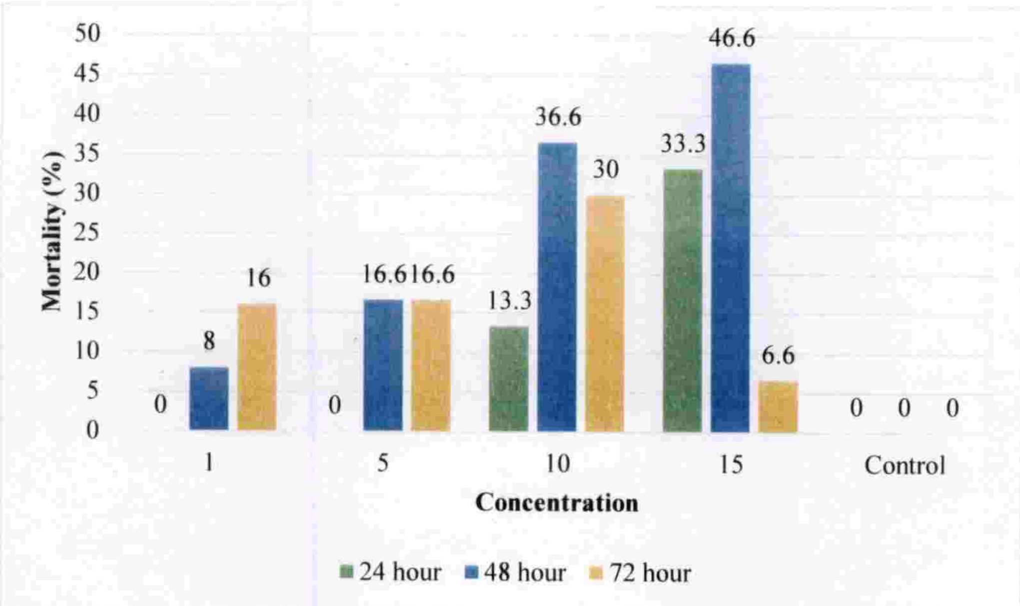


Figure 21. Mortality rate (%) of *E. narcissus* under different concentrations of *Bacillus thuringiensis* (10% a.i.)

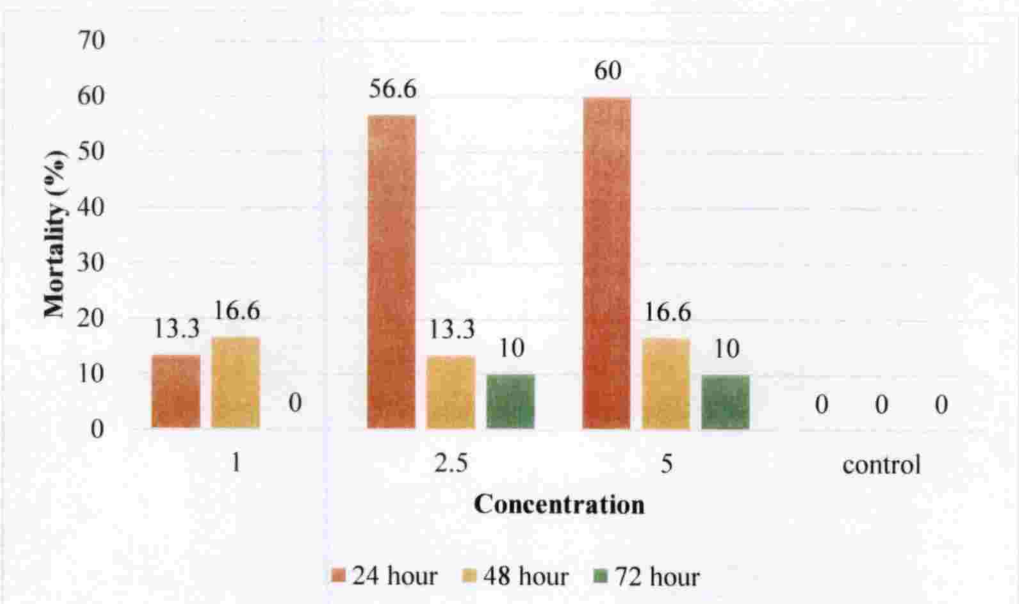
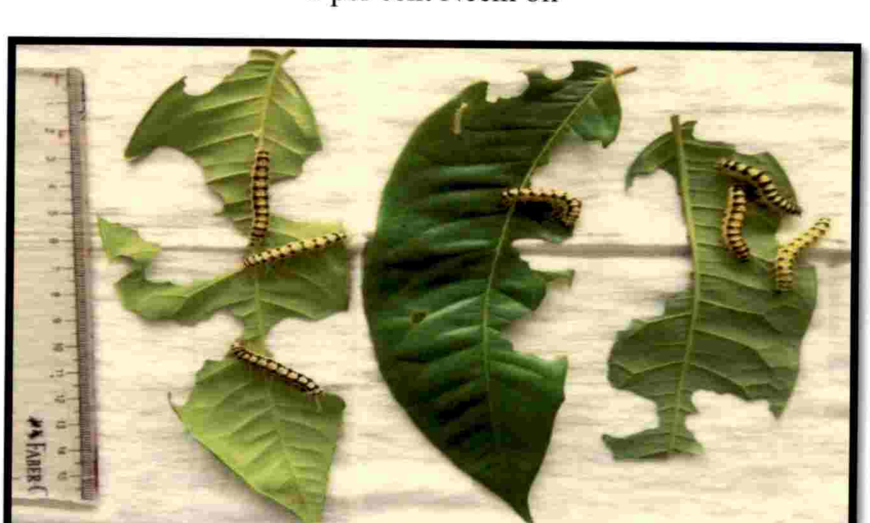


Figure 22. Mortality rate (%) of *A. fabriciella* under different concentrations of *Bacillus thuringiensis* (10% a.i.)

Plate 8. Feeding rate of *Eligma narcissus* under different concentration of neem oil

1 per cent Neem oil

2 per cent Neem oil



Control

4.5 SCORING OF PEST INCIDENCE

4.5.1 *Eligma narcissus* Cramer

The data was analysed to find out the variation in score among the progenies against insect attack. The result revealed, there was no significant difference in the extent of attack of *E. narcissus* among the progenies of different Candidate Plus Trees (CPTs) (Table 15 and Figure 24). The progenies with higher score meant to be lower in resistant and vice versa. The overall mode score was found to be 5, which denotes all the progenies were affected moderately against *E. narcissus*.

4.5.2 *Atteva fabriciella* Swederus

The result revealed, there was no significant difference in the extent of attack of *A. fabriciella* among the progenies of different Candidate Plus Trees (CPTs) (Table 15 and Figure 24). The progenies with high score, meant to be lower in resistant and vice versa. The overall mode score was found to be 5, which denotes all the progenies were affected moderately against *A. fabriciella*.

Table 15. Scoring of progenies of different Candidate Plus Trees (CPTs) against the attack of *E. narcissus* and *A. fabriciella*

CPTs	*E. narcissus*		*A. fabriciella*	
	Score	Friedmen's value	Score	Friedmen's value
FCV AT 1	5 (0.00)	07.75	5 (0.00)	07.50
FCV AT 2	5 (0.50)	10.13	5 (0.50)	09.75
FCV AT 3	5 (0.00)	07.75	6 (0.50)	14.25
FCV AT 4	5 (0.50)	10.13	5 (0.00)	07.50
FCV AT 5	5 (0.50)	10.13	5 (0.50)	09.63
FCV AT 6	5 (0.50)	10.13	5 (0.81)	08.00
FCV AT 7	5 (1.25)	08.50	5 (1.00)	10.75
FCV AT 8	6 (0.50)	14.63	5 (0.95)	13.13
FCV AT 9	5 (0.50)	10.13	5 (0.50)	09.63
FCV AT 10	5 (0.00)	07.75	5 (0.00)	07.50
FCV AT 11	5 (0.50)	10.13	5 (0.50)	09.63
FCV AT 12	6 (0.57)	12.50	6 (0.57)	12.13
FCV AT 13	6 (1.00)	13.00	5 (0.95)	12.13
FCV AT 14	6 (0.95)	10.38	5 (0.00)	07.50
FCV AT 15	5 (0.50)	06.00	6 (1.00)	12.75
FCV AT 16	6 (0.50)	14.63	5 (0.50)	09.75
FCV AT 17	5 (0.95)	13.50	6 (0.50)	14.00
FCV AT 18	5 (0.81)	08.13	5 (0.50)	05.50
FCV AT 19	6 (0.50)	14.63	6 (0.50)	14.38
FCV AT 20	6 (0.95)	10.13	6 (1.25)	13.63
Mode	5 (0.64)		5 (0.65)	
P	0.462^{ns}		0.282^{ns}	

Superscript "ns" indicate not-significant

Values within parenthesis is Standard Deviation (SD)

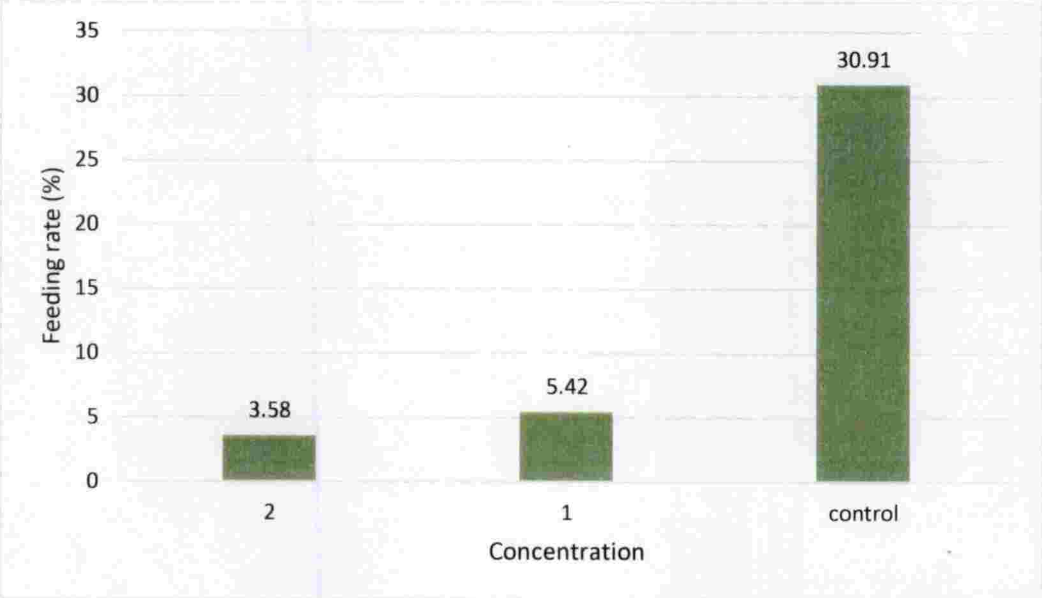


Figure 23. Feeding rate (%) of *E. narcissus* under different concentrations of neem oil (Azadirachtin= 400-500 ppm) after 24 hours of application

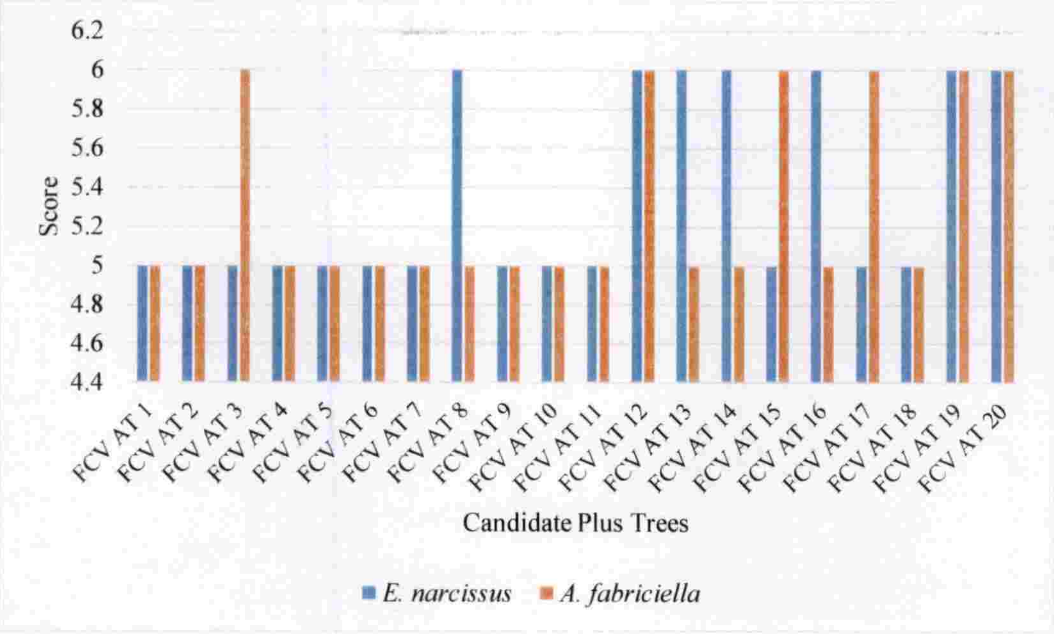


Figure 24. Variation in score of progenies of different Candidate Plus Trees against pest incidence in *Ailanthus triphysa*

4.6 GENETIC STUDIES

4.6.1 General combining ability

4.6.1.1 Height

General combining ability of different Candidate Plus Trees (CPTs) was calculated for height (Table 16 and Figure 25). It was found that eleven CPTs had positive GCA namely FCV AT 1, 2, 3, 5, 6, 7, 8, 9, 11, 13, and 20. The Candidate Plus Trees with positive GCA could be mentioned as good general combiners. The highest GCA value was +0.35 found in FCV AT 6 CPTs and the lowest GCA was – 0.52 found in FCV AT 16 CPTs.

4.6.1.2 Collar diameter

Genetic combining ability of collar diameter was calculated for all the Candidate Plus Trees (CPTs) included in the study (Table 16 and Figure 26). Twelve CPTs had positive GCA namely FCV AT 1, 2, 3, 5, 6, 8, 9, 10, 11, 13, 17, and 20. The highest GCA was +5.58 for FCV AT 8 CPTs and the lowest was – 9.21 for FCV AT 16 CPTs.

4.6.2 Broad sense heritability (H^2)

Broad sense heritability (H^2) for height and collar girth was calculated. The H^2 for height was found to be 0.03 and for collar diameter H^2 was 0.1, which was very low.

Table 16. General Combining Ability of different Candidate Plus Trees (CPTs) for height and collar diameter

CPTs	Height	Collar diameter
FCV AT 1	+0.33	+2.66
FCV AT 2	+0.02	+2.54
FCV AT 3	+0.2	+4.25
FCV AT 4	-0.17	-6.78
FCV AT 5	+0.31	+2.75
FCV AT 6	+0.35	+1.7
FCV AT 7	+0.08	-0.67
FCV AT 8	+0.14	+5.58
FCV AT 9	+0.1	+2.13
FCV AT 10	-0.16	+3.25
FCV AT 11	+0.32	+3.45
FCV AT 12	-0.34	-4.07
FCV AT 13	+0.07	+0.61
FCV AT 14	-0.3	-7.84
FCV AT 15	-0.09	-1.51
FCV AT 16	-0.52	-9.21
FCV AT 17	-0.17	+0.57
FCV AT 18	-0.03	-0.35
FCV AT 19	-0.05	-0.79
FCV AT 20	+0.33	+3.8

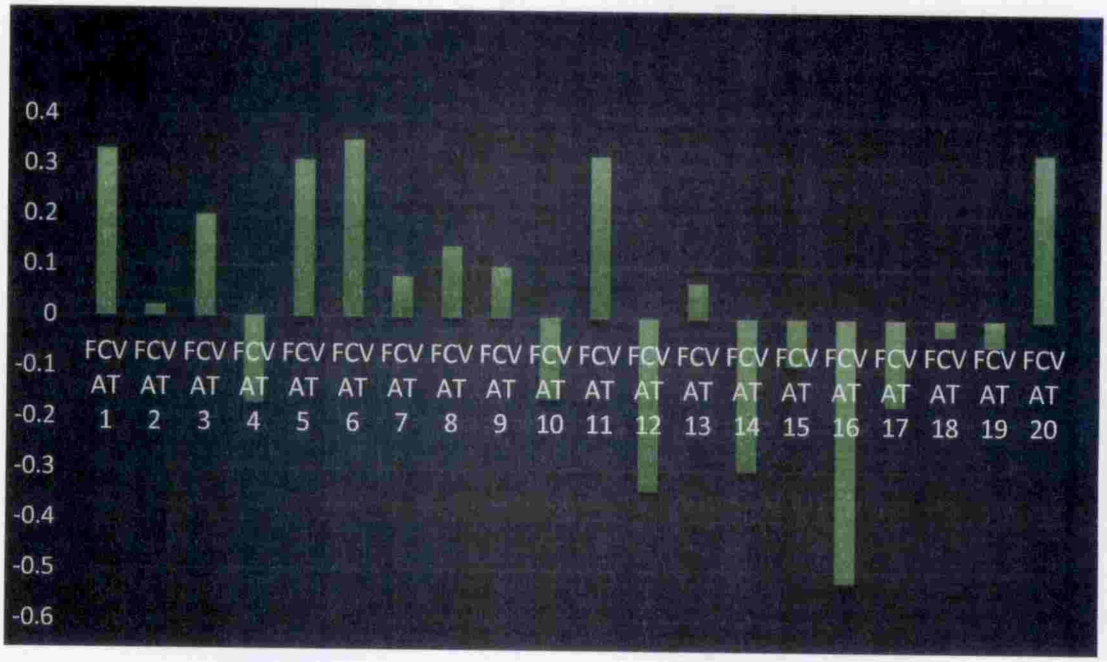


Figure 25. General Combining Ability of different Candidate Plus Trees of *Ailanthus triphysa* for height

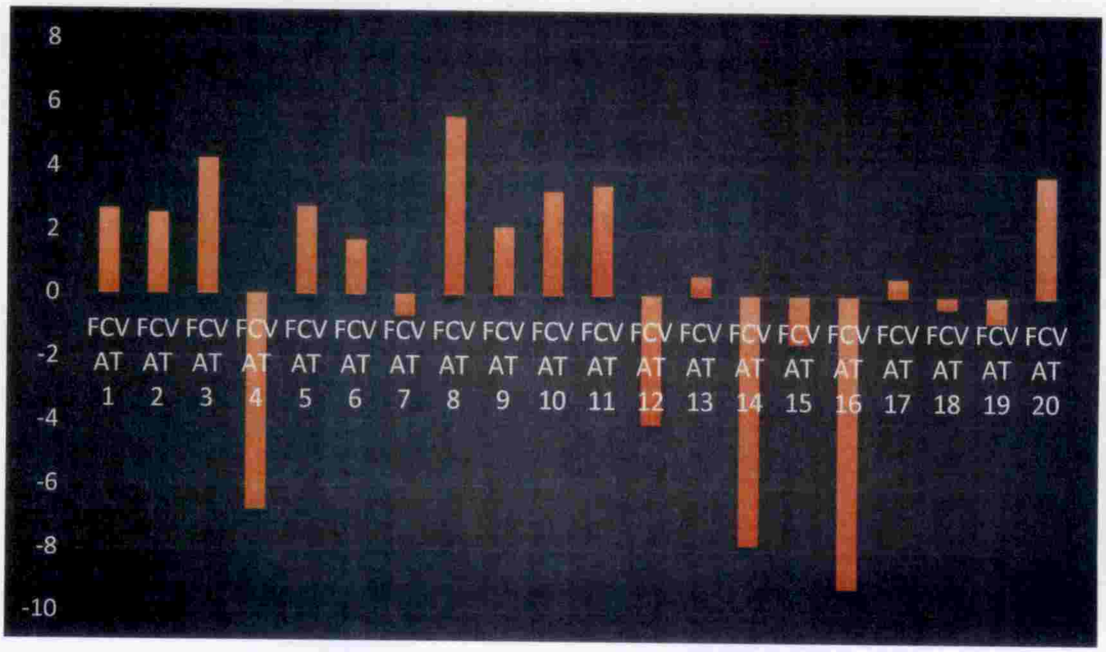


Figure 26. General Combining Ability of different Candidate Plus Trees of *Ailanthus triphysa* for collar diameter

Discussion

5. DISCUSSION

5.1 FIELD TRIAL

The present investigation aimed at evaluating the variation among twenty seed sources of *Ailanthus triphysa* (Dennst.) Alston. The study was conducted at College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur, Kerala. Selection is a key part of all applied tree improvement programs. The key objective of a selection program is to occur significant amount of genetic gain as quickly and inexpensively as possible (Zobel and Talbert, 1984). In the present study, an attempt was made to identify the best performing Candidate Plus Trees (CPTs) suitable for growing in the agro-climatic conditions of Kerala.

The variables like seedling height and collar diameter were measured in a bimonthly interval. The seedling height was found to be non-significant among the progenies of different Candidate Plus Trees (CPTs) over time (Table 2, Table 3, and Figure 3). After 28 months of planting the progeny of FCV AT 6 CPTs showed the highest value (3.14 m). Five best performing progenies for height were FCV AT 6, 1, 20, 11 and 5. Paul (2017) reported that the height did show significant difference among the progenies of different CPTs up to 150 days after planting (DAP), while analyze the data obtained from the same experimental plot of *A. triphysa*. Moreover the progeny of FCV AT 1 CPTs found to be best among all. Analyzing both the study it could be said that the height showed significant variation after field planting which was later on reduced to non-significant 16 months after field planting. Considering that collar girth and collar diameter were found to be non-significant among the progenies of different CPTs (Table 4, Table 5, Figure 4, and Figure 5). The progeny of FCV AT 8 CPTs showed highest collar diameter (74.69 mm) after 28 months of planting. Five best performing progenies for collar diameter were FCV AT 8, 3, 20, 11 and 16. Among the five best performing progenies, FCV AT 11 and FCV AT 20 were found to perform well in terms of height and collar diameter (Table 2, Table 4). Indira (1996) in *Ailanthus triphysa* reported that the variation in height was significant whereas, girth was non-significant among the families. The mean height after 3 ½ years of planting was 1.79 m which was low compared to the present study 2.79 m, which could be possibly due to edaphic factor. Moreover it was mentioned that *A. triphysa* performed equally well in degraded soils as in fertile land whereas, *A. integrifolia* failed to survive in such degraded areas. Paul (2017) reported the collar diameter showed significant different result only till 60 DAP, the highest collar diameter was found in progeny of FCV AT 8 CPTs. Collar diameter also follow a similar pattern of variation like height, where collar diameter showed significant result at very early stage of field planting which was later found to be non-significant after 24 months of planting. At this stage, it was confirmed that the variation in height and collar diameter was non-significant and uncertain, hence selection was not possible based on these traits. There may or may not be any significant variation at rotation age but the present data will be helpful to correlate with the future data. Moreover it will be helpful to trace the early gain of the species for the present site condition. However, the outcome of present study is not an exception. A provenance trial in *Acacia mangium* using 30 provenances showed no significant difference in growth parameter (Suhaendi, 1993). Low variation between provenances in *Acacia auriculiformis* had been reported from Karnataka, India (Bulgannawar and Math, 1991).

Branching habit and tree form affect the quality of final product (Zobel and Talbert, 1984). Undesirable branching and tree form decreases the volume and economic value of the timber (Codesido and Fernandez-Lopez, 2008). Number of branches shown non-significant result whereas in bole straightness significant variation was found among the progenies of different Candidate Plus Trees (CPTs) (Table 7). The overall mode value for number of branches was found to be zero. The number of branches for all the progenies were found to be zero except the progeny of FCV AT 3 CPTs, which had a value of one. Ginwal *et al.* (2004) in *Jatropha curcas* Linn. reported significant difference in number of branches. The presence of such difference among populations may induced by different intensities of natural selection action upon these traits in their natural habitat. As the number of branches for all the progenies were ranged between zero to one, there is a chance to produce good quality log with volume. Bole straightness was found to be significantly different among the progenies of different CPTs. The overall mode score for bole straightness was found to be three which denotes "almost straight with 1 or 2 small bends". For all the progenies score was found to be three whereas progeny of FCV AT 8 and FCV AT 14 CPTs scored two (slightly crooked with 2 small bends or less than 2 serious bends). Progenies of FCV AT 7 and FCV AT 13 CPTs shown the best performance in bole straightness. According to Wilmot (1929), the shape and size of the trees appropriate for matchmaking should have certain criteria like a. Logs must be as cylindrical as possible b. Logs must be reasonably straight c. Logs must be free from branches and knots. In the present study, it was found that the majority of the progenies had good branching habit and bole straightness except few above mention progenies. This aspect should be utilized in breeding programme so that it will be helpful to improve the tree form, which ultimately increases the quality and economic value of the timber. It could also be helpful to meet the demand in match wood sectors in Kerala. Stand quality assessment of *Tectona grandis* did not show any significant variation in bole straightness and branching habit (Mollick *et al.*, 2005).

Whether a species is an exotic or native, the environment can induce changes in the individual behavior at the physiological or morphological level and such changes is crucial for survival (Gratani, 2014). After 28 months of planting mean survival percentage was found to be 94.98 %, ranged between 84.61 % to 100.00 % (Table 6 and Figure 6). Paul (2017) reported that the average survival percentage of *A. triphysa* after 150 days of planting was found to be 98.44 %, the value ranged between 87.5 % to 100.00 %. Such high survival percentage revealed suitability of climatic conditions of Kerala for the species *A. triphysa* and the suitability for all the CPTs included in the study. Baharudin *et al.* (1987) also found good survival percentage ranging between 83.00 % to 95.00 % for *Acacia mangium*. The variation in stem volume was found to be non-significant among the progenies of different CPTs after 28 months of planting (Table 6 and Figure 7). Kindo *et al.* (2010) reported that good performance of *Acacia crassicarpa* in volume production is attributed to its advantages in good growth in height and diameter. In the present study, the progenies of FCV AT 11 CPTs shown highest mean volume production 0.006 m^3 , which also performed among the five best performing progenies in height and collar diameter. Singh and Pokhriyal (2000) in *Dalbergia sissoo* found the biomass production differ significantly among the seed sources which was contrary to the present findings.

5.2 WOOD PHYSICAL PROPERTIES

5.2.1 Basic density

Basic density is an important physical property of wood, along with that it also determines the morphological, physiological, and ecological characteristics of wood (Jerome *et al.*, 2006). Density of a wood could also be taken as a potential tool for determining the solid and fibrous property, which leads to an efficient utilization (Bhat, 1985).

Analysis revealed that the variation in basic density among the Candidate Plus Trees (CPTs) was significantly different (Table 8 and Figure 8). The average basic density was found to be 0.37 g cm^{-3}. Shukla and Sangal (1986) reported mean basic density of *Ailanthus excelsa* was 0.36 g cm^{-3}, which also used for match splint production in some parts of India. Miranda *et al.* (2001) in *Eucalyptus globulus* reported that the variation between the sites within provenance exhibited significant result in basic density (P= 0.004). Gartner *et al.* (2007) in *Alnus rubra* found significant difference in specific gravity between the trees whereas in Japanese larch (*Larix kaempferi*), the basic density did not vary significantly between the provenance. Machado *et al.* (2014) in *Acacia melanoxylon* noticed non-significant difference in basic density between the trees, which was not matched with the present finding. Bhat *et al.* (2007) reported that the variation in basic density was significantly different among the samples collected from different age groups of *Eucalyptus grandis* in Kerala, India. The possible reason for the variation could be (a) definite pattern of age related variation (b) age-environment-genotype related variation. In the present study also age of the different CPTs were not considered, which could be a possible reason for the variation in basic density. Strong, heavy, and hard woods are unsuitable for match making, they are too brittle and not readily impregnated. A combination of strength with lightness is desirable (Wilmot, 1929). In the present study average basic density of all the CPTs of *Ailanthus triphysa*, which falls in light weight category (300-450 k gm^{-3}). It was known that the species was being used for match splint making, but the present result strengthen the technical side for the suitability of the species for matchmaking.

5.2.2 Colour

Colour is an important feature in wood, which is also equivalent to other physical properties. Wood colour has a significant effect on the aesthetic value of the wood, hence it helps to increase the market demand and price as well. Hon and Minemura (2001) stated that the interaction of light with chemical components of wood is responsible for colour characteristic. It was also stated that lignin is the chromophore binding molecule in wood along with phenolic extractives such as quinines, tannin, and flavonoids. During colour study of *Ailanthus triphysa,* one colour pattern (pale yellow) was found predominantly in all the CPTs. Munsell colour system was used while studying the wood colour. Similar result was reported by Thulasidas *et al.* (2006), they did not notice any significant difference in heartwood colour between homesteads and plantation grown teak. The wood colour variation in *Calycophyllum spruceanum* at young stages was found to be significantly different within and between the provenances (Montes *et al.,* 2008). The genetic correlation revealed that the selection of denser wood species or the species with faster growth rate would have less effect on wood colour. The species *Ailanthus triphysa* does not have any distinct colour difference between heart wood and sap wood and moreover due to the faster growth rate the colour of this species follows a similar pattern. Elegance is an crucial in match manufacture and most producer demand light coloured wood, dark coloured wood are only used in the time of shortage (Wilmot, 1929).

5.2.3 Grain

Grain is one among few characters which considered before selecting wood for end use. While studying the grain pattern of different Candidate Plus Trees (CPTs) of *Ailanthus triphysa,* it was noticed that the straight grain was predominant in all the CPTs. The present study found parallel with the findings by Cown *et al*. (1991), who reported spiral grain arrangement in *Pinus radiata* D. Don was dominant in all the trees. The grain structure could be attributed to the growth rate of the trees. Considered to matchmaking the wood must be straight grained and easy to peel on peeling (Cox, 2000). Fine grain along with high density is not suitable for matchmaking as it fail to take the impregnation of chemical and later paraffin wax (Wilmot, 1929).

5.3 WOOD ANATOMICAL PROPERTIES

5.3.1 Fibre morphology

Fibre morphological characters viz. fibre length, fibre width, and fibre wall thickness varied considerably among the Candidate Plus Trees (CPTs) (Table 9). The mean value of fibre length was found to be 1163.83 μm whereas fibre width 29.84 μm and fibre wall thickness was 4.25 μm. In the previous study (Paul, 2017) reported the difference in fibre length, fibre width, and fibre wall thickness was found to be significant among the CPTs of *Ailanthus triphysa*. The mean value of fibre morphological parameters was viz. fibre length 1696.05 μm, fibre width 42.97 μm, fibre wall thickness 4.84 μm. All the fibre morphological parameters showed higher value compared to the present study. Quilho *et al*. (2006) reported that the variation fibre morphological parameters varied significantly within tree of *Eucalyptus grandis*. Fibre length, fibre width, and fibre wall thickness increased with the increase in distance from pith to bark. In this regards, radial position of the fibre parameters was neither considered in present nor in the previous study. Which may lead to the difference in fibre morphological characters between both the studies. Sahoo *et al*. (2017) in *Artocarpus hirsutus* Lam. noticed fibre length varied significantly between different agro climatic zones, the variation in fibre width and fibre wall thickness were least significant. Fibre length was ranged between 1154.13 μm to 1814.94 μm. This can be describe by the information given by Moya *et al.* (2009) that the fibre parameters was affected by the climate and type of the growing site. Verghese *et al.* (2000) studied 60 year old teak in nine different locations of peninsular India and did not found any considerable variation in fibre properties, which is contrary to the present findings.

5.3.2 Vessel morphology

In the present study, the average vessel length of different Candidate Plus Trees (CPTs) was found to be 618.9 μm, which ranged between 541.50 μm to 720.91 μm. The difference in vessel length was found to be significant among the CPTs (Table 10). Paul (2017) found considerable variation in vessel length among the different CPTs of *Ailanthus triphysa*. The mean vessel length was found to be 635 μm, which was almost matched with the present result. Sahoo (2017) in *Artocarpus hirsutus* observed that the vessel length varied considerably among the agro-climatic zones, the highest mean vessel length was 284 μm. The wood samples of *Artocarpus nitidus* collected from Assam and Mizoram and the mean vessel length found was 284.4 μm (Singh *et al.*, 2017). Ahmed and Chun (2011) claimed the mean vessel length in teak was 279 μm. It was noted that the factors like moisture availability, geographical location, phenology (e.g. slope exposure, deciduous nature of the plant, seasonal stem dieback, leaf size) potentially effect the vessel structure (Carlquist, 2001). Therefore, it could be deduce that the variation in vessel length among different CPTs can be attributed to variability in locality of the CPTs. Nevertheless, environmental factors clearly do affect some aspects of xylem structure, as found for wood density and soil fertility (Muller-Landau, 2004), temperature and vessel diameter (Thomas *et al.* 2007), climate and annual ring width (Wang *et al.* 2005), soil water and vessel diameter (Stevenson and Mauseth, 2004).

The variation in vessel diameter and vessel area was found to be significant among the different Candidate Plus Trees (CPTs) (Table 9). The highest vessel diameter was found in FCV AT 17 CPTs (330.10 μm) and the lowest in FCV AT 08 CPTs (245.99 μm). The average vessel diameter was found to be 289.71 μm. Gartner *et al.* (2007) reported the vessel diameter varied significantly between the trees of *Alnus rubra*.. Vessel diameter ranges between 43 μm to 71 μm. Perhaps the between trees variation in vessel diameter was due to genetic factor rather than growth rate, because they did not notice any marked difference in growth ring among the trees. The average vessel area for all the seed sources was 48351.41 μm^2, with the highest vessel area 62419.82 μm^2 (FCV AT 17 CPTs) and the lowest 37496.02 μm^2 (FCV AT 08 CPTs) respectively. Sahoo (2017) in *Artocarpus hirsutus* reported the difference in vessel area was least significant between the agro-climatic zones as well as girth classes. The vessel area ranged between 63349.27 μm^2 to 90083.68 μm^2 among the agro-climatic zones. It was reported that the vessel element length and vessel diameter reduced with increasing aridity whereas, vessel number increases (Zhang *et al.*, 1988). We found vessel frequency ranged between 1-3/mm^2, which differed significantly among the different CPTs (Table 9). However Anoop *et al.* (2012), did not found any significant variation in vessel frequency between the provenances of some selected *Acacia* species. In *Artocarpus hirsutus* Sahoo (2017), noticed the vessel frequency was 2-3/mm^2 and the variation was non-significant between the agro-climatic zones and between the girth classes. Vijayan (2017) stated that the greater in vessel frequency, smaller the diameter of vessel and greater the chance of grouping. In the present study it was noticed that the Candidate Plus Trees (FCV AT 15) with higher number of vessels 3/mm^2 exhibited smaller vessel diameter 268.41 μm (Table 15 and Table 16).

5.3.3 Ray morphology

The main function of ray parenchyma includes, storage of mineral inclusions, transitional function from sapwood to heartwood, provides mechanical strength stability, and protection against pathogen attack to wood (Deflorio *et al.*, 2008; Nawrot *et al.*, 2008; Reiterer *et al.*, 2002). In *Ailanthus triphysa* (Dennst.) Alston both multiseriate and uniseriate ray found predominantly. The average multiseriate ray height was 1262.89 μm and width 112.42 μm, although average uniseriate ray height was 346.60 μm and width 27.75 μm. Morphological characters for both multiseriate and uniseriate ray cells varied considerably among the different Candidate Plus Trees (CPTs) (Table 12). A study on Cork oak (*Quercus suber* L.) also reported similar result, the variation in ray dimension was significant between the trees. They found the average multiseriate ray height 5.16 mm and width 0.48 mm, and average uniseriate ray height was 227 μm (Leal *et al.*, 2006). Anoop *et al.* (2012) studied the wood anatomical properties of the different provenance of some selected *Acacia* species and did not found significant result in ray morphology between the provenances. Generally ray height and width shows periodic changes with tree growth. The ray height increases with the increase in age of tree, as a result of transverse division of ray cell initials, fusiform initials of adjacent rays or addition of segment from fusiform initials. The width increases with increase in tree age in very young trees and stabilize later (Larson, 1994). The variation in ray morphology may due to the effect of cambial growth, also environment had a great effect on ray height as environmental stress reduces the growth of cambium (Larson, 1964).

5.3.4 Tissue proportion

Characterization of tissue proportion in hardwoods can possibly render for the enhanced end use in papermaking. This would have remarkable effect on the use of hardwoods (Anon, 1973). In the present study, it was found that the difference in the tissue proportion (fibre, parenchyma, vessel) were non-significant among the Candidate Plus Trees (CPTs). The mean proportion of tissues were, fibre 61.84 %, parenchyma 34.72 %, and vessel 3.43 % respectively (Table 11). The variation in tissue proportion was found to be significant among the different provenances of *Acacia mangium and Acacia auriculiformis* (Anoop *et al.*, 2012), which was well match with the present finding. Tissue proportion greatly influenced by environmental condition especially rate of growth which determines the mature wood and juvenile wood proportion in the tree, which in turn influence the tissue proportion (Ajayghosh, 2010).

5.4 BIO-CONTROL OF TWO MAJOR INSECT-PEST

The major problem associated with the *Ailanthus triphysa* species is heavy attack of insect pests. Two major insect pest of the genus *Ailanthus* are *Eligma narcissus* Cramer and *Atteva fabriciella* Swederus (Chaterjee *et al*., 1969). The larval period of *Eligma narcissus* between 22-23 days and 8-9 generation in a year whereas, in *Atteva fabriciella* the larval period between 13-20 days and 9 generation in a year (Mathur *et al*., 1970). In this regards it could be said that both of the insect pest remained active more than half of a year time period and caused wide spread defoliation to the plantation. *Eligma narcissus* considered as the serious pest of *Ailanthus triphysa* in South India, the pest feeds on almost all species of genus *Ailanthus* (Chatterjee and Sen Sarma, 1968). *Eligma narcissus* fed on the matured leaves of *A. triphysa* and stabilize the growth. Ailanthus webworm *Atteva fabriciella* fed on the tender leaves and apical bud of *A. triphysa* tree. Mainly it damage the apical portion of a tree which induce branching, therefore it reduces the growth and quality of a tree. Kerala forest department stopped growing *A. triphysa* plantation due to the extensive damage by insect pest outbreak in the early stages. Neem oil was taken as a biocontrol agent because it act like a repellent moreover it readily available. The product of neem oil used in the present study contained 400-500 ppm azadirachtin. *Bacillus thuringiensis* (Bt) was selected as a biocontrol agent due to its long range of host killing ability and its higher potency. Bt also potentially safer than many synthetic chemical pesticides currently used for controlling the insect pests (Schnepf *et al*., 1998).

After 72 hour, the effect of different concentrations of Bt was found to be significant against *Eligma narcissus* (Table 13 and Figure 21). The highest mortality (89.9%) was found in 15% Bt concentration. Likewise, for *Atteva fabriciella* the variation in mortality rate was found to be significant among three different concentrations of Bt after 72 hours (Table 14 and Figure 22). Among the three different concentrations of Bt tested, highest mortality (83.3%) was reported in 5% concentration. The effectiveness of different concentrations of Bt obtained in the present study was only for first and second instar larvae of *E.*

narcissus and the similar result may not be obtained for higher instar larvae. In *A. fabriciella* the instar of the larvae were not considered during bioassay. Joshi *et al.* (1996) reported *ailanthus* leaf defoliator *Atteva fabriciella* (ailanthus webworm) was controlled efficiently by spraying the Bt on host plant. It was noticed that the endotoxin was found to be highly effective against the larva at 1.5% level of Bt concentration. In the present study it was observed that the mortality was induced in both the insects (*E. narcissus* and *A. fabriciella*) due to Bt, but the concentration varied greatly among both the insect larvae. In case of *E. narcissus* 10 % and 15 % Bt concentration showed significantly higher result whereas, in *A. fabriciella* 2.5 % and 5 % Bt concentration does the same. Comparing both the result it can be inferred that, the larvae of *E. narcissus* imparts higher resistance against Bt then *A. fabriciella,* hence it consumed higher concentrations of Bt to induce considerable mortality. In case of *E. narcissus* median lethal dose (LD_{50}) was achieved with 10% concentration of Bt. Whereas in *A. fabriciella*, 2.5% Bt concentration was found to be effective. During the study it was observed that, the body of the dead larvae were shrank to a certain extent, colour changed in to darker and the faecal matter changed to liquid. This kind of reaction was explained by (Heimpel and Angus, 1963), after feed on *B. thuringiensis* treated leaves, the larva becomes lethargic and inactive and seizes feeding due to the loss of appetite. At first stage the larva becomes light brown color, gradually shrinks in size and becomes dark brown finally death. Apart from this, the larval mortality was observed even after 72 hours of Bt application. In some cases the larvae undergone pupation after feeding over Bt treated leaves and got damaged thereafter, hence did not able to complete the pupation successfully (Plate 6d. non-arrow). In a work Bai *et al.* (2015), studied the bio efficacy of 25 isolates of *Metarhizium anisopliae* against *E. narcissus* in the laboratory and field condition. They found the fungi was highly effective in MIS7 + MIS13 formulation causing 93.93% mortality. Shamila and Lall (2000) experimented on the efficacy of *Bacillus thuringiensis* on some important forest insect pest. They found that all the defoliators were controlled effectively by spraying 1.5 % concentration of Bt. While comparing the present study with previous work regarding *A. fabriciella*, the concentration of Bt was found to be higher to induce the similar kind of result. In the present study the minimum sample size (30 larvae per concentration) was taken for bioassay. Which could be further studied by taking large number of samples. After bioassay in laboratory a small trial was carried out in field condition to know the effectiveness. Since then the season for *E. narcissus* was ended and only few trees were found attacked by *A. fabriciella,* it was decided to apply 2.5 % Bt to the affected trees. Total six trees selected and the number of number of larvae was counted before the application of Bt. It was found that eight out of total ten larvae were died after 24 hour of application. From the above observations it could be stated that, the *Bacillus thuringiensis* (Bt) could be act as a potential bio-control agent against both the lepidopteran insect (*E. narcissus* and *A. fabriciella*) and could be taken potentially for further experimental programmes.

Neem oil did not show any mortality against *Eligma narcissus* Cramer but a clear antifeedant activity was observed. With the increase in concentration of neem oil the antifeedant effect was also increased (Figure 23). The average leaf area consumed by larvae was reduced to 3.58 % in 2 % neem oil treated leaves as compared to 30.91 % in control. Furthermore in 1 % of neem oil treatment the feeding rate was 5.42 %. It could be stated that, with the increase in concentration of neem oil the feeding rate was decreased. During the study it was found that some larvae were not able to undergo pupation, if they do some larvae were not able to complete the pupation. It could be defined that after fed over neem oil treated leaves the larvae were unable to perform normal growth. These effects could be because of tetranortriterpenoid, a chemical compound associated with azadirachtin which present in the neem oil (400-500 ppm) used in the present study. The presence of tetranortriterpenoid induce feeding deterrence, reduces the fertility of females, restrain the growth, and affects survival (Martinez and Emden, 1999; Nisbet *et al*., 2000). These aspects could be studied more intensively taking large number of samples with a strong methodology. Almeida *et al.* (2014) reported, the presence of more than 500 ppm of neem seed kernel extract (NSKE) in the diet induced 100% larval mortality of *Anticarsia gemmatalis*. Moreover lower doses decreased food intake and reproductive capacity, and increased production of pupae with morphological deformities. The *Aloe vera* leaf extract was found to be potent and most effective antifeedant agent against teak skeletonizer (Meshram *et al.* 1996). Govindachari *et al.* (1996) found larval mortality of *Spodoptera litura* due to azadirachtine. Nathan *et al.* (2005) found first to third instar larvae of *Anopheles stephensi* were more susceptible to the neem limonoids.

5.5 SCORING OF PEST INCIDENCE

Application of chemical insecticide is an option which provides effective action within a short period of time. Developing resistant genotypes is an alternative and efficient way of combating the problem for longer period of time (Floyd *et al.*, 1994; Farrel and New, 1980). Many studies revealed that even a damage of small leaf portion by herbivorous insect may alarmingly effect the plant growth. The scoring of pest incidence revealed the difference among the seed sources was non-significant for *Eligma narcissus* Cramer and *Atteva fabriciella* Swederus (Table 15, Figure 24). The mode score was found to be 5 for both the insects, which means all the progenies collectively affected by both of the insect pests. It was observed some trees with heavily infested with insect attack whereas some trees showed free from any attack but there number was very less, so while averaged it could not provide a significant impact on the final result. Trees with good resistant were inconsistent in nature, most of the trees had good resistant for certain period and found to be infested by insects thereafter. Farrow *et al.* (1994) in *Eucalyptus globulus* reported the resistant of all the eight provenances was inconsistent. Shujauddin and Kumar (2003) stated in *Ailanthus triphysa* that the higher dose of chemical fertilizer increased the incidence of two major insect pests.

5.6 GENETIC STUDIES

The objective behind selection in any tree improvement programme is to identify the superior genotypes as planting stock, which can also be used for further breeding programme (Namkoong *et al.*, 1972). Success in the establishment and productivity of a forestry plantation mainly depends on species used and source of seed within the species (Larsen, 1954; Lacaze, 1978). General combining ability (GCA) is the average performance of the progeny of an individual when it mated to a number of other individuals (Falconer, 1960). It was noticed that eleven Candidate Plus Trees (CPTs) showed positive GCA for height whereas twelve CPTs showed Positive GCA for collar diameter (Table 16). Ten CPTs namely FCV AT 1, 2, 3, 5, 6, 8, 9, 11, 13, 20 were found to be good combiners for both the characters. FCV AT 6 recorded highest GCA for height whereas, FCV AT 8 recorded highest GCA for collar diameter. Therefore it is the reflection of parent's additive genetic value; that is, it reflects that portion of its genotype for height and collar diameter trait that the parent may transmit to its progeny (Zobel and Talbert, 1984). Gupta (1996) reported that more than 50 % of the total clones included in the study were found to have positive GCA value for at least one character in *Tectona grandis*. The CPTs with positive GCA could be mention as good combiners and could be potentially included in a seed production and further breeding. Heritability is the ratio indicating the degree to which parent pass their characters to the offspring. Heritability is the key factors to estimate the gain from a selection programme (Zobel and Talbert, 1984). Broad sense heritability (H^2) for height and collar girth was found to be 0.03 and 0.1 which was very low. Indira (1996) in *Ailanthus triphysa* reported individual tree heritability was higher in early period of growth and decreases at the age 3.6 year. Similar result also reported in other species *tecomella undulata* (Jindal *et al.*, 1992) sitka spruce (Samuel and Johnstone, 1979). High heritability need not always accompanied by greater genetic progress (Johnson *et al.*, 1955). From the above result it could be concluded that the height and collar diameter in *A. triphysa* are highly influenced by environmental factor rather than genetic factors.

5.7 CONCLUSION

The importance of screening and selection of superior genotypes of *Ailanthus triphysa* is reiterated by the increasing demand for match splints production in Kerala. The present study was intended to screen the superior genotypes from the population being raised based on twenty Candidate Plus Trees (CPTs), so as to provide a platform for further improvement programme. In the present study, the variation in morphometric parameters like height, collar diameter, volume, number of branches was found to be non-significant among the progenies. It was found that the progenies of FCV AT 11 and 20 CPTs performed among the best five progenies for height and collar diameter even though there was no significant difference. At this stage selection of superior genotypes is not possible based on height and collar diameter character but there may be significant difference at the age of rotation. The result obtained in present study would be helpful to establish a correlation with future result. Overall mode for number of branches was found to be zero, only one progeny (FCV AT 3) had single branching habit. Average survival percentage of the progenies were found to be 94.98 %, which ranged between 84.61 % to 100.00 %. Regarding bole straightness all the progenies scored 3 "almost straight with 1 or 2 small bends" except progeny of FCV AT 8 and 14 CPTs scored two "slightly crooked with 2 small bends or less than 2 serious bends". The progenies of FCV AT 7 and FCV AT 13 CPTs shown best performance in bole straightness. The result of stand quality assessments viz. number of branches, bole straightness, and survival percentage not only displayed the suitability of the progenies for match splints but also unveil the opportunity for future breeding programme. Study regarding wood physical properties of CPTs fulfil the general criteria kept of match splints making. All the anatomical properties showed significant variation among the CPTs except tissue proportion. The data obtained from wood anatomical studies would be helpful to correlate with the wood anatomical properties of progenies in future. *Bacillus thuringiensis* (Bt) was found to be potent against both the major insect pest (*E. narcissus* and *A. fabriciella*) associated with the species during the bioassay. However the concentration of Bt required to induce median lethal dose (LD_{50}) was higher for both the insect as compared to other studies. Which could be further studied by taking large number of samples with regards to the bioassay. Neem oil shown a clear antifeedant activity against *E. narcissus*, the feeding rate was reduced to 3.58 % in 2 % neem oil treated leaves as compared to 30.91 % in control. There is a need for more intensive research and development on neem oil with respect to *E. narcissus* and *A. fabriciella*, which could be an efficient way to control the economic loss of the species due to insect pests attack. The scoring of pest incidence was found to be non-significant among the progenies, all the progenies affected moderately against two major defoliators (*E. narcissus* and *A. fabriciella*). It was found that more than 50 % of the total Candidate Plus Trees (CPTs) included in the study had positive GCA value for both height and collar diameter. The CPTs with positive GCA could be mention as good combiners and could be potentially included in seed production and further breeding. Broad sense heritability (H^2) elucidate the height and collar diameter character highly influenced by environmental factors rather than genetic factors.

Summary

6. SUMMARY

The study was conducted in the department of Forest Product and Utilisation of College of Forestry, Kerala Agricultural University, Vellanikkara. The research trial was located at the Kerala Agricultural University (KAU) main campus near Aramkal, Thrissur district (N 10° 55' 10'' latitude E 76° 29' 63'' longitude and elevation 42 m above mean sea level) of central Kerala, India. For studying wood physical and anatomical properties, core and cube samples were collected form ten Candidate Plus Trees (CPTs) located in Madakkathara, Nadathara, Pananchery panchayaths of Thrissur district. Koppam and Pattambi panchayaths of Palakkad district respectively. The salient features of the investigation are given below.

- At 16 months after planting, the average height was found to be 2.79 m. The highest value was 3.14 m found in the progenies of FCV AT 6 CPTs and the lowest was 2.27 m found in the progenies of FCV AT 16 CPTs. Even though the results revealed there was no significant difference among progenies over time.
- At 22 months after planting the average collar girth was found to be 17.50 cm, progenies of FCV AT 20 CPTs exhibited the highest value of 19.34 cm and the progenies of FCV AT 12 CPTs exhibited lowest value of 15.08 cm. Collar girth did not show any significant difference among progenies.
- After 28 months of planting, the average collar diameter for all the progenies was found to be 69.11 mm, progenies of FCV AT 8 CPTs exhibited the highest value 74.69 mm, progenies of FCV AT 16 CPTs exhibited the lowest value 59.90 mm. The result however revealed there was no significant difference among the progenies over time.
- Results of variation in number of branches revealed that there was no significant difference among the progenies. The overall mode for number of branches was found to be 0. The results revealed the number

of branches was 0 for all seed sources, except the progenies of FCV AT CPTs which had a value of 1.

- Friedmen's test of bole straightness revealed that there was significant difference among the progenies of different CPTs. The overall mode score of bole straightness was found to be 3. For all the progenies the score was found to be 3 except the progenies of FCV AT 17 CPTs which had a value of 2.
- The average survival percentage observed was 94.93%, which ranged between 84.61% to 100.00%.
- The variation in stem volume among the progenies was found to be non-significant. The overall mean volume was found to be 0.004 m^3. Progenies of FCV AT 11 CPTs (0.006 m^3) had the highest mean volume whereas progenies of FCV AT 12 CPTs (0.002 m^3) had the lowest mean value.
- The average basic density for all the Candidate Plus Trees (CPTs) were found to be 0.37 gcm^{-3}, the highest value was 0.41 gcm^{-3} for FCV AT 15 CPTs and the lowest 0.35 gcm^{-3} was for FCV AT 3 CPTs respectively.
- Regarding wood colour using Munsell colour system 2.5 Y 8/4 (pale yellow) was predominant in all the Candidate Plus Trees (CPTs).
- Grain pattern was found to be straight for all the Candidate Plus Trees (CPTs).
- Fibre length ranged between 1076.48 μm to 1269.16 μm among the Candidate Plus Trees (CPTs). The average fibre length of the CPTs were found to be 1163.83 μm, the variations being significant among the CPTs.
- The average fibre width was 29.84 μm with the value ranged between 26.46 μm to 36.15 μm. Analysis of variance revealed significant difference in fibre width among the Candidate Plus Trees (CPTs).
- Fibre wall thickness varied considerably among the Candidate Plus Trees (CPTs). The average fibre wall thickness was found to be 4.25 μm. The

highest fibre wall thickness was 4.88 μm for FCV AT 1 CPTs and the lowest was 3.77 μm for FCV AT 3 CPTs respectively.

- The average vessel length was found to be 618.9 μm, the highest vessel length was 720.91 μm for FCV AT 17 CPTs and the lowest was 541.50 μm for FCV AT 03 CPTs respectively. The analysis of variance revealed that there was significant difference among the Candidate Plus Trees (CPTs).
- Average vessel area for all the Candidate Plus Trees (CPTs) was found to be 48351.41 μm^2, with the highest vessel area 62419.82 μm^2 shown by FCV AT 17 CPTs and the lowest 37496.02 μm^2 shown by FCV AT 08 CPTs. The variation was found to be significant among the CPTs.
- Vessel diameter ranged between 245.99 μm to 330.10 μm among the CPTs. The average vessel diameter of the CPTs were found to be 289.71 μm. Analysis of variance revealed significant difference in vessel diameter among different CPTs.
- The average vessel frequency was found to be 2 Vessel/mm^2. The highest vessel frequency was 3/mm^2 shown by FCV AT 02 CPTs and the lowest 1/mm^2 shown by FCV AT 18 CPTs. Significant difference found among the CPTs.
- The variation in tissue proportion revealed non-significant result among Candidate Plus Trees (CPTs). The average fibre proportion for all the CPTs were found to be 61.84 per cent, the highest fibre proportion was 67.65 per cent shown by FCV AT 1 CPTs and the lowest was 55.98 per cent shown by FCV AT 16 CPTs respectively.
- The result showed that there were no significant difference in parenchyma proportion among different CPTs. The average parenchyma proportion for all the CPTs were found to be 34.72 per cent, the highest value was 41.07 per cent shown by FCV AT 8 CPTs and the lowest was 28.11 per cent shown by FCV AT 2 CPTs.
- The vessel proportion among the CPTs were found to be non-significant. The average vessel proportion for all the CPTs was found to be 3.41 per

cent, the highest value was 4.76 per cent shown by FCV AT 2 CPTs and the lowest 2.41 per cent shown by FCV AT 8 CPTs.

- Height of multiseriated rays was ranged between 1022.81 µm to 1397.61 µm, the average ray height of CPTs was found to be 1262.89 µm. The variation among the CPTs was found to be significantly different.
- The average width of multiseriated ray for all the CPTs were found to be 112.42 µm, with the highest value 142.44 µm shown by FCV AT 8 CPTs and the lowest was 82.69 µm shown by FCV AT 17 CPTs respectively. The variation among the CPTs was found to be significant.
- Height of uniseriated ray ranged between 264.27 µm to 425.39 µm among the CPTs. The average ray height of the CPTs was found to be 346.60 µm. The variation among the CPTs was found to be significantly different.
- The average width uniseriated ray for all the CPTs were found to be 27.75 µm, with the highest value 33.79 µm shown by FCV AT 8 CPTs and the lowest was 20.65 µm shown by FCV AT 4 CPTs. The variation among the CPTs was found to be significantly different.
- The analysis revealed, the effect of different concentrations of (Bt) was found to be significantly different against *Eligma narcissus* Cramer. As the data obtained from bioassay did not follow normality, there was a need to transform the data in to arcsine value. The average mortality (%) after 72 hours was found to be 44.7 % (Arsin value= 0.36), the highest mortality (%) was 86.5% (Arsin value= 0.64) exhibited by 15% Bt concentration and the lowest mortality rate was 0% (Arsin value= 0.00) exhibited by control.
- The effect of different concentrations of (Bt) was found to be significantly different against *Atteva fabriciella* Swederus. The average mortality (%) after 72 hours was found to be 49.1 % (Arsin value= 0.34), the highest mortality (%) was 86.6% (Arsin value= 0.56) exhibited by 5% Bt concentration and lowest effect was 0% (Arsin value= 0.00) exhibited by control.

- A marked difference was found in the feeding rate of *Eligma narcissus,* when the leaf samples were treated with neem oil (Azadirachtine= 400-500 ppm). The feeding rate decreased with the increase in concentration of neem oil. The average leaf area consumed by larvae was reduced to 3.58 % in 2 % neem oil treated leaves as compared to 30.91 % in control. Moreover in 1 % of neem oil treatment the feeding rate was 5.42 %.
- The scoring of pest incidence was found to be non-significant for both of the insect-pest *E. narcissus* and *A. fabriciella* respectively. The mode score was found to be 5 for both the insects, which means all the progenies were moderately affected by both of the insect pests.
- Ten CPTs namely FCV AT 1, 2, 3, 5, 6, 8, 9, 11, 13, 20 were found to be good combiners for both height and collar diameter.
- Broad sense heritability (H^2) for height and collar girth were found to be 0.03 and 0.3 which was very low. It could therefore be stated that height and collar diameter were highly influenced by environmental factors rather than genetic factors.

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SCREENING OF SUPERIOR GENOTYPES OF *Ailanthus triphysa* (Dennst.) Alston. (MATTI) FOR MATCHWOOD QUALITY

By

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ABSTRACT OF THE THESIS

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8. ABSTRACT

A study entitled "Screening of superior genotypes of *Ailanthus triphysa* (Dennst.) Alston. (*Matti*) for matchwood quality" was conducted in the College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur during the period, 2016-2018. The objectives were to assess the variation in growth and wood traits of *Ailanthus triphysa* grown in the main campus of Kerala Agricultural University, Vellanikkara under a tree improvement trial. It was also aimed at selecting the superior genotype in this population through an assessment of the genetic worth of their parents. Among the five best performing progenies, FCV AT 11 and FCV AT 20 were found to perform well in terms of height and collar diameter. The progenies of FCV AT 11 also showed highest mean stem volume of 0.006 m^3. Overall mode for number of branches was found to be zero, only one progeny (FCV AT 3) had single branching habit. Regarding bole straightness all the progenies scored 3 "almost straight with 1 or 2 small bends" except progeny of FCV AT 8 and 14 CPTs scored two "slightly crooked with 2 small bends or less than 2 serious bends". At this stage of the trial, majority of the progenies had good branching habit and bole straightness. This aspect should be utilized in breeding programme so that it will be helpful to improve the tree form, which ultimately upgrade the quality and economic value of the timber. Average survival percentage of the progenies were found to be 94.98 %. The average basic density of CPTs was found to be 0.37 g cm^{-3}, which shows that the wood belongs to the light wood category. Wood colour and grain pattern studies revealed that, single colour (pale yellow) and straight grain pattern was found in all the CPTs respectively. Fibre morphology, vessel morphology, and ray morphology exhibited significant variation among the CPTs whereas, the variation in tissue proportion was found to be non-significant. Pest incidence was found to be one of the major hindrances to the growth of the species. Bioassay using *Bacillus thuringiensis* (Bt) was found to be effective against both the lepidopteran defoliators, *Eligma narcissus* (Cram.) and *Atteva fabriciella* Swederus. In case of *E. narcissus,* median lethal dose (LD_{50}) was achieved with 10 % concentration of

Bt whereas in *A. fabriciella*, 2.5% Bt concentration was found to be effective. Neem oil showed a clear antifeedant activity against *E. narcissus*, the feeding rate was reduced to 3.58 % in 2 % neem oil treated leaves as compared to 30.91 % in control. Scoring of pest incidence was found to be non-significant among the progenies, all the progenies affected moderately by both *E. narcissus* and *A. fabriciella*. Ten CPTs namely FCV AT 1, 2, 3, 5, 6, 8, 9, 11, 13, 20 were found to be good combiners for both height and collar diameter. The CPTs with positive GCA could be potentially included in a seed production programme and for further breeding. Broad sense heritability (H^2) for height was found to be 0.03 and for collar diameter, 0.1. It could therefore be concluded that height and collar diameter were highly influenced by environmental factors rather than genetic factors.

Appendices

APPENDICES

1. Analysis of variance of height (m) among the progenies of CPTs of *A. triphysa* after 16 months of planting

Source	df	Type III SS	MS	F- value	P- value
Corrected model	22	2.423	0.110	0.737	0.779
Intercept	1	225.04	225.04	1505.34	0.000
Treatment	19	2.270	0.119	0.799	0.696 ^{ns}
Replication	3	0.109	0.036	0.243	0.866
Error	57	6.877	0.149		
Total	80	239.46			
Corrected total	79	9.30			

ns= non-significant at 0.05 level

2. Analysis of variance of height (m) among the progenies of CPTs of *A. triphysa* after 18 months of planting

Source	df	Type III SS	MS	F- value	P- value
Corrected model	22	2.784	0.127	0.961	0.526
Intercept	1	244.4	244.4	1855.34	0.000
Treatment	19	2.690	0.142	1.075	0.405 ^{ns}
Replication	3	0.099	0.033	0.251	0.860
Error	57	6.060	0.132		
Total	80	258.42			
Corrected total	79	8.84			

ns= non-significant at 0.05 level

3. Analysis of variance of height (m) among the progenies of CPTs of *A. triphysa* after 20 months of planting

Source	df	Type III SS	MS	F- value	P- value
Corrected model	22	2.783	0.126	0.970	0.516
Intercept	1	263.9	263.9	2023.88	0.000
Treatment	19	2.605	0.137	1.051	0.428 ^{ns}
Replication	3	0.190	0.063	0.486	0.694
Error	57	5.999	0.130		
Total	80	279.05			
Corrected total	79	8.78			

ns= non-significant at 0.05 level

4. Analysis of variance of height (m) among the progenies of CPTs of *A. triphysa* after 22 months of planting

Source	df	Type III SS	MS	F- value	P- value
Corrected model	22	2.929	0.133	1.014	0.468
Intercept	1	299.85	299.85	2283.38	0.000
Treatment	19	2.799	0.147	1.122	0.362 ^{ns}
Replication	3	0.204	0.068	0.517	0.673
Error	57	6.04	0.131		
Total	80	317.3			
Corrected total	79	8.97			

ns= non-significant at 0.05 level

5. Analysis of variance of height (m) among the progenies of CPTs of *A. triphysa* after 24 months of planting

Source	df	Type III SS	MS	F- value	P- value
Corrected model	22	3.923	0.178	1.130	0.353
Intercept	1	389.84	389.81	2470.9	0.000
Treatment	19	3.639	0.192	1.214	0.288 ^{ns}
Replication	3	0.412	0.137	0.871	0.463
Error	57	7.25	0.158		
Total	80	411.21			
Corrected total	79	11.1			

ns= non-significant at 0.05 level

6. Analysis of variance of height (m) among the progenies of CPTs of *A. triphysa* after 26 months of planting

Source	df	Type III SS	MS	F- value	P- value
Corrected model	22	4.176	0.190	0.965	0.521
Intercept	1	461.02	461.02	2344.15	0.000
Treatment	19	3.744	0.197	1.002	0.477 ^{ns}
Replication	3	0.506	0.169	0.858	0.470
Error	57	9.04	0.197		
Total	80	487.39			
Corrected total	79	13.22			

ns= non-significant at 0.05 level

7. Analysis of variance of height (m) among the progenies of CPTs of *A. triphysa* after 28 months of planting

Source	df	Type III SS	MS	F- value	P- value
Corrected model	22	5.11	0.232	0.958	0.529
Intercept	1	525.1	525.1	2164.14	0.000
Treatment	19	4.245	0.223	0.921	0.563 ^{ns}
Replication	3	0.902	0.307	1.26	0.298
Error	57	11.16	0.243		
Total	80	557.06			
Corrected total	79	16.27			

ns= non-significant at 0.05 level

8. Analysis of variance of collar girth (cm) among the progenies of CPTs of *A. triphysa* after 16 months of planting

Source	df	Type III SS	MS	F- value	P- value
Corrected model	22	84.234	3.82	0.893	0.603
Intercept	1	13125.3	13125.3	3061.09	0.000
Treatment	19	72.03	3.791	0.884	0.603 ^{ns}
Replication	3	12.20	4.068	0.949	0.423
Error	57	244.4	4.288		
Total	80	13453.9			
Corrected total	79	328.6			

ns= non-significant at 0.05 level

9. Analysis of variance of collar girth (cm) among the progenies of CPTs of *A. triphysa* after 18 months of planting

Source	df	Type III SS	MS	F- value	P- value
Corrected model	22	134.68	6.12	1.236	0.256
Intercept	1	15429.4	15429.4	3115.6	0.000
Treatment	19	105.7	5.655	1.124	0.354 ^{ns}
Replication	3	28.9	9.647	1.948	0.132
Error	57	282.2	4.952		
Total	80	15846.3			
Corrected total	79	416.9			

ns= non-significant at 0.05 level

10. Analysis of variance of collar girth (cm) among the progenies of CPTs of *A. triphysa* after 20 months of planting

Source	df	Type III SS	MS	F- value	P- value
Corrected model	22	142.3	6.47	1.110	0.364
Intercept	1	19510.7	19510.7	3346.9	0.000
Treatment	19	120.2	6.328	1.085	0.389^{ns}
Replication	3	22.1	7.390	1.268	0.294
Error	57	332.2	5.829		
Total	80	19985.4			
Corrected total	79	474.6			

ns= non-significant at 0.05 level

11. Analysis of variance of collar girth (cm) among the progenies of CPTs of *A. triphysa* after 22 months of planting

Source	df	Type III SS	MS	F- value	P- value
Corrected model	22	144.6	6.57	0.960	0.524
Intercept	1	24509.7	24509.7	3346.9	0.000
Treatment	19	113.5	5.978	0.873	0.615^{ns}
Replication	3	31.1	10.37	1.515	0.221
Error	57	390.3	6.84		
Total	80	25044.7			
Corrected total	79	535.02			

ns= non-significant at 0.05 level

12. Analysis of variance of collar diameter (mm) among the progenies of CPTs of *A. triphysa* after 24 months of planting

Source	df	Type III SS	MS	F- value	P- value
Corrected model	22	1280.9	58.22	0.537	0.942
Intercept	1	226819.1	226819.1	2092.5	0.000
Treatment	19	1172.0	61.6	0.569	0.909^{ns}
Replication	3	148.7	49.5	0.457	0.719
Error	57	4986.1	108.3		
Total	80	240689.0			
Corrected total	79	6267.0			

ns= non-significant at 0.05 level

13. Analysis of variance of collar diameter (mm) among the progenies of CPTs of *A. triphysa* after 26 months of planting

Source	df	Type III SS	MS	F- value	P- value
Corrected model	22	1372.0	62.36	0.563	0.927
Intercept	1	285760.2	285760.2	2581.8	0.000
Treatment	19	1095.1	57.6	0.521	0.938 ^{ns}
Replication	3	366.5	122.1	1.104	0.357
Error	57	5091.3	110.68		
Total	80	302342.6			
Corrected total	79	6463.4			

ns= non-significant at 0.05 level

14. Analysis of variance of collar diameter (mm) among the progenies of CPTs of *A. triphysa* after 28 months of planting

Source	df	Type III SS	MS	F- value	P- value
Corrected model	22	1637.1	74.4	0.571	0.922
Intercept	1	317835.6	317835.6	2440.7	0.000
Treatment	19	1312.4	69.07	0.530	0.933 ^{ns}
Replication	3	427.2	142.4	1.094	0.361
Error	57	5990.2	130.2		
Total	80	337215.0			
Corrected total	79	7627.4			

ns= non-significant at 0.05 level

15. Analysis of variance of number of branches among the progenies of different CPTs of *Ailanthus triphysa*

N	4
Chi-Square	24.011
df	19
Asymp. Sig.	0.196 ^{ns}

ns= non-significant at 0.05 level

16. Analysis of variance of bole straightness among the progenies of different CPTs of *Ailanthus triphysa*

N	4
Chi-Square	30.341
df	19
Asymp. Sig.	0.048 *

**= significant at 0.05 level*

17. Analysis of variance of volume (m^3) among the progenies of different CPTs of *Ailanthus triphysa* after 28 months of planting

Source	df	Type III SS	MS	F- value	P- value
Corrected model	22	8.036E-005	3.653E-006	1.372	0.169
Intercept	1	0.001	0.001	550.1	0.000
Treatment	19	6.039E-005	3.178E-006	1.194	0.295 ^{ns}
Replication	3	1.997E-005	6.656E-006	2.500	0.069
Error	57	0.000	2.662E-006		
Total	80	0.002			
Corrected total	79	0.000			

ns= non-significant at 0.05 level

18. Analysis of variance of density (g cm^{-3}) of the different CPTs of *Ailanthus triphysa*

Source	df	Type III SS	MS	F- value	P- value
Corrected model	11	0.11	0.001	5.209	0.001
Intercept	1	2.249	4.249	21768.06	0.000
Treatment	9	0.011	0.001	6.203	0.001 *
Replication	2	0.000	0.000	0.734	0.494
Error	18	0.004	0.000		
Total	30	4.264			
Corrected total	29	0.015			

**Significant at 5 per cent level*

19. Analysis of variance of fibre length (μm) of the different CPTs of *Ailanthus triphysa*

Source	df	Type III SS	MS	F- value	P- value
Corrected model	18	535926.9	29773.7	1.339	0.187
Intercept	1	135450026.9	135450026.9	6089.6	0.000
Treatment	9	417375.3	46375.0	2.085	0.040*
Replication	9	118551.5	13172.3	0.592	0.800
Error	81	1801669.4	22242.8		
Total	100	137787623.3			
Corrected total	99	2337596.4			

**Significant at 5 per cent level*

20. Analysis of variance of fibre width (μm) among the different CPTs of *Ailanthus triphysa*

Source	df	Type III SS	MS	F- value	P- value
Corrected model	18	1168.2	64.90	3.178	0.187
Intercept	1	89030.6	89030.6	4359.4	0.000
Treatment	9	992.08	110.23	5.398	0.000 **
Replication	9	176.20	19.57	0.959	0.480
Error	81	1654.2	20.42		
Total	100	91853.1			
Corrected total	99	2822.5			

***Significant at 1 per cent level*

21. Analysis of variance of fibre wall thickness (μm) among the different CPTs of *Ailanthus triphysa*

Source	df	Type III SS	MS	F- value	P- value
Corrected model	13	13.53	0.752	1.971	0.021
Intercept	1	1802.42	1802.42	4726.3	0.000
Treatment	9	9.569	1.063	2.788	0.007 *
Replication	4	3.961	0.440	1.154	0.336
Error	36	30.89	0.381		
Total	50	1846.8			
Corrected total	49	44.4			

**Significant at 5 per cent level*

22. Analysis of variance of vessel length (μm) among the different CPTs of *Ailanthus triphysa*

Source	df	Type III SS	MS	F- value	P- value
Corrected model	13	123147.4	9472.8	2.068	0.043
Intercept	1	19151414.8	19151414.8	4181.4	0.000
Treatment	9	116888.0	12987.5	2.838	0.012 *
Replication	4	6259.46	1564.8	0.342	0.848
Error	36	164884.8	4580.1		
Total	50	19439447.2			
Corrected total	49	288032.3			

**Significant at 5 per cent level*

24. Analysis of variance of vessel area (µm) among the different CPTs of *Ailanthus triphysa*

Source	df	Type III SS	MS	F- value	P- value
Corrected model	18	7294653908	405258550.5	2.738	0.001
Intercept	1	2.134E+11	2.134E+11	1442.1	0.000
Treatment	9	6254976560	694997395.5	4.698	0.000
Replication	9	1134310925	126034547.3	0.852	0.572
Error	81	11099912607	147998834.8		
Total	100	2.132E+11			
Corrected total	99	18394566515			

****Significant at 1 per cent level*

25. Analysis of variance of vessel diameter (µm) among the different CPTs of *Ailanthus triphysa*

Source	df	Type III SS	MS	F- value	P- value
Corrected model	18	69717.9	3873.2	6.46	0.000
Intercept	1	8393379.6	8393379.6	14012.29	0.000
Treatment	9	62617.9	6957.5	11.61	0.000**
Replication	9	7100.0	788.8	1.317	0.241
Error	81	48519.1	599.0		
Total	100	8511616.7			
Corrected total	99	118237.1			

****Significant at 1 per cent level*

26. Analysis of variance of vessel freequency (no./mm^2) among the different CPTs of *Ailanthus triphysa*

Source	df	Type III SS	MS	F- value	P- value
Corrected model	18	17.6	1.357	6.531	0.000
Intercept	1	154.8	154.8	745.4	0.000
Treatment	9	17.12	1.902	9.15	0.000**
Replication	9	0.520	0.130	0.626	0.647
Error	81	7.48	0.208		
Total	100	180.0			
Corrected total	99	25.12			

****Significant at 1 per cent level*

27. Analysis of variance of tissue proportion (Fibre %) among the different CPTs of *Ailanthus triphysa*

Source	df	Type III SS	MS	F- value	P- value
Corrected model	13	1230.7	94.6	1.229	0.300
Intercept	1	191224.1	191224.1	2483.4	0.000
Treatment	9	912.13	101.3	1.316	0.263^{ns}
Replication	4	318.58	79.64	1.034	0.403
Error	36	2772.02	77.00		
Total	50	195226.8			
Corrected total	49	4002.7			

Superscript "ns" indicate not significant

28. Analysis of variance of tissue proportion (Parenchyma %) among the different CPTs of *Ailanthus triphysa*

Source	df	Type III SS	MS	F- value	P- value
Corrected model	13	1218.4	93.72	1.345	0.234
Intercept	1	60303.7	60303.78	865.12	0.000
Treatment	9	1044.6	116.07	1.665	0.134^{ns}
Replication	4	173.8	43.45	0.623	0.649
Error	36	2509.3	69.70		
Total	50	64031.6			
Corrected total	49	3727.8			

Superscript "ns" indicate not significant

29. Analysis of variance of tissue proportion (Vessel %) among the different CPTs of *Ailanthus triphysa*

Source	df	Type III SS	MS	F- value	P- value
Corrected model	13	51.5	3.96	0.959	0.508
Intercept	1	581.7	581.7	140.5	0.000
Treatment	9	19.11	2.124	0.513	0.855^{ns}
Replication	4	32.4	8.111	1.960	0.122
Error	36	148.9	4.138		
Total	50	782.2			
Corrected total	49	200.5			

Superscript "ns" indicate not significant

30. Analysis of variance of multiseriate ray height (μm) among the different CPTs of *Ailanthus triphysa*

Source	df	Type III SS	MS	F- value	P- value
Corrected model	18	2212502.2	122916.7	3.848	0.00
Intercept	1	159489292	159489292	4992.8	0.000
Treatment	9	1816451.27	201827.9	6.318	0.000**
Replication	9	396051.0	44005.6	1.378	0.212
Error	81	2587448.4	31943.8		
Total	100	164289242.7			
Corrected total	99	4799950.7			

***Significant at 1 per cent level*

31. Analysis of variance of multiseriate ray width (μm) among the different CPTs of *Ailanthus triphysa*

Source	df	Type III SS	MS	F- value	P- value
Corrected model	18	45468.7	2526.0	8.120	0.000
Intercept	1	1263879.6	1263879.6	4062.5	0.000
Treatment	9	40882.7	4542.5	14.6	0.000**
Replication	9	4585.9	509.5	1.638	0.118
Error	81	25199.3	311.1		
Total	100	1334547.6			
Corrected total	99	70668.0			

***Significant at 1 per cent level*

32. Analysis of variance of uniseriate ray height (μm) among the different CPTs of *Ailanthus triphysa*

Source	df	Type III SS	MS	F- value	P- value
Corrected model	18	324171.6	18009.5	4.872	0.000
Intercept	1	12013218.3	12013218.3	3249.7	0.000
Treatment	9	270655.5	30072.8	8.135	0.000**
Replication	9	53516.0	5946.2	1.609	0.127
Error	81	299427.3	3696.6		
Total	100	12636817.4			
Corrected total	99	623599.0			

***Significant at 1 per cent level*

33. Analysis of variance of uniseriate ray width (μm) among the different CPTs of *Ailanthus triphysa*

Source	df	Type III SS	MS	F- value	P- value
Corrected model	18	1332.86	74.04	2.49	0.003
Intercept	1	77071.19	77071.19	2598.44	0.000
Treatment	9	1221.04	135.67	4.57	0.000**
Replication	9	111.81	12.42	0.419	0.922
Error	81	2402.50	29.66		
Total	100	80806.56			
Corrected total	99	3735.36			

**Significant at 1 per cent level

34. Analysis of variance of mortality rate of *E. narcissus* under different concentrations of *Bacillus thuringiensis* (Bt).

Source	df	Type III SS	MS	F- value	P- value
Corrected model	14	4.727	0.338	8.529	0.000
Intercept	1	6.047	6.047	152.7	0.000
Treatment	4	2.690	0.672	16.98	0.000**
Time	2	0.768	0.384	9.704	0.001
Treatment × Time	8	1.269	0.159	4.007	0.002
Error	30	1.188	0.040		
Total	45	11.962			
Corrected Total	44	5.915			

**Significant at 1 per cent level

35. Analysis of variance of mortality rate of *A. fabriciella* under different concentrations of *Bacillus thuringiensis* (Bt).

Source	df	Type III SS	MS	F- value	P- value
Corrected model	11	3.455	0.314	3.217	0.008
Intercept	1	4.441	4.441	45.487	0.000
Treatment	3	1.999	0.666	6.826	0.002*
Time	2	0.903	0.452	4.626	0.020
Treatment × Time	6	0.553	0.092	0.944	0.483
Error	24	2.343	0.098		
Total	36	10.238			
Corrected Total	35	5.798			

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

37. Analysis of variance of score among the progenies of different CPTs against the attack of *E. narcissus*

N	4
Chi-Square	18.924
df	19
Asymp. Sig.	0.462^{ns}

ns= non-significant at 0.05 level

38. Analysis of variance of score among the progenies of different CPTs against the attack of *A. fabriciella.*

N	4
Chi-Square	22.054
df	19
Asymp. Sig.	0.282^{ns}

ns= non-significant at 0.05 level