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Final report

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1 Acknowledgments

The greatest acknowledgement goes to the farmers and rural communities who reached out to colleagues in Ethiopia to ask for help, assistance, and support in managing the threats from pests and diseases in their *Acacia* plantings. We hope this research is the first step toward protecting and sustaining *Acacia* production as a key component of smallholder livelihoods in rural Ethiopia.

Thank you to ACIAR for understanding the serious challenge Ethiopian wattle farmers are facing and funding this research. An especially huge thank you to Nora Devoe whom has been pivotal in championing, supporting and guiding this work. A big thank you to Bridgette Gusner for managing the finer details of the project and answering our countless questions.

Many thanks go to the team at EEFRI for building the bones of this research, there would be no project without you. A special thanks to the team at FABI and ICFR for supporting the on-ground teamwork. And to USC, thank you for making this project happen. Together we all make a fantastic team.

2 Executive summary

Wattle is widely planted in Awi Zone, Ethiopia, for soil reclamation and improvement, land rehabilitation, afforestation, reforestation, construction, charcoal, firewood, and animal fodder. Recently, several insect pests and diseases were reported threatening wattle production in the nursery and the field. To address these threats, surveys of *Acacia* plantations were conducted in four districts of the Awi Zone to determine the key pests, their distribution, and to quantify their prevalence and severity.

The results indicated that the main disease was the wattle rust pathogen, *Uromycladium acaciae* (Pucciniales: Pileolariaceae), with severe epidemics present at all surveyed plantations. In addition, three insect pests were identified at low levels of infestation and severity, including cottony cushion scale, *Icerya purchasi* (Hemiptera: Monophlebidae), a treehopper (Hemiptera: Membracidae), and a bagworm (Lepidoptera: Psychidae). The soil-borne pathogens *Phytophthora* spp. and *Calonectria pauciramosa* and the stem canker pathogen *Diaporthe australafricana* were also detected.

In Ethiopia, wattle production sustains many jobs in rural communities such as nursery production, silvicultural activities in plantations, charcoaling, and the associated roles of transportation, handling, wholesaling, and retail selling. However, the production of seedlings and cultivation of year-one and year-two seedlings has become almost impossible due to the rust pathogen. Production in the Awi Zone is, therefore, threatened and causing concern among growers, foresters, developmental agents, rural communities, and all actors along the value chain. Considering the current threat, the socioeconomic impact in the coming years is likely to increase. Therefore, we suggest the following approaches as a step toward sustainable management of wattle pests and diseases in Ethiopia:

- establishing trials of different provenances of *A. decurrens* and *A. mearnsii* to assess susceptibility to pests and diseases
- refining identification and assessing the diversity, prevalence, severity, and distribution of pests and diseases in different seasons in the Awi Zone
- expanding the survey to other wattle-growing regions to gain a comprehensive overview of pests across the country
- working towards Integrated Pest Management (IPM) strategies
- developing a forestry site classification to inform site forestry potential, site species matching, and biotic and abiotic risks
- building local capacity in forest health, including training on digital curation of pest occurrence data
- creating awareness about pests among the farming community

It must be noted that the wattle species in Ethiopia was previously thought to be green wattle, *A. decurrens,* but field observation of the planted wattle leaf morphology is consistent with *A. mearnsii.* Phylogenetic analysis did not, however, provide a clear resolution of the wattle species identity as the commonly used DNA markers seem to be conserved in *Acacia* spp. and are unable to differentiate between the two species. However, based on leaf morphology and the presence of *U. acacia,* (*A. decurrens* is less susceptible to *U. acacia*), the wattle species planted in Ethiopia is highly likely to be *A. mearnsii*. Therefore, establishment of trials to assess the best species/provenance to grow across a variety of sites is the highest priority for future research.

3 Background

Acacia was introduced to the highlands of central and northwest Ethiopia in the early 1990s to mitigate firewood shortages exacerbated by deforestation (Kassie, 2015; Chanie and Abewa, 2021). Since then, wattle has been adopted as a multipurpose species with significant ecological and economic benefits and is widely planted in four-to-five-year rotations with other crops (e.g., teff and various vegetables). Its uses include afforestation and reforestation, soil improvement and conservation through reclamation of acidified soils, and rehabilitation of degraded land (Chanie and Abewa, 2021). Wattle also offers opportunities for supplementary income through the sale of wood for construction, firewood, and charcoal, with foliage used as animal fodder (Chanie and Abewa, 2021). *Acacia* contributes significantly to food security and the livelihoods of local communities in Ethiopia (Nigussie et al. 2021)[1].

In Sub-Saharan Africa, more than 70% of the population depends upon forests for their livelihoods (World Bank Africa Region 2017). One-fifth of rural families' daily needs are sourced from forests, with forest-related activities accounting for a large part of the GDP of most of the continent's countries (World Bank Africa Region, 2017). In Ethiopia, agriculture is the cornerstone of the economy contributing approximately 53% of GDP and accounting for more than 90% of exports (FAO, 2001). Forestry GDP as a proportion of the whole economy is low; however, forestry can play a significant role in Ethiopia's economic and social development. For instance, most forestry operations occur in rural areas, where more than 90% of Ethiopia's population lives, and high numbers of labourers are required for nursery operations, afforestation, and the construction and maintenance of roads (FAO 2001). Fuelwood production alone accounts for nearly 50% of the total forestry employment in Ethiopia, to which a sustainable *Acacia* industry can continue to contribute to.

Traditionally, farmers practiced grain crop production in high rainfall areas. Due to declining soil fertility and acidification, production became unviable, and farmers began practicing sequential agroforestry, planting *Acacia* and harvesting the woody biomass for charcoaling. Once prepared, the charcoal is transported to the central market in Addis Ababa. Charcoal is the major fuel type used for cooking in the country, especially in urban settlements. After charcoaling, farmers cultivate high-yielding crops of teff or wheat in a sequential agroforestry model with *Acacia* the preferred species for ameliorating acid soils. Wattle production has now expanded outside charcoal to include wood production for firewood, construction and on farm fodder. As a result, the livelihoods and production systems of farming families are now diversified, food security increased, and many have become commercial charcoal producers and legally organized traders (Gossa June 2022). *Acacia* production has expanded to neighboring districts and 80-85% of land use has changed from grain farming to the practice of sequential agroforestry in the Awi Zone, Amhara Region.

Until recently, there had been no reports of significant pest damage to *Acacia* plantations in Ethiopia. However, reports increased in late 2021, as described by the Ethiopia Environment and Forest Commission (formerly EEFRI), Amhara Regional Government, growers, and researchers working in the area. Before this SRA commenced, there was no identification of the damaging agents, and no control options available, so *Acacia* production remains under threat and the socioeconomic impacts along the value chain will continue to be significant.

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[1] The species introduced into Ethiopia has been reported as *A. decurrens* (green wattle). However, observations at the onset of this project questioned the accuracy of the tree species identification, which is more likely *A. mearnsii*. Therefore, herein, we refer to the species in Ethiopia as *Acacia* or wattle.

4 Objectives

The goal of this SRA was to protect the remaining *Acacia* resource in Ethiopia and conserve the capacity to grow *Acacia* by identifying the significant pests and diseases to develop management responses for the future.

The objectives, therefore, were (1) to determine the key insect pests and pathogens through plantation and nursery surveys, and identify, and monitor pest distribution, and impact; and (2) to assess and test (where possible) the efficacy of IPM options including genetic (improving tolerance/resistance to *U. acacia*), cultural (silviculture), biological (biocontrol agents), and chemical solutions (pesticides and soft options such as white oil) in small-scale nursery trials. To do so, these activities were undertaken:

- Surveys to identify pest and disease distribution across the Fagita Lekoma, Banja, and Ankasha Gagusa Districts (Awi Zone, Amhara Region)
- Assessment of pest and disease severity and damage
- Development of nursery-based experiments (and planning the implementation of future field trials) to assess a range of control options against priority pests and diseases in plantations and the nursery
- Delivery of a training workshop on morphological and molecular diagnostics, breeding programmes, and some basic IPM
- Support of the curation of a digital forest insect pest and disease collection.

5 Methodology

5.1 Surveys

5.1.1 Site information

Survey one was conducted at 17 sites across four districts of the Awi Zone (Table 1; Fig. 1) from March 6 -27, 2022. Sites were selected to represent the major wattle-growing districts of Awi Zone, covering the various elevation ranges. The location name, GPS coordinates, elevation, and tree age were recorded for each site (Table 1).

Table 1: Site information for pest and disease survey conducted in wattle plantations in Awi Zone, Ethiopia.

Site No.	District	Location	Tree age (yr)	Geographic coordinates		Elevation (m.a.s.l.)
				Latitude (N)	Longitude (E)	
1	Dangila	Kuandisha	3	11.2038	36.8575	2186
2	Fageta Lekoma	Ashewa Tsebel 1	3	11.1513	36.8652	2353
3	Fageta Lekoma	Gafera	3	11.0663	36.8935	2538
4	Fageta Lekoma	Adilta	3	11.0473	36.9021	2378
5	Fageta Lekoma	Ashewa Tsebel 2	3	11.1192	36.8741	2364
6	Fageta Lekoma	Zimbayita	3	11.1092	36.9014	2416
7	Fageta Lekoma	Furi	3	11.1010	36.9448	2364
8	Banja	Zik and Gomerta 1	3	10.9589	36.8165	2506
9	Banja	Gashena Akayita	3	10.9689	36.9510	2617
10	Banja	Kesachewsa	3	10.9234	36.9554	2543
11	Banja	Zik and Gomerta 2	3	10.8841	36.9539	2502
12	Ankesha Gagusa	Bekefta	3	10.8700	36.8779	2323
13	Ankesha Gagusa	Dangula	3	10.8693	36.9341	2435
14	Ankesha Gagusa	Habiti	3	10.8647	36.8954	2366
15	Ankesha Gagusa	Amara Mender	4	10.9138	36.8297	2402
16	Ankesha Gagusa	Aneba	3	10.8799	36.8776	2337
17	Ankesha Gagusa	Mungula	3	10.8606	36.9220	2385

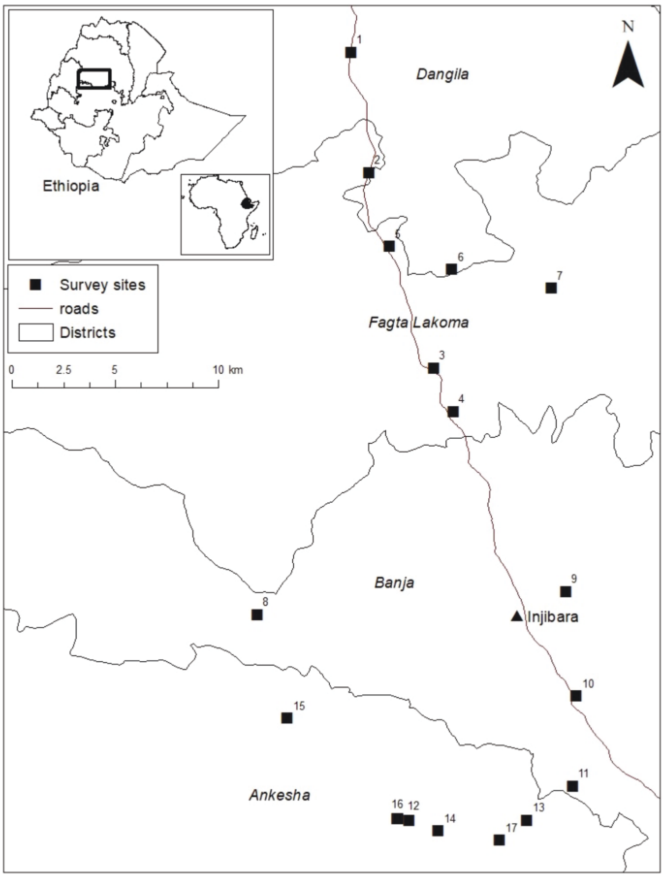

Figure 1: Map showing the distribution of survey sites in the Awi Zone. Numbers on the map correspond to the 'Sites' in Table 1.

A second survey was conducted from July 12 – 22, 2022 to compare the incidence and severity of the pathogen and insect pests. In addition, wattle growing highlands in southern Ethiopia were also surveyed, covering Gurage zone - Cheha, Gumer and Eja districts, and Gamo Zone - Qogota district of Gamo Zone.

Data for surveys were collected using a Fulcrum field App developed for the project.

5.1.2 Sampling and data collection

Thirty trees per site were assessed in a transect to determine the presence, prevalence, and severity of pests and diseases. Trees were consecutively assessed and the direction of the transect line was changed at every fifth tree in a 'zig-zag' fashion. Each tree was assessed for disease symptoms (powdery telial mass, canker, lesions, leaf spots, necrosis, wilting, malformation etc.) and different developmental stages and damage symptoms of insects.

Pest and disease prevalence and distribution were determined by presence/absence data. Disease severity was scored for each tree following a 0 to 3 infection rating scale - 0 = no infection; 1 = 1-25%; 2 = 26-50%; 3 = >50 infection. This was followed by an estimation of the actual percentage of infection within a given range.

Samples of insects, rust spores, infected leaves and wood tissue, and soil were collected from each site. For the rust disease, infected leaf and spore samples were collected in RNA later and silica gel from twenty-eight trees across ten sites (three trees each at nine sites and one tree at another site). Depending upon availability, insect samples were collected and preserved, individually, in ethanol. Scale insects and bagworms were collected from ten sites whereas treehoppers were collected from five sites. Thirty-one soil samples were collected from the rhizosphere of trees showing gummosis and canker symptoms. Where there was evidence of vascular stain, wood tissue samples were collected.

Leaf samples were also collected from four trees across two sites to determine the species identity of the wattle tree planted in Awi Zone.

Export and import permits were obtained for all samples [soil samples: permit issued on 25/3/2022, Ref. No.: NSTC027/00225; other samples: permit issued on 16/07/2014 Ethiopian Calendar, Reference No: 21/132/47). Samples were transported to the Forestry and Agricultural Biotechnology Institute (FABI) at the University of Pretoria, South Africa following standard phytosanitary procedures. The samples were then used to confirm the identity of the pests, pathogens, and the wattle tree.

5.2 Diagnostics

Initial sample identification was based upon morphology and/or observed symptoms and confirmed using DNA sequence data. Identification of the wattle species was based on a combination of leaf morphology and DNA sequence data. For the rust, spore masses were collected from infected plant material and DNA was extracted with the Prepman® Ultra Sample Preparation Reagent (Thermo Fisher Scientific, Waltham, MA, USA). The LSU region of rDNA was amplified and sequenced following the PCR protocols recommended by Pham et al. (2019) and McTaggart et al. (2015). For the insects, DNA was extracted from tissue using prepGEMTM Insect DNA extraction kit (ZyGEM). The barcoding region of COI gene was amplified and sequenced using universal insect primers.

The soil samples were split into three equal amounts to isolate soil-borne pathogens. One-third to isolate *Calonectria* spp., one-third to isolate *Phytophthora* spp., and the remaining third was cold stored for future use. For *Calonectria*, soil samples were baited with germinating alfalfa (*Medicago sativa*) seeds following the method recommended by Crous (2002). Isolations were made from infected alfalfa seedlings using 2% (w/v) malt extract agar. DNA was extracted from 7-day-old isolates grown on 2% MEA using Prepman® Ultra Sample Preparation Reagent and the Translation Elongation Factor 1 (TEF1) gene region was amplified and sequenced. For *Phytophthora*, samples were baited with leaves and isolations made from the infected leaves. Direct tissue isolations and carrot bait were made for the wood tissue samples showing signs of canker and vascular stains. DNA was extracted from the isolates and the Internal Transcribed Spacer (ITS) region was amplified and sequenced.

The *Acacia* leaf samples collected from Ethiopia and a known *A. mearnsii* sample from South Africa and sent to Inqaba Biotechnology Industries for sequencing. Three chloroplast DNA markers, namely matK, rbcL, and trnH-psbA intergenic spacer were amplified and sequenced. Previous studies (Newmaster et al., 2006; Newmaster and Ragupathy, 2009; Magona et al., 2018; Ismail et al. 2020) recommended these markers for DNA-based identification of plant species, including *Acacia* spp.

5.3 Chemical trials of fungicides against *Acacia* Rust

5.3.1 Chemical trials design and data collection methodology

The nursery chemical trial started with site acquisition at five sites for raising healthy nursery stock. Pot filling was carried out using standard nursery substrate (forest soil, compost and sand) in a ratio 3:2:1. Seeds from healthy trees were collected and seeded in nursery pots with the healthy seedlings that emerged used in the trial.

The trial design consisted of five treatments (two fungicides at different rates and one control), three replications, in a completely randomized design. Each plot consisted of 1 m x 1.5m area with 400 healthy seedlings. Spacing between the blocks/rows was 1 m and between adjacent plots was 0.5 m. This design was employed at all five sites, Endwuha, Furta, Derbezeit, Bakafta and Newata (Fig. 2).

Figure 2: Locations of nursery trials

5.3.2 Chemical Sprays

The treatments consisted of two fungicides: Amistra Top® - Azoxystrobinstrobilurin (200gl^{-1} + Difenoconazole (triazole) (125gl^{-1}) and Amestra Xtra® Azoxystrobin (strobilurin (200gl^{-1} + cyproconazole (triazole) (80gl^{-1}) applied at two rates (the recommended rate and half the recommended rate). Using a knapsack sprayer, the treatments were applied to the foliage. During application the adjacent plots were covered with plastic sheet to reduce fungicide drift. The fungicide treatments were applied twice in the nursery period. The first spray at initial appearance of the rust symptoms and the second spray 30 days after. The control treatment were unsprayed plots.

5.3.3 Disease assessment and data collected

The effect of the fungicide treatments on disease development was assessed on a 0 – 3 damage scale (Table 2) and severity quantified through visual estimation using a combination of uredosori masses on leaves, deformed pinnules, stem and branches lesions. Incidence and disease severity on nursery seedlings was observed from sample plots at four points in the nursery bed and calculated over the total number of seedlings affected for all treatment (plots). Site characteristics, including altitude, longitude, monthly temperature and precipitation trend, were also recorded.

Table0 2: Disease incidence and severity rating scale

Scale	Percentage area affected infected	
0	0% (no sign of uredosori)	**Nil**
1	Uredosori present on leaf pinnae and leaf petioles; branches and stems with lesions (covering 1-25% sample seedlings)	**Low**
2	Uredosori present on leaf and leaf petiole; deformed pinnae; branches and stems have lesions (covering 26-50% of sample seedlings)	**Medium**
3	Uredosori present on leaf and leaf petiole; deformed pinnae; branches and stems with severe lesions (covering >50% of sample seedlings)	**Severe**

Disease occurrence data (incidence and severity) were recorded at first spray, second spray (30 days) and one month after the second spray, including measuring plant height and root collar diameter (cm). Data on nursery experiment is still underway and will be completed in September 2022, with the results write up to follow.

6 Achievements against activities and outputs/milestones

Objective 1: Determine the key pests and pathogens of Acacia through plantation and nursery surveys and identify and monitor pest distribution

no.	activity	outputs/ milestones	completion date	comments
1.1	Field surveys in Ethiopia	Assessment and surveillance protocols available for use by field staff	March 2022	The first surveys took place in March 2022 with visits from FABI. Follow up surveys will occur after project completion to build an understanding of seasonal variation.
1.2		Assessment and surveillance training delivered	March 2022	Completed during field surveys and the EEFRI visit to FABI, South Africa.
1.3		Report on field surveys	June 2022	Reports by EEFRI and FABI attached as appendix 1 and 2
	Pest and pathogen diagnostics	Diagnostics performed – morphological and molecular	May 2022	Completed by FABI, South Africa
		Report on diagnostics undertaken	June 2022	Reports by EEFRI and FABI attached as appendix 1 and 2
	Quantify pest distribution	Database of pest and pathogen distribution compiled. Report on pest and pathogen distribution and abundance.	May 2022	Reports by EEFRI and FABI attached as appendix 1 and 2. Database compiled and ongoing.
		Remote sensing – Landsat imagery, coupled with ground truthing for *Acacia* rust		
	Impact assessments	Report detailing the damage impact of key pests identified in activity 1.1.	June 2022	Reports by EEFRI and FABI attached as appendix 1 and 2
	Digital forest collection	Online digital database compiled from specimens collected during the field surveys (activity 1.1 and 1.2)	June 2022	Reports by EEFRI and FABI attached as appendix 1 and 2. Database compiled and ongoing.
	First reports	First reports of pest and pathogens published	June 2022	Manuscripts in preparation

Objective 2: To assess and test the efficacy of integrated pest management (IPM) options including genetic (tolerance/resistance) cultural (silvicultural), biological (biocontrol agents), and chemical solutions (biopesticides and soft options such as white oil) in small-scale nursery and plantation trials.

no.	activity	outputs/ milestones	completion date	comments
2.1	Review literature on existing control options for key pests as identified in Activity 1.2	Best IPM strategies identified	March 2022	Completed and options identified for nursery trial development.
2.2	Nursery trials	Sites identified	January 2022	Completed and setup (Feb 2022)
2.3		Nursery trials established to evaluate preliminary impacts control options Report detailing trial results and recommending ongoing activities beyond the life of the project	February 2022	Trials established and almost complete Ongoing, final data still being collected.

PC = partner country, A = Australia

Objective 3: To support capacity building in diagnostics, field trials and surveys

no.	activity	outputs/ milestones	completion date	comments
3.1	Mentoring and technical assistance	Ongoing across the life of the project	June 2022	Ongoing
3.2	Training visit to South Africa including training workshop	Deliver a training workshop on morphological and molecular diagnostics	May 2022	See appendix 1 and 2
3.3	Remote training in surveillance, data management and analysis.	Ongoing across the life of the project		Ongoing
3.4	Community engagement	Education materials and community consultations with grower groups and smallholders	June 2022	Ongoing

7 Key results and discussion

A total of 370 wattle trees were assessed across the Awi Zone. Most (70.2%) were in Fageta Lekoma and Ankesha Gagusa districts, where 12 of the 17 sites were assessed, whereas the remaining 29.8 % of the trees were in Banja and Dangila district (Fig. 3).

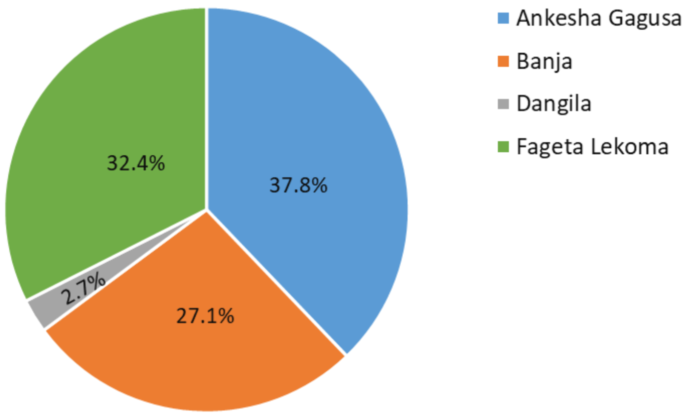

Figure 3. The proportion of trees assessed across the different districts of the Awi Zone.

7.1 Diagnostics

Pathogens

The results show that *U. acaciae* is the wattle rust causing tree mortality in the Awi Zone. All trees surveyed were infected with high damage scores of 2 and 3 (Fig. 4). Multiple symptoms, including masses of powdery telia on the leaves, petiole, and stem; matted leaves, gummosis on stems and branches, scars on the stems and trunks, dieback, seedling mortality and stunting of infected trees were observed (Fig. 5). These symptoms are the same caused by *U. acaciae* on *A. mearnsii* in South Africa. *U. acaciae* is of Australian origin and was first reported in Africa in 2013 and this is the first report of *U. acaciae* in Ethiopia.

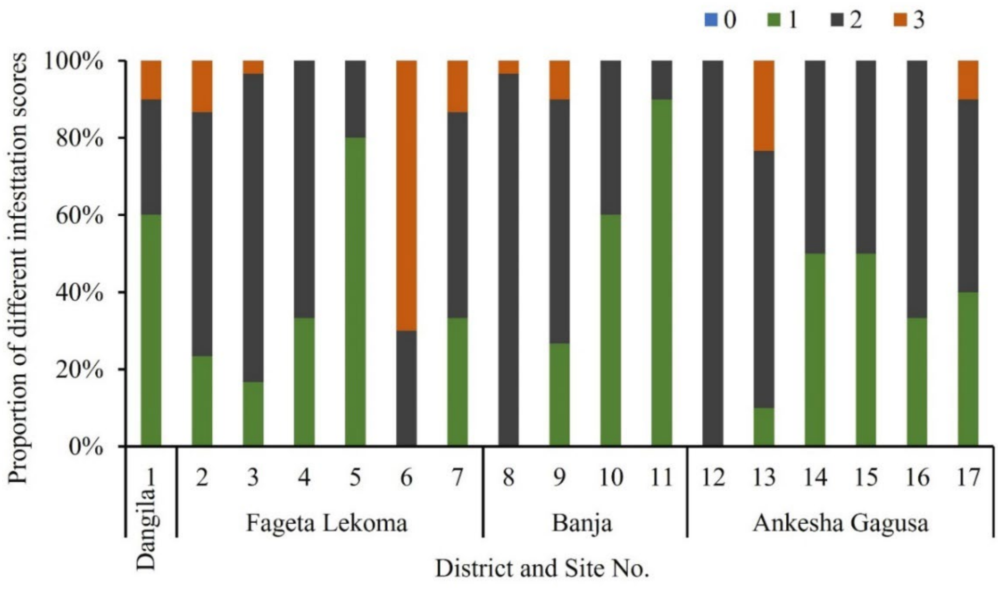

Figure 4. Proportion of different infection scores for *Uromycladium acaciae* across sites, where 0 = no infection; 1 = 1-25%, 2 = 26-50%; 3 = >50%.

Calonectria pauciramosa, a well-known plant pathogen and five putative *Phytophthora* spp. were also identified as established populations across the surveyed sites. Studies are in progress to determine the species identities of the *Phytophthora* spp. and pathogenicity of *C. pauciramosa*. *Diaporthe austrolafricana*, a causal agent of stem canker, was also identified from wood samples from a tree with canker symptoms.

Figure 5. Major signs and symptoms of the rust epidemics. **A.** brown powdery mass of telia on the stem, petiole, and leaflets; **B.** matted leaves; **C.** stunted growth; **D.** dieback of saplings; and **E.** gummosis.

Insect pests

Three insect species were identified as cottony cushion scale, *Icerya purchasi* (Hemiptera: Monophlebidae); an unknown species of bagworm (Lepidoptera: Psychidae) and a treehopper (Hemiptera: Membracidae) (Fig. 6 and 7). The bagworm was found in all the four surveyed districts, whereas the scale insect, *I. purchasi* and the treehopper were found in only three of the districts (Fig. 8). Infestations varied across sites but were generally low. Percentage infested trees ranged from 0% to 50% for bagworms, 0% to 60% for *I. purchasi* and 0% to 90% for the treehopper. It is likely these insects are moving in as secondary pests as a result of the stress caused by the wattle rust.

Figure 6. Key pests identified **B.** adults of the cuttony cushion scale, *I. purchasi*, **C.** adults and nymphs of unknown treehopper species, and **D.** unknown bagworm species.

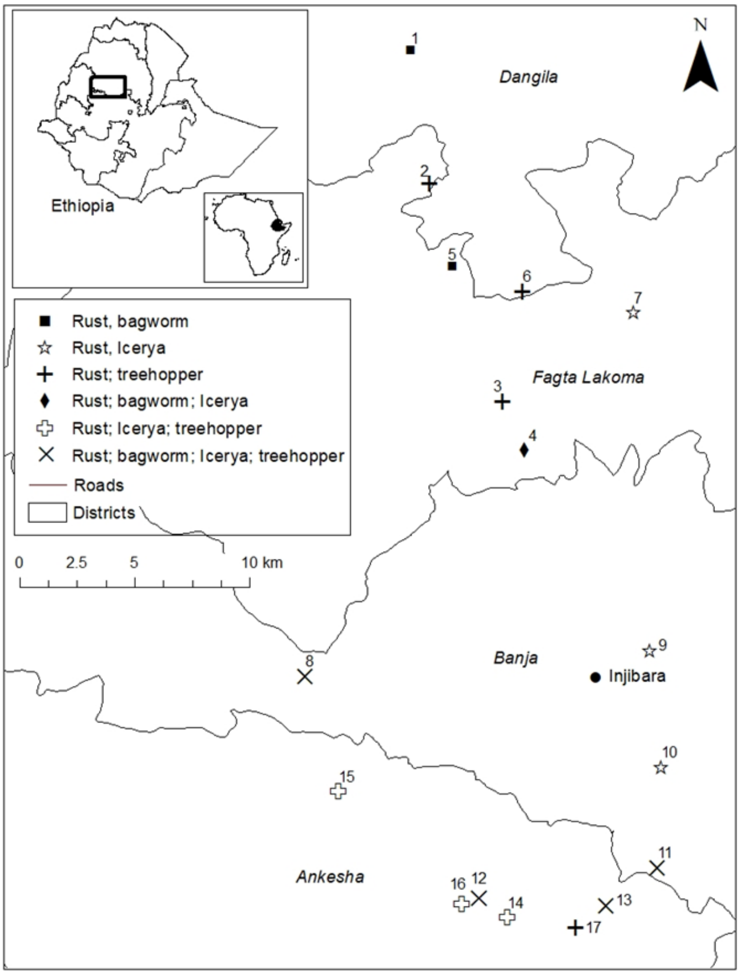

Figure 7. Map showing the distribution of the rust disease and the three insect pests across the surveyed sites. Numbers on the map correspond to the 'Sites' in Table 1.

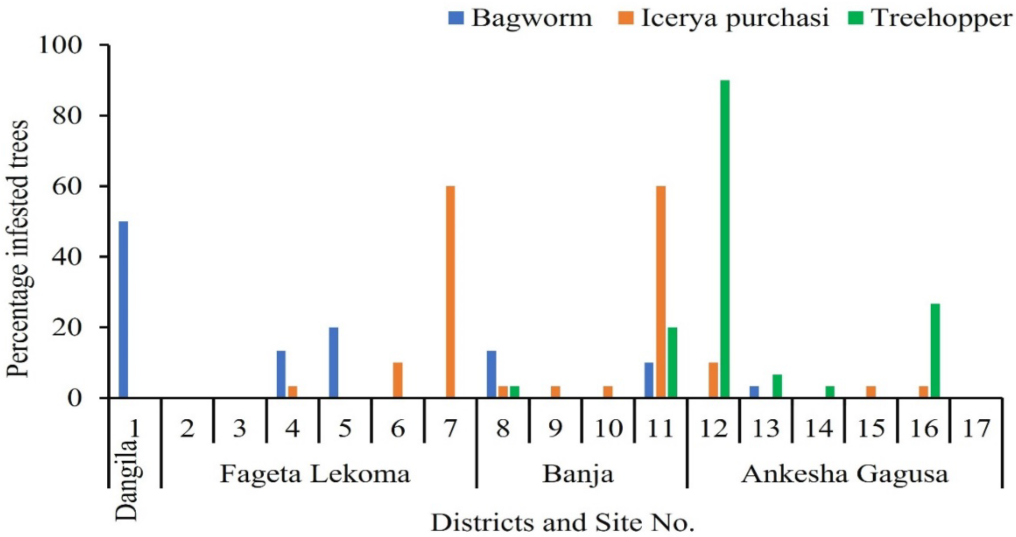

Figure 8. Percentage infested trees by bagworms, *Icerya purchasi* and treehoppers across the different sites.

The cottony cushion scale, *I. purchasi* is a scale insect of Australian origin, widely spread in most tropical and subtropical countries. Although it is mainly known as a pest of *Citrus* and *Pittosporum*, this insect has a broad host range of > 80 families of woody plants. Among forest trees, it is mostly associated with *Acacia* spp., although it has also been reported from other genera including *Pinus*, *Juglans*, *Albizia*, *Cassia*, *Eucalyptus*, and *Morus* (Roychoudhury and Mishra, 2021). Infestation by *I. purchasi* is destructive on nursery and transplanted seedlings, causing stunting and die back in severe cases. Ethiopia is classified as one of the countries that have high habitat suitability areas for *I. purchasi* (Liu and Shi, 2020). This includes the northwest part of the country where Awi Zone is located.

The family Psychidae, commonly known as bagworms, are widely distributed globally (Rhainds et al. 2008). Most are not pests, but a few are serious pests, including bagworms on black wattle (*A. mearnsii*) in South Africa (Henkel and Bayer, 1932). In wattle plantations, when abundant, the larvae defoliate trees, decreasing tree vigour and bark and timber production.

The family Membracidae, commonly known as treehoppers, comprises approximately 3100 described species (Dietrich et al. 2001). Injury often results from punctures made during egg laying and sap sucking by the nymphs. A rough and ragged appearance develops on twigs on which eggs have been laid and the nymphs suck the plant sap, giving parts of the plant a girdled appearance. In older trees, injury is often confined to the twigs or smaller branches (Yothers 1934).

Wattle

Investigation into the leaf morphology of the wattle species planted in Ethiopia strongly suggests that it is not green wattle, *A. decurrens*, as the leaf structure conforms to *A. mearnsii* (Fig. 9). In *A. mearnsii*, the pinna and pinule are denser and shorter compared to *A. decurrens*. The fact that *A. mearnsii* in its introduced range in South Africa is also severely affected by the same rust species, *U. acaciae,* supports the morphological observation that the wattle tree planted in the Awi Zone is possibly *A. mearnsii*. Unfortunately, identification of the specimens using sequence data of three chloroplast markers, namely, matK, rbcL and trnH-psbA is inconclusive as the markers do not seem to differentiate between species.

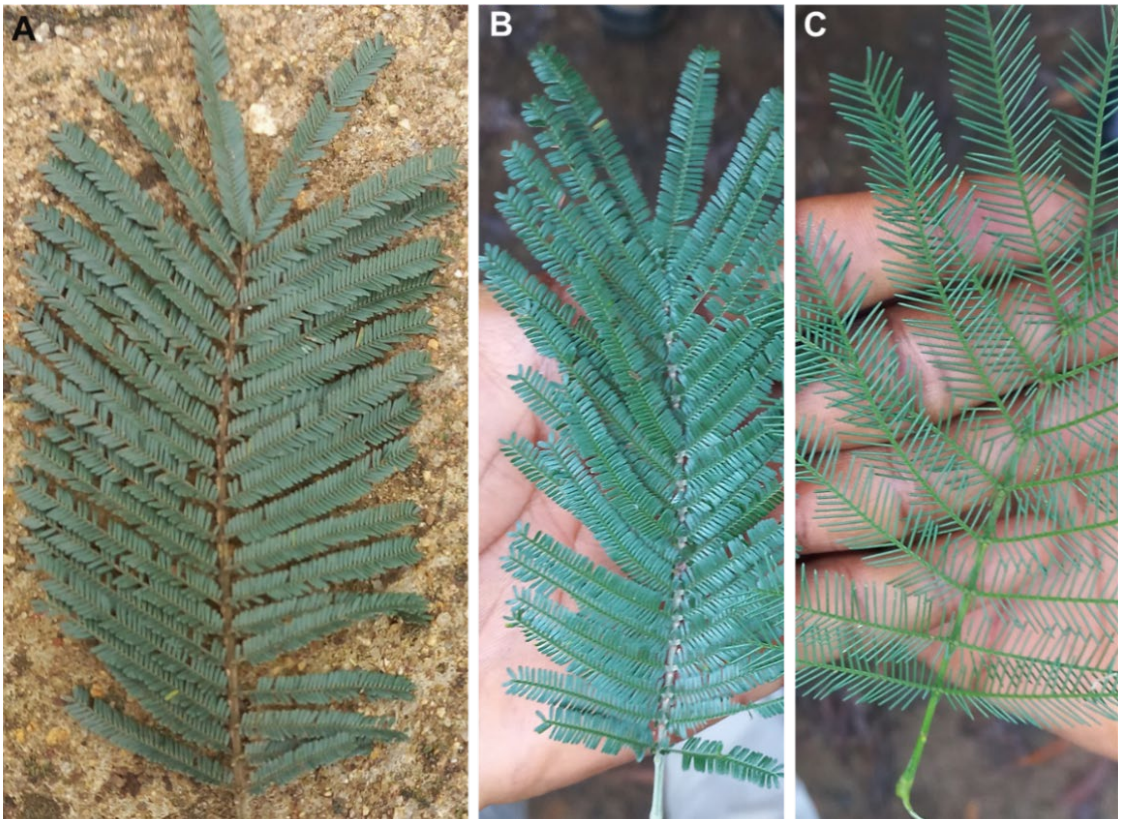

Figure 9. Leaf morphology of **A.** *Acacia* sp. planted in Ethiopia, **B.** *Acacia mearnsii* and **C.** *Acacia decurrens*.

Nursery Trials

The nursery trials at the time of report writing (25th August 2022) were not yet complete, so the full results cannot yet be reported. Upon completion and data analysis, an additional report will be provided to ACIAR.

8 Impacts

8.1 Scientific impacts – now and in 5 years

The scientific impacts from this project are significant. Determining that the *Acacia* species is unlikely to be *A. decurrens* has immediate implications for management and control of *Acacia* rust in particular, but also the insect pests. In addition, confirmation of the wattle rust as *U. acaciae* means that specific measures of control and management can be implemented once the nursery trials are complete. Considering these two findings, the impacts on production and livelihoods could be immediate through use of fungicides in the nursery to control the rust. This could lead to the immediate provision of clean and healthy seedlings to replace the destroyed plantations of smallholder growers.

These findings establish the base for future trials to control wattle rust but also, and most importantly, the use of *A. decurrens* as an additional option for sustainable wattle growth (considering it is less susceptible to *U. acaciae*). In the long-term, this could provide a safe and sustainable option for wattle production in the area, reducing the impact of wattle rust and other pests and diseases. In addition, this is the first report of *U. acaciae* in Ethiopia, contributing to the knowledge of the invasion of this disease and providing warning for other countries in Africa and around the world.

8.2 Capacity impacts – now and in 5 years

Visits by FABI/ICFR to Ethiopia and EEFRI to FABI/ICFR provided significant learning opportunities as well as establishing a strong working relationship. The visit to FABI exposed the EEFRI researchers to a range of forestry research, operations, and facilities, including the opportunity to interact with academics, researchers, and technicians within the fields of forestry, agriculture, and plant health. EEFRI members were introduced to new diagnostic methods, molecular techniques, and breeding research (Fig. 10 and 11). In the short term, this will allow EEFRI to identify *Acacia* pests in the field and provide growers with up-to-date technical knowledge and advice.

Figure 10. EEFRI researchers visiting various FABI facilities, including **A.** research laboratories; **B**, **C**, **D.** biocontrol and quarantine facilities; **E.** insect rearing tunnel and **F.** attending the annual meetings of TPCP.

In the next five years, these capacity impacts will have many flow on effects. From greater diagnostic ability, IPM development of *Acacia* growers including access to mentoring and technical support within FABI and ICFR (in particular) and ISC. The relationships established mean there is a greater likelihood that two of the forestry officers will embark on PhDs as part of a potential new ACIAR project.

Figure 11. EEFRI researchers visiting ICFR and various forestry industries, including **A**. wattle and Eucalyptus breeding trials at NCT, **B**. ICFR nursery, **C.** Gonipterus on Eucalyptus, **D**. Mondi nursery production facilities, **E**. ICFR wattle hybrid trials, and **F.** community forestry supported by Natal Tannin Extract (NTE) at Matimatolo.

8.3 Community impacts – now and in 5 years

The immediate benefit to the community is the potential roll out of disease-free seedlings to growers who were severely impacted by wattle rust. This in turn has flow on effects along the value chain, but immediately to the communities who rely on wattle production for livelihoods and environmental impacts too. However, it must be understood that the fungicide option is not stand-alone. Therefore, long-term, the potential for a future ACIAR project would aim to develop a robust and sustainable IPM program incorporating chemical, cultural, and biological control options. This will include investigating mixed planting operations (in a socio-ecological production landscape approach) which is advantageous from a production (diversification) and environmental point of view. Therefore, the impacts to community over the next five years could be significant and possibly immediate.

8.3.1 Economic impacts

In the shorter term, provision of disease-free seedlings may mean that farmers can potentially replace their destroyed and damaged plantations and restart the flow of income that was derived from wattle production, although this is yet to be tested. In many cases, *Acacia* has not yet been replaced by an alternate crop. Disease-free seedlings in the short-term may mean that many of the job opportunities that rely on *Acacia* production can begin again, jump-starting income for families that rely upon the timber and charcoal industries for their livelihoods, for instance.

In the longer term, this project is likely to help sustain *Acacia* production and the industries it supports into the future. In particular, with healthy seedling production it may be that the industry can become more robust, and the socioeconomic benefits increase accordingly.

In the medium to longer term, switching from the highly disease-susceptible *A. mearnsii* to less susceptible acacia species such as *A. decurrens* is the best management option and a high priority for Ethiopia. EEFRI is currently looking at obtaining *A. decurrens* seed to begin trials in the most-affected areas.

In addition, a follow-on project would allow for research into tree crop diversification, which would safeguard against this type of monocropping, or rather, overreliance on a single tree crop alone.

8.3.2 Social impacts

As indicated throughout this report, wattle production provided a stable source of income for many people, including providing employment along the value chain. Therefore, the social impacts of this project in the recovery of wattle production would mean recovery of income which may have flow-on effects at the household level in terms of nutrition, education and more (although this is only speculation). Recovery of the industry would mean that women do not need to walk long distances to collect timber from what remains of the natural forests. In addition, this means reducing the burden of collection, potentially freeing their time to pursue other endeavours (employment or education for instance). Reducing the need to walk long distances to collect timber would also have an effect on the health, safety and wellbeing of those (largely women) who would be burdened with this task.

A potential wider impact of the project may be in promoting awareness of the importance of good biosecurity practices amongst growers, communities and at the government level. In the longer term, regular surveillance of plantations involving trained staff should be carried out, and the field apps used during this project could be used as part of this process. This is especially important for an exotic tree species such as Acacia in Ethiopia which has had an extended honeymoon period from the pests and diseases that will inevitably arrive.

8.3.3 Environmental impacts

The recovery of wattle production means that soil health can again be sustained in an agroforestry system that was working well prior to the introduction of the rust disease. Recovery of *Acacia* production would also assist in the preservation of natural forests from timber collection, which is the very reason *Acacia* was introduced into Ethiopia in the 1990's, to mitigate firewood shortages from native forest.

8.4 Communication and dissemination activities

Several media outputs have been generated from this SRA. These include:

To the rescue of Ethiopia's 'black gold' tree https://www.aciar.gov.au/media-search/news/rescue-ethiopias-black-gold-tree

Survey of wattle pests and pathogens in Awi Zone, Ethiopia – media release, FABI https://www.fabinet.up.ac.za/index.php/news-item?id=1279

Ethiopian researchers visited FABI, ICFR and local forestry companies -media release, FABI https://www.fabinet.up.ac.za/index.php/news-item?id=1308

9 Conclusions and recommendations

9.1 Conclusions

The current survey of wattle plantations in Awi Zone confirmed the occurrence of severe epidemics of a rust disease caused by *U. acaciae*. The epidemics caused by the rust disease are further complicated by the occurrence of three insect pests, namely *I. purchasi*, bagworms and treehoppers which were found consistently across the surveyed sites. The devastation by the rust disease has caused huge concern among tree growers, foresters, developmental agents, and the whole spectrum of actors along the value chain of wattle production. Particularly as observations during the survey confirmed the strong economic reliance of the community on wattle production, including the many jobs that are associated with *Acacia* plantations. The results from the nursery trials are likely to have an impact on the production of healthy seedlings, thereby supporting the recovery of the industry. Considering the current threat from the rust disease, the socioeconomic impact in the coming years is likely to increase without such an intervention. However, fungicide usage is not a long-term or sustainable solution.

Based on the observations during the surveys we recommend deployment of rust-resistant planting stock (possible *A. decurrens* and hybrids) as soon as possible following trial plantings to determine the best genetics-site matching for the affected regions in Ethiopia. This option is being investigated currently between EEFRI and ICFR, where there is an active industry-supported breeding program for rust tolerant *Acacia* in South Africa that can potentially be tapped into. Research into the development of IPM programs for *Acacia* in conjunction with research into mixed-planting strategies could also be developed to reduce the sole reliance on *Acacia*.

9.2 Recommendations

Considering the current threat to nursery production and young trees, the socioeconomic impact of the epidemics in the coming few years is apparent and undoubtedly discouraging to the wattle growers and all parties along the value chain. Thus, we suggest the following short- and long-term approaches to address the current problem and develop sustainable management strategies of wattle pests and diseases in the country.

Short term

Continue to conduct systematic surveys to obtain a comprehensive overview of wattle pests and diseases in the country. This can be done by surveying the main wattle growing regions of the country in different seasons to understand the diversity, distribution, prevalence and severity of pests and diseases and the patterns of seasonal variations. In line with this, further field trips will take place (after the project ends) until the end of 2022 to Awi Zone and other wattle growing regions to develop a comprehensive overview of Ethiopian wattle production.

We suggest that *A. decurrens* and hybrids with *A .mearnsii* are assessed as potential species of use considering *A. decurrens* is (likely) not present in plantations in Ethiopia and are less susceptible to *U. acaciae*. In the case that this was feasible, introduction of *A. decurrens* and hybrids could be done following all protocols and standards developed for the introduction and use of exotic plant material or seeds. The established connection between EEFRI, ICFR and the various forestry industries visited will be a valuable resource for the successful introduction of *A. decurrens* seeds to Ethiopia.

Long-term

Develop a forestry site classification for the region based on available bioclimatic and edaphic parameters as a platform for the evaluation of site forestry potential, site-species matching, and biotic and abiotic risk. The site classification will also support research uptake and enable technology transfer by facilitating the development of site-specific silviculture and integrated pest management recommendations to optimise productivity and mitigate risk sustainably.

Establish trials of *A. decurrens* and *A. mearnsii* (if other genetic material can be obtained) to assess susceptibility to pests and diseases This is important as there will be possibilities for increased mortality of *A. decurrens* considering its relative susceptibility to *Phytophthora* infection and the identification of five putative *Phytophthora* spp. from wattle plantations in Awi Zone in the current survey. This could also include assessing other native or commonly used tree species in Ethiopia such as other *Acacia*, *Eucalyptus* and Morninga.

Work towards developing IPM approaches for sustainable management of wattle pests and diseases includes investigating natural enemies of key pests and pathogens both locally and overseas; developing resistant/tolerant cultivars; screening and verification of effective and safe pesticides; and identification of silvicultural practices that minimise pest and disease incidence. This should also include engaging with the local farming communities, foresters, and development agents to transfer knowledge on emerging pests and diseases of wattle to enhance reporting, timely management interventions and also trust between EEFRI and other governmental agencies and local growers.

Support a potential wattle/tree breeding initiative within the EFFRI and encourage collaboration with the ICFR to facilitate the exchange of knowledge and breeding materials that are productive and resistant/tolerant to pests and diseases. This will aid in increasing the genetic variation of the ‘black wattle’ population in Ethiopia, which was originally (presumably) introduced from a narrow genetic pool.

Contribute towards building sustainable tree health program within EFFRI through short- and long-term capacity building activities. Short-term, this includes further training on various plant health topics, including surveillance and monitoring, sampling, diagnostics, and digital curation of pest and disease occurrence data using mobile. The partnership between FABI, ICFR and USC also provides a good opportunity to train young EEFRI researchers at a postgraduate (i.e., MSc and PhD) level for on long-term capacity building and impact in the forestry space.

10 References

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10.2 List of publications produced by project

First reports in preparation

11 Appendixes

11.1 Appendix 1: Final Report FABI

Please see attached

11.2 Appendix 2: Final Report EEFRI

Please see attached