

MAKERERE



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**RESISTANCE OF SOYBEAN GERMPLASM TO THE
GROUNDNUT LEAF MINER (*Aproaerema modicella*)
IN UGANDA**

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DECLARATION

I Mercy Namara, declare that the work presented in this thesis is my own research and has not been submitted for the award of degree in any other University.

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DEDICATION

I dedicate this thesis to my beloved mother Mrs. Joiva Twinamatsiko, my sister, brothers and nieces.

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ABSTRACT

Soybean is an important food and cash crop. Its production trend in Uganda has been increasing for the past 10 years, though yields are still below the potential. Soybean productivity is constrained by a number of both biotic and abiotic factors. Most importantly, ravages by the groundnut leaf miner, *Aproaerema modicella*, an increasingly economic threat to soybean production in eastern Uganda. Most farmers in Uganda have tried to control the pest by use of pesticides with limited success. Use of resistant cultivars may provide cost-effective and environmentally friendly control of the pest for the resource-poor soybean farmers. However, there are no known/documented sources of resistance to this pest among soybeans in Uganda and the amount of damage caused by this pest on soybeans hasn't been quantified. This study was therefore geared towards identifying sources of resistance to the groundnut leaf miner, that will be deployed into the soybean breeding program for incorporation of resistance to the already existing high yielding varieties, and quantifying yield losses caused by this pest on soybeans.

In experiment I, a total of 160 exotic and local genotypes were evaluated in three environments that is Iki Iki A and Iki Iki B in Budaka district and NaSARRI in Serere district, in eastern Uganda, in a 16 by 10 alpha lattice design replicated two times. The experiment was conducted in the field under natural infestation. Staggered planting was done in Iki Iki whereby Iki Iki B was planted a month after the first planting in Iki Iki (Iki Iki A) in the second planting season of 2013.

The study identified a number of moderately resistant exotic genotypes which included BSPS 48C, 4.21, PI 615437, PI 644103, PI 605638, PI 567034, PI 567102B, NIIGC 4.1-2, PI 578457A and PI 605865B. Two commercial varieties, Maksoy 3N and Maksoy 5N, were found to be moderately resistant.

In experiment II, six commercial varieties were used in the yield loss quantification study in a split plot RCBD with two treatments (protected and unprotected) as the main plots and varieties as the sub-plots. This was also implemented in the three environments.

Results indicated that yield losses ranging between 38.9-53.9% were recorded among the tested commercial varieties in the unprotected plots. The highest yield loss was recorded from Maksoy 4N (53.9%) while the lowest was recorded in Namsoy 4M (38.9%). The highest loss was recorded from Iki Iki A (53.1%) while the lowest yield loss was recorded in Iki Iki B (39.8%). These

levels of yield loss are relatively high and confirm the fact that *A. modicella* is a priority pest and strategies for its effective management are pertinent.

In general, the study showed that there is potential of breeding for leaf miner resistance since some stable and moderately resistant genotypes were identified though most of the genotypes succumbed to the pest. Furthermore, the leaf miners pose a threat to soybean productivity as shown by the relatively high levels of yield loss due to the pest and confirm the fact that *A. modicella* be considered a priority pest, and strategies for its effective management are pertinent.

CHAPTER ONE

1.0 Introduction

1.1 Background

Soybean (*Glycine max* (L.) Merrill) is a member of the family, *Leguminosae*, also known as *Fabaceae* and sub family, *Papilionoideae* (Poelhman & Sleper, 2006). The crop is believed to have originated from south eastern China, about 4000-5000 years ago and later was gradually disseminated to Korea, Japan, Indonesia, the Philippines, India, Thailand and other Asian countries. Soybean was first introduced into Europe in the 16th century, United States in the mid 17th century (Qiu & Chang, 2010; Poelhman & Sleper, 2006), in Africa in the 19th century and in Uganda between 1908-1913 (Bashaasha, 1992; William & Akiko, 2009). Currently, it is a very popular crop and is extensively grown across the world (Shirale & Uttamrao, 2010).

Soybean seed contains approximately 20% oil and 40% protein for human consumption and animal feeds. The crop is known to have the highest protein content and gross output of vegetable oil among all crops cultivated in the world, with a superior amino acid profile (Gibson & Garren, 2005; IITA, 2009; Qiu & Chang, 2010). It can be consumed directly as food or as traditional soybean products which include soybean milk and paste (Shivakumar & Guriqbal, 2010; Hartman, et al., 2011). Soybean is a source of income for farmers and a potential non-traditional export crop in Uganda (Bashaasha, 1992; Tukamuhabwa, 2001). Furthermore, it helps in improving the soil's properties through residual incorporation by shedding of leaves, soil water conservation due to the thick and dense foliage and soil nitrogen enrichment through biological nitrogen fixation. It also disrupts build-up of pests and diseases in cereals when included in rotations (Shivakumar & Guriqbal, 2010). In eastern Uganda, which is one of the major soybean growing areas, soybean is mainly used in food processing factories for example Seba Foods Uganda, located in Tororo district, which produces a low cost meat substitute (Tasty Soy Pieces) (Ronner & Giller, 2013).

Globally, soybean production has been steadily increasing over the past decade by about 60 million MT from 2000 to 2012 (FAO, 2012). Currently, total world soybean production is 241.8 million MT cultivated on an area of 102 million hectares, with USA being the lead producer

accounting for 33.9% of the total tonnage (FAO, 2012). Other major soybean producing countries are: Brazil, 27.2% (65.8 million MT), Argentina, 16.6% (40.1 million MT), China, 5.3% (12.8 million MT) and India, 4.8% (11.5 million MT) totaling to 87.8% of world production. The remaining 12.2% is contributed by the other soybean producing countries (FAO, 2012). In Africa, total soybean production is 2 million Mt as of 2012, with South Africa producing 32.5% as the leading producer followed by Nigeria, 29% (580,000tonnes), Zambia 10.2% (203,038 tonnes) and Uganda 7.7% (153,300 tonnes) (FAO, 2012). In East Africa, Uganda is the leading producer of soybean with production having steadily increased from 144,000 tonnes in 2001 to 153,300 tonnes in 2012 (FAO, 2012).

Although soybean production has continuously increased, a number of important biotic and abiotic constraints have remained a threat to its production, leading to a decline both in seed yield and quality. The key constraints facing soybean production in Uganda range from poor marketing systems, unavailability of improved seed and lack of appropriate technology for processing soybeans at household level (Tukamuhabwa, 2001). A number of diseases and insect pests cause severe yield reduction in soybean. The most predominant and devastating soybean diseases in Uganda include red leaf blotch (*Ductuliochaeta glycines*), frog eye leaf spot (*Cercospora sojina*), purple stain (*Cercospora kikuchii*) and soybean rust (*Phakospora pachyizi*). Important insect pests include the stink bug (*Nezera viridula* and the groundnut leaf miner (GLM) (*Aproaerema modicella* Deventer), which is currently a major threat to soybean production in the eastern part of Uganda (Tukamuhabwa, 2001).

1.2 Statement of the problem

The Groundnut leaf miner (GLM), *Aproaerema modicella* (Lepidoptera: Gelechiidae), is a serious pest of soybean in the tropics (Cugala, et al., 2010; Praveena, 2010). It reduces soybean yield by mining and feeding on the leaves causing a reduction in the photosynthetic area, which leads to reduced assimilates channelled to the pods during the pod-filling stage (Shanower, et al., 1993). However, despite the increasing importance of this pest in Uganda, there has been very limited research on it on soybean in Uganda and most parts of Africa. Yield losses of about 60-100% and 75% loss in leaflets caused by the leaf miner have been reported in unprotected groundnut in Mozambique (Cugala, et al., 2010) and > 50% in India (Shanower, et al., 1993).

Leaf miner is an oligophagus pest (Praveena, et al., 2011b) that was confined to groundnuts since its discovery in Uganda in 1997 but it is now established on soybean and other legumes and even on cotton (Okello, et al., 2013). *Aproaerema modicella* has been observed to severely attack soybean fields in eastern Uganda, a major soybean growing area, especially during the second growing season (August-December) as it is known to occur in the short rainy cycle (Okello, et al., 2013). Moreover, groundnut, which is also widely grown in eastern Uganda acts as a source of infestation for soybean. Current trends show that if the leaf miner problem is not effectively addressed, most farmers may abandon soybean growing altogether, as was the case in southern Mozambique, where farmers abandoned groundnut production because of heavy losses due to the pest (Cugala, et al., 2010). This is a situation we don't want to see happen in eastern Uganda.

1.3 Justification

Currently, pesticides are the major control strategy being used by the farmers in Uganda to control GLM (Okello, et al., 2013). However, the use of pesticides is associated with a number of limitations which include, high cost, pest resurgence, outbreaks of secondary pests and environmental pollution (Hajek, 2004; Shirale & Uttamrao, 2010; Joshi & Patel, 2011). In resource constrained communities like in Uganda, use of resistant or tolerant cultivars maybe the most cost-effective method of controlling GLM (Sharma & Ortiz, 2002). For long term GLM management, there is a need to characterize the imported soybean germplasm for GLM resistance to facilitate soybean breeding through identification of resistant genotypes that can be used to introgress GLM resistance into farmer preferred varieties.

In addition, quantifying the yield losses associated with the GLM will provide a basis for management of GLM and will pin point when management should be started to prevent populations reaching economic injury levels. This is of paramount importance as GLM is spreading from eastern Uganda where it is endemic to other regions in the country. Furthermore, sustainable soybean production depends on establishing losses caused by pests in relation to existing genotypes. Knowledge on the extent of damage and impact of the pest will guide the breeding program during resource allocation according to the urgency needed to control GLM.

1.4 Overall objective

The main aim of the study is to increase soybean production through reduction of losses caused by *A.modicella* by contributing to development of soybean varieties with resistance to the pest.

1.4.1 Specific objectives

- To characterise and identify sources of groundnut leaf miner resistance among local and exotic soybean genotypes
- To quantify the yield losses caused by groundnut leaf miner damage on commercial soybean varieties in Uganda

1.5 Hypotheses

- All the available soybean accessions in Uganda are susceptible to the groundnut leaf miner
- Yield losses attributed to the leaf miner on soybeans are significant and genotype dependent

CHAPTER TWO

LITERATURE REVIEW

2.1 Agronomy and Ecology of Soybean

Soybean is a small, erect, branching and short-day annual crop (Norman, et al., 1995; Nieuwenhuis & Nieuwelink, 2002). It requires warm and humid climate with a minimum temperature of 10°C, optimum temperature of 22°C and maximum temperature of 40°C (Nieuwenhuis & Nieuwelink, 2002). It is sensitive to photoperiods. Soybean has two critical periods for water requirement that is sowing to germination and pod-filling stages (Nieuwenhuis & Nieuwelink, 2002). Soybean can be grown on soils of a wide range of textural classes (Purseglove, 1968) although it is most productive on fertile loam soils with high organic matter content and pH between 5.8-7.8 (Tukamuhabwa, 2001; Nieuwenhuis & Nieuwelink, 2002). Recommended planting depth is 2-5cm, at a spacing of 60cm x 5cm giving a plant population of about 330,000 plants/ha. In cases where soybean has never been grown, seed should be inoculated with *Bradyrhizobium japonicum* (Tukamuhabwa, 2001). For a good soybean yield, 200kg/ha of Single Superphosphate (SSP) or 100kg/ha of Tripple Superphosphate (TSP) should be incorporated in the soil before planting; 50kg/ha of NPK may be applied on poor soils (Tukamuhabwa, 2001).

Growth period of adapted cultivars and landraces is commonly 90-110 days and up to 140 days (Norman, et al., 1995), with a flowering period of 15-30 days and pod and seed development period of 30-70 days (Norman, et al., 1995). Two weedings are recommended that is at 3 weeks and 6 weeks after planting (Tukamuhabwa, 2006). During the first week of emergence, young seedlings should be protected from birds. Harvesting is done at the stage when soybeans make a rattling sound when shaken and should be done in dry conditions in order to maintain seed quality and the seed should be dried to about 10% moisture content (Tukamuhabwa, 2001). Soybean can be raised as an intercrop with maize with one row of soybean grown between two rows of maize (Nieuwenhuis & Nieuwelink, 2002).

2.2 Insect pests of Soybean

Soybean insect pests are classified into foliage feeders, which comprise the biggest group of insect pests; pod feeders, affecting the harvestable product directly, and stem and root feeders (Wright, et al., 2008). The foliage feeders include grasshoppers (*Melanoplus spp.*), spotted cucumber beetle (*Diabrotica undecimpunctata* Howardi), striped blister beetle (*Epicauta vittata*), Japanese beetle (*Popillia japonica*), Mexican bean beetle (*Epilachna varivestis*), bean leaf beetle (*Cerotoma trifurcata*), green clover worm (*Plathypena scabra*), soybean looper (*Pseudoplusia includens*), velvet bean caterpillar (*Anticarsia gemmatilis*), beet armyworm (*Spodoptera exigua*) and soybean aphid (*Aphis glycines*); pod feeders include corn earworm (*Heliothis zea*), green stink bug (*Nezara viridula*) and brown stink bug (*Euschistus servus*). Stem feeders include soybean stem borer (*Dectes texanus texanus*), lesser cornstalk borer (*Elasmopalpus lignosellus*), cut worms (*Agrotis spp.*), grape colapsis (*Colaspis brunnea*) and white grubs (*Phyllophaga* and *Cyclocephala spp.*) that feed on roots (Wright, et al., 2008; Akin, 2009). The GLM is principally a key pest of groundnuts but has recently become a major problem on soybean and is reported to be spreading widely and reaching out break densities, causing great losses on the crop in Uganda (Kenis & Cugala, 2006).

2.3 The groundnut leaf miner

2.3.1 Origin and distribution of the groundnut leaf miner

In Asia, GLM distribution is limited to South and South East Asia, from Pakistan to China and as far south as the Philippines and Sri Lanka (Shanower, et al., 1993; Jyothi, et al., 2008). It has also been reported in Africa in Uganda (1998), Malawi (2000), Mozambique (1999), Democratic Republic of Congo and South Africa (2000) (Munyuli, et al., 2003; Van der Walt, 2007; Du Plessis & Van Der Berg, 2011). GLM is known to be a very sporadic pest with large fluctuations in seasons and generations, though in Uganda, it is known to always be present mainly in the second season (Kenis & Cugala, 2006; Buthelezi, et al., 2012).

2.3.2 Host range and Biology of *A. modicella*

A. modicella is an oligophagus pest and feeds only on leguminous host plants which include soybean (*Glycine max*), mung bean (*Vigna radiata*), ground nut (*Arachis hypogaea*), pigeon pea,

(*Cajanus cajan*) and lucerne (*Medicago sativa*) (Shanower, et al., 1993; Praveena, et al., 2011b). Adult brownish gray female moths lay about 50-400 eggs, singly either on the underside of leaves, stems or petiole (Shanower, et al., 1993; Du Plessis, 2002; Du Plessis, 2003). The eggs are small (<1.0mm), oval shaped and with longitudinal pits on their surface (Shanower, et al., 1993). They hatch into yellowish green larvae within a period of 3-4 days under ideal warm conditions (Wightman & Amin, 1988; Du Plessis, 2003). The first instar larvae mine their way into the leaf through the epidermis and create serpentine mines which develop into blotches (Shanower, et al., 1993; Subrahmanyam, et al., 2000; Du Plessis, 2003). Once the instars become too big to stay in the leaf mesophyll, they emerge from the mine and form webs by webbing two or more halves of leaflets together (Shanower, et al., 1993; Du Plessis, 2003). The five GLM instar development takes about 9-28 days. Pupation of the larvae takes place within the webs (Amin, 1987; Wightman & Amin, 1988; Du Plessis, 2003) (Figure 1) and takes about 3-10 days. The entire life cycle of the leaf miner takes about 3-4 weeks and there can be 2-7 generations per crop season, depending on season and climate (Kenis & Cugala, 2006).



Figure 1: Groundnut leaf miner larva feeding on a soybean leaf resulting in the characteristic necrotic blotches (left) and pupa on dry webbed leaflets (right), at NaSARRI

2.3.3 Crop damage and yield loss caused by *A. modicella*

The groundnut leaf miner larvae are the most destructive stage which cause blister-like mines on the midrib cutting water and nutrient flow to and from the leaf (Figure 1, left). Damaged leaves become brownish, rolled and dessicated, and eventually dry up (Wightman & Amin, 1988;

Subrahmanyam, et al., 2000; Du Plessis, 2003; Van der Walt, 2007) (Figure 2). This leads to early defoliation that affects growth and yield of the crop under heavy infestation (Du Plessis, 2003; Kenis & Cugala, 2006). Leaf miners can cause a yield loss of >50% as has been reported on groundnut in India (Shanower, et al., 1993; Jyothi, et al., 2008). Cugala et al. (2010) recorded yield losses of 62.9% and 86.2% on groundnut in Chidenguele (Gaza province) and Nhacoongo (Inhambane province) of Mozambique respectively. This resulted in groundnut farmers in southern Mozambique completely abandoning the crop because of experiencing the high yield losses (Cugala, et al., 2010). Total crop losses have also been reported by some groundnut farmers in Uganda (Okello, et al., 2013). However, data on losses caused by GLM on soybean is not as available.

2.4 Management Options for *A. modicella*

Most of the published research emphasizes chemical use for the control of the GLM. Commercial insecticide groups such as carbamates, organophosphates, pyrethroids, antifeedants and plant products have been evaluated and found variably effective against GLM (Praveena, 2010; Praveen, et al., 2011a). In a bio-efficacy experimentation of new insecticides against GLM on groundnut in northern dry zone of Karnataka, Praveen et al. (2011a) reported significantly higher yields in insecticidal treated plots compared to the untreated plots. Cugala et al. (2010) also recorded significantly higher grain weight in the insecticide treated plots as compared to the untreated plots, in an experiment to assess groundnut yield losses due to GLM infestation in Mozambique. Cugala et al. (2010) also recorded 60-86% yield losses in the unprotected plots. However, use of insecticides may lead to destruction of natural enemies and also have an effect on the environment in addition to them being expensive for the resource-poor farmers (Munyuli, et al., 2003) and also, GLM is confined within the stem and the leaves hence not easily reached by contact insecticides (Jyothi, et al., 2008).

Different cultural measures have been recommended for the management of the GLM. Logiswaran and Mohanasundaram (1985) recorded significantly lower GLM incidence on groundnut that was intercropped with black gram or cowpea in a ratio of 3:1 in Tamil Nadu, India. In the same study, there was also a significant reduction in the level of infestation on groundnut that was mulched with rice straw and that which was planted closely together at

(20×10) cm and (5×10) cm as compared with a normal spacing of (30×10) cm. In a related study carried out on groundnut in Karnataka, India, Rajagopal and Hanumanthaswamy (2000) also recorded higher pod yield on groundnut that was sown as an intercrop with sorghum, cowpea or maize as opposed to the monocrop.

Various *A.modicella* natural enemies which include predators, parasites, parasitoids, pathogens and nematodes, that suppress GLM population growth have been reported both in Africa and Asia. However, the use of natural enemies in the control of *A.modicella* has not yet been studied in detail in Africa though some reports show their occurrence in some regions. Munyuli et al. (2003) reported 4 larval parasitoids of *A.modicella* on groundnut namely *Euryscotolynx* sp. (Hymenoptera: Eulophidae) and *Diglyphus* sp. (Hymenoptera: Eulophidae) in Uganda and *Teleopteris* sp (Eulophidae, Hymenoptera) and *Pteromalus* sp (Pteromalidae: Hymenoptera) in DRC. Parasitism rates in their study ranged between 1.4-4.5%. Du Plessis and Van Der Berg (2011) also recorded 6 parasitoid species in South Africa namely *Goniozus* sp (*Bethylidae*), *Apanteles* sp (*Braconidae*), *Brachymeria* sp (*Chalcididae*), *Pteromalus* sp (*Pteromalidae*), *Pachyneuron* sp and *Eurytoma* sp (*Eurytomidae*) on groundnut. Shanower et al. (1992) also reported 9 primary and 8 secondary parasitoids on GLM in India, namely *Goniozus* sp (*Bethylidae*), *Apanteles* sp (*Braconidae*), *Capidosoma* sp (*Encyrtidae*) and *Brachymeria* sp (*Chalcididae*). Shanower et al. (1992) further noted that 30% and 50% of the *A.modicella* larval mortality was as a result attributed to certain pathogens (viral and fungal) and parasitoids respectively.

Seven parasitoids have been reported on the pest on soybeans and they include; *Bracon gelechi-ae* Ashm. and *Elasmus brevicornis* Gahan, *Chelonus* (*Microchelonus*) sp., *Apanteles* sp., *A. litae* Nixon, *Stenomeseioideus ashmeadi* Subba Rao and Sharma and *Goniozus* sp. (Gujrati, et al., 1973; Shetgar & Thombre, 1984; Rajagopal & Gowda, 2008). Despite the large number of parasitoids that have been reported, none of them has been reported to be solely effective in the control of *A.modicella* (Shanower, et al., 1993). Srinivasan and Siva Rao (1987) reported predation by undetermined spiders and robber flies (*Diptera* : *Asilidae*). Ranga Rao and Reddy (1997) reported a fungus *Metarhizium anisopliae* (Metschn.) that caused GLM larval mortality in

a field in India. Rajagopal and Gowda (2008) also reported the fungus *Beauveria bassiana* and the bacterium *Bacillus thuringiensis* that causes GLM larval mortality in India.

Host plant resistance is another recommended management strategy that may be feasible for the control of GLM in soybeans (Ramani & Lingappa, 1988; Tukamuhabwa, 2001).

2.4.1 Mechanisms and application of host plant resistance to *A. modicella*

Host plant resistance is considered to be an effective, economical, and environment friendly method of pest control. In addition, farmers do not need any skill to apply the technique and it requires reasonably low cash investment by the resource-poor farmer (Sharma & Ortiz, 2002). Host plant resistance breeding involves identification of resistance sources and understanding their mechanisms of resistance (Pedigo, 2000). The mechanisms of host plant resistance against insect pests include; non-preference/antixenosis which refers to plant characteristics that orientate insects away from a particular host for example trichomes, surface waxes, and repellants; antibiosis which impairs the insect's metabolic process and involves consumption of plant metabolites; and tolerance which is the plant's ability to give satisfactory yields regardless of injury levels that would hinder non-resistant plants (Pedigo, 2000).

Moreira et al. (2009) evaluated eight lycopersicon genotypes which showed different antibiosis mechanisms to the related *Tuta absoluta* (Lepidoptera: Gelechiidae) and they included larval and pupae mortality, short oviposition periods on the genotypes and prolonged larval period. Another study on resistance of tomato strains to the moth, *Tuta absoluta* imparted by allelochemicals and trichome density showed that genotypes with higher densities of glandular trichomes had greater resistance than the susceptible controls (De Oliveira, et al., 2012). In a study on resistance to leaf miners in groundnut, Rao (2000) reported that GLM appeared to display some oviposition preference for cultivars with hairy leaves.

Some progress has been made in assessing soybean germplasm for resistance to *A. modicella*. Shirale and Uttamrao (2010) evaluated different soybean cultivars in India and identified some cultivars with resistance to the pest though the mechanisms of resistance were not reported. Earlier, Behera et al. (1990), working on 13 soybean cultivars in India also reported that some cultivars had resistance to leaf damage. However, most studies concerning GLM host plant

resistance have been done on groundnut and to a less extent on soybean which has also been limited to India. Therefore this research will particularly contribute to knowledge of GLM on soybean in Uganda.

CHAPTER THREE

SCREENING SOYBEAN GERMPLASM FOR RESISTANCE TO GROUNDNUT LEAF MINER UNDER UGANDAN CONDITIONS

3.1 Background

Groundnut leaf miner is a serious oligophagous leguminous pest that is known to cause serious damage to both soybean and groundnut crops in South and South East Asian countries and some African countries, Uganda inclusive (Cugala, et al., 2010). This pest is becoming endemic on soybean in eastern Uganda, which is a major soybean growing area, and has become a constraint to many small scale resource-poor farmers that depend on the crop for their livelihood. Groundnut leaf miner is currently controlled by use of insecticides which are associated with a number of limitations that include suppression of natural enemies, secondary pest outbreaks, environmental pollutions and health hazards (Shirale & Uttamrao, 2010) and therefore a need to develop alternative control methods. Host plant resistance maybe an economically achievable tool in the management of GLM though thus far no attempts have been made to develop GLM resistant soybean varieties in Uganda. Hitherto, attention has been on groundnuts. Consequently, this study screened 160 soybean genotypes, introduced from different origins, to establish possible sources of resistance to GLM.

3.2 Study sites and materials

The study was conducted in 2013 in three environments, in eastern Uganda, a GLM hot spot. These sites were also selected because the pest is known to be endemic in this region of the country. These environments were Iki Iki A, Iki Iki B both in Iki Iki sub-county, Budaka district, and National Semi-Arid Resources Research Institute (NaSARRI) in Serere town council, Serere district. NaSARRI is located at 1°31'N/33°27'E at an altitude of 1,139 m.a.s.l and receives mean annual rainfall and temperature of 1,972 mm and 24°C, respectively. Iki Iki lies at 1°06'N/34°00'E at an altitude of 1,156 m.a.s.l and receives mean annual rainfall and temperature of 1,200 mm and 24.7°C, respectively. Both sites have sandy loam soils. In Iki Iki, the trial was repeated by staggered planting and thus Iki Iki A was the first planting (02/09/2013) while Iki Iki B was the second planting (10/10/2013). The staggering was because the pest is only reported to occur in the second growing season. This site was also considered a separate environment. The

NaSARRI site was also planted on 10/10/2013. A total of 160 soybean accessions were screened for resistance to GLM and they included 74 from USA, 27 from the Asian Vegetable Research and Development Center (AVRDC), 9 from Zimbabwe, 19 from the International Institute of Tropical Agriculture (IITA) and 31 from Uganda.

3.3 Experimental design

A 16 by 10 alpha lattice design, with 10 incomplete blocks per replication, each with 16 genotypes was used in this study. The genotypes were replicated two times and planted at a spacing of (60x5)cm. A 5m long row was planted per genotype in each of the two replications. The field that was used was prior ploughed and then harrowed using a tractor to create a fine seedbed. All the cultivation practices were done according to the guidelines of Tukamuhabwa (2006). Two weedings were done in each of the environments, first at 3 weeks after planting and second at 6 weeks after planting. Screening for resistance to the leaf miner was done under natural field infestation.

3.4 Data collection

Data was collected on 10 randomly sampled plants per treatment (genotype). Data was collected at 40 days after planting and continued at 14 days interval until the crop's physiological maturity (Ramani & Lingappa, 1988). Soybean morphological traits such as pubescence colour, leaf colour, plant height, leaf area and trichome presence or absence were recorded following standard measures (Dayaman, 2007). For trichomes, the scores were 1 = for trichome presence, 2 = for trichome absence. Leaf colour was: 1= light green, 2 = dark green. Pubescence colour was: 1= white, 2 = brown. One-metre rulers calibrated in centimetres, were used in measuring the plant heights and leaf areas. Data on GLM incidence and severity (extent of defoliation) was also recorded. GLM incidence was recorded as the number of plants affected out of the 10 sampled plants and for severity, a scale of 1-5 where 1- no pest damage (0% leaf damage) while 5- severely damaged (61-100% leaf damage) was used (Praveena, et al., 2011b) (Table 1). To quantify the soybean productivity, each of the plots were harvested separately, threshed and total seed yield per plot was recorded.

Table 1: Severity scores and resistance categories of GLM damage

Foliage Damage (%)	Severity Score	Resistance Category
0	1	Immune
1-20	2	Resistant
21-40	3	Moderately resistant
41-60	4	Moderately susceptible
61-100	5	Highly susceptible

Adopted from Praveen *et.al.*,2011b

3.5 Data analysis

Data was subjected to Analysis Of Variance (ANOVA) using the Genstat statistical computer package (14th Edition). Means were separated using Fisher's protected least significant difference (LSD) test at 5% probability level. In addition to a general analysis being done for the three environments, separate analysis was done for Iki Iki A and Iki Iki B, to determine any effect of planting date on GLM severity. Leaf colour and trichome data was subjected to a t-test to determine significance among groups by comparing the t-calculated (tcalc) value with the t-critical (t-crit) value. The t-crit values were based on 0.05 probability level and tcalc was computed as;

$$= \frac{\text{Difference in group means}}{\text{Standard error of the difference}}$$

$$= \frac{XA - XB}{\sqrt{S^2A/n + S^2B/n}}$$

Where;

XA = mean of group A

XB = mean of group B

S^2A/n = standard error of the difference for group A

S^2B/n = standard error of the difference for group B

The genotypes were also grouped according to origin and mean GLM severity categories and the different expected numbers of each group were computed as shown in Table 2.

The expected number of genotypes for each of the categories was computed as;

$$Expected = \frac{Row\ total(i) \times Column\ total\ (i)}{Grand\ total}$$

Where i is the individual observation.

Table 2: Observed and expected number of genotypes according to origin and GLM severity categories

Genotype Origin	Genotype number				Row total
	Observed		Expected		
	Moderately resistant	Moderately susceptible	Moderately resistant	Moderately susceptible	
AVRDC	10	17	9	18	27
USA	22	52	25	49	74
Zimbabwe	2	7	3	6	9
Uganda	13	18	10	21	31
IITA	7	12	6	13	19
Column total	54	106	54	106	160

Chi-square test of independence was done at a probability level of 0.05 to determine the relationship between the two variables (genotype origin and GLM severity). The degrees of freedom for the test of independence was calculated as; (number of rows) – 1 x (number of columns) – 1. in the contingency Table. The χ^2 calculated value was obtained by the formula;

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

Where O_i stands for the observed number, E_i = expected number and $i = 1, 2, 3, \dots, n$, where n is the number of cells in the contingency table.

Table 3: The skeleton ANOVA for Lattice Analysis used in the field assessment for GLM resistance

Source of Variation	Df	F-test denominator
Environment	n-1	MS Envt.Rep
Environment × Rep	n(r-1)	MS Envt.Rep.Blk
Environment × Rep. × block	e (r(b-1))	MS Residual
Genotypes	g-1	MS Envt.Genotype
Environment × Genotype	(g-1)(n-1)	MS LEE
L.E.E		

LEE = Lattice effective error, MS = mean square, e = environment, g = genotype, r = replication.

In addition, phenotypic correlations among the different soybean traits studied were recorded. Using the insect infestation data as the dependent variable and the data on studied plant parameters as independent variables, a regression was run.

3.6 Results

3.6.1 GLM Incidence as influenced by genotypes

With regard to GLM incidence, there were highly significant differences ($P < 0.001$) among genotypes only at 40 DAP and non-significant genotype x environment interaction for all the sampling dates (Table 4). The ANOVA results showed that blocking within replications was effective across environments ($P < 0.001$). On average, percentage incidence of GLM among the genotypes ranged from 93% (at 40 DAP) to 100% (by 82 DAP) in all the three environments (Appendix 1).

Table 4: Mean squares for percentage incidence of GLM as influenced by genotypes across environments for the four different sampling dates

Source of Variation	Df	40 DAP	54 DAP	68 DAP	82 DAP
Environment	2	6836.5	15514.7	2722.5	146.4
Genotype	159	232.7***	80.57	83.30	26.89
Genotype × Env't	318	133.0	74.20	74.70	27.44
L.E.E	423	145.5	83.07	78.58	27.43

Values marked *** are significantly different at probability level 0.001; DAP- Days after planting; L.E.E- Lattice Effective Error

3.6.2 Effect of soybean genotypes on GLM severity

Results for GLM severity as influenced by soybean germplasm are presented in Table 5. Across the three environments, highly significant differences for severity to GLM were observed ($P < 0.001$), at all the four different sampling dates. Results showed that blocking was highly effective and the highest severity variance among the genotypes was observed at 54 DAP which coincides with the soybean reproductive growth stage that ranges from 45-90 DAP.

Table 5: Combined mean squares for GLM severity of genotypes across environments

Source Of Variation	Df	40 DAP	54 DAP	68 DAP	82 DAP
Environment	2	10.443	15.230	35.624	17.073
Genotypes	159	0.872***	1.918***	1.469***	1.644***
Genotype $\times$ Env't	318	0.259	0.310	0.288	0.364
L.E.E	423	0.276	0.342	0.308	0.392

Values marked *,*** are significantly different at probability 0.05 and 0.001, respectively; DAP- Days after planting; L.E.E – Lattice Effective Error

All the 160 soybean genotypes that were screened, were infested by the GLM, albeit to different levels. The least damaged 10 genotypes with the least mean severity score of 2.5-2.9 (21-40% leaf damage) and the most damaged 10 genotypes with a mean severity score of 4.3-4.5 (41-60% leaf damage) are listed in Table 6. The Ugandan commercial soybean varieties, Maksoy 3N, Maksoy 5N, Maksoy 1N, Maksoy 2N and Maksoy 4N are also shown in Table 6 and scored values ranging between 3-3.9 (21-60% leaf damage). Following the categorization scale in Table 1, BSPS 48C, 4.21, PI 615437, PI 644103, PI 605638, PI 567034, PI 567102B, NII GC 4.1-2, PI 578457A, PI 605865B, Maksoy 3N and Maksoy 5N were considered moderately resistant whereas PI 628833, PI 628915, PI 287197, NGDT 2.15-4, 10.41, BSPS 47B, K-local, Siesta, PI 628948, Namsoy 4M, Maksoy 1N, Maksoy 2N and Maksoy 4N fell in the group considered moderately susceptible (Table 6).

Genotypes PI 605638, PI 567056A, PI 506695, PI 605865B, and PI 567123 had consistently low severity scores (2-3) in all the three environments (Appendix 2). Other best genotypes that had relatively low severity scores in each of the individual environments were PI 567034, PI 605885 in Iki Iki A; PI 578457A, PI 416810, PI 605885A in Iki Iki B all with a severity range of 2-2.5

and PI 605638, PI 587056A, PI 506695, PI 628908, PI 615437 and PI 567053 at NaSARRI with a severity score of 2.7-2.9. From the categorization of GLM used in the study, a total of 46 genotypes were found to be moderately resistant, of which 7 were from AVRDC, 11 from Uganda, 20 from USA, 7 from IITA and 1 from Zimbabwe. The remaining 114 genotypes were moderately susceptible of which 20 were from AVRDC, 20 Uganda, 54 USA, 12 IITA and 8 from Zimbabwe (Appendix 4).

The chi square test of independence for genotype origin and GLM severity showed that the probability of the test statistic ($P_{\text{calc}} = 0.46$) is greater than the α -probability ($P_{\alpha} = 0.05$) and that χ^2 calculated (observed) ($\chi^2_{\text{calc}} = 3.6$) is less than χ^2 critical (expected) ($\chi^2_{\text{crit}} = 9.49$) thus the null hypothesis was retained implying that genotype origin and GLM severity were independent. With regard to sampling time, there was a gradual increase in severity scores across sampling dates until the peak at 68 DAP for NaSARRI and Iki Iki A and at 54 DAP for Iki Iki B (Figure 2). Peak infestation in all the environments occurred during the crop's reproductive stage which is about 45-90 DAP (Figure 2). Details of GLM severity over time and environments are presented in Appendix 1.

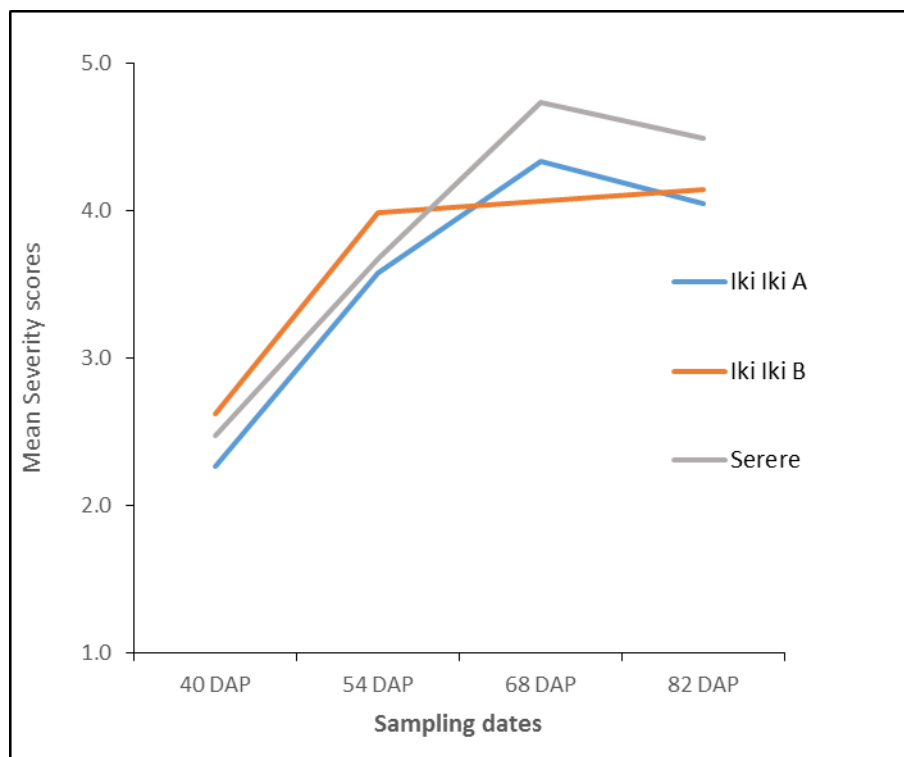


Figure 2: GLM severity with time under the three environments for the 160 genotypes

Table 6: GLM severity scores across environments (Iki Iki A, Iki Iki B, and NaSARRI) at the four different sampling dates

Genotype	Severity scores					Origin
	40 DAP	54 DAP	68 DAP	82 DAP	Mean	
10 least damaged genotypes						
BSPS 48C	1.9	2.5	3.0	2.7	2.5	Uganda
4.21	1.9	2.6	3.3	2.7	2.6	IITA
PI 615437	1.9	2.7	3.3	3.2	2.7	USA
PI 644103	2.0	2.6	3.1	3.4	2.8	USA
PI 605638	2.0	3.1	3.0	3.2	2.8	USA
PI 567034	1.9	2.7	3.4	3.3	2.8	USA
PI 567102B	2.0	2.6	3.5	3.2	2.8	USA
NII GC 4.1-2	2.0	2.7	3.4	3.3	2.8	Uganda
PI 578457A	1.7	2.9	3.6	3.2	2.9	USA
PI 605865B	2.1	3.3	3.2	3.1	2.9	USA
Commercial Uganda varieties						
Maksoy3N	1.9	2.6	3.7	3.9	3.0	Uganda
Maksoy 5N	2.1	3.2	3.7	3.2	3.1	Uganda
Maksoy 4N	2.5	3.8	4.5	4.1	3.7	Uganda
Maksoy 1N	2.4	3.8	4.4	4.7	3.8	Uganda
Maksoy2N	2.6	3.9	4.5	4.7	3.9	Uganda
10 most damaged genotypes						
PI 628833	2.8	4.6	4.9	4.8	4.3	USA
PI 628915	3.0	4.7	4.7	4.7	4.3	USA
PI 287197	3.1	4.6	4.8	4.6	4.3	USA
NGDT 2.15-4	3.2	4.6	4.8	4.7	4.3	Uganda
10.41	2.8	4.3	5.7	4.5	4.3	IITA
BSPS 47B	3.1	4.5	5.1	4.8	4.4	Uganda
K-local	3.4	4.5	4.9	4.7	4.4	Uganda
Siesta	3.2	4.6	4.9	4.8	4.4	Zimbabwe
PI 628948	3.2	4.5	4.9	4.9	4.4	USA
Namsoy 4M	3.3	4.7	5.0	5.0	4.5	Uganda
Overall mean	2.5	3.7	4.4	4.2	3.7	
LSD	0.60	0.63	0.61	1.59	0.9	
CV%	20.74	14.87	12.27	14.29	15.5	

LSD is Least significant difference for genotypes down column at 5% probability level; Full table in appendix 1

3.6.3 Effect of Planting time on GLM severity on soybean

The T-test results showed that there were significant differences in GLM severity between the two planting dates as manifested at 40, 54, and 68 DAP at $P < 0.05$ (Table 7). On the contrary there was no significant difference at 82 DAP.

Table 7: T-calc for GLM severity for the two planting dates for the different sampling dates

	Sampling dates			
	40 DAP	54 DAP	68 DAP	82 DAP
F test	2.4	1.3	2.1	1.3
T calc	4.48	3.95	2.76	0.89
Tcrit	2.0	2.0	2.0	2.0

T-calc; T-calculated; T-crit; T-critical

3.6.4 Effect of genotypes on plant parameters

3.6.4.1 Soybean plant height

Highly significant differences in plant height were observed among the genotypes ($P < 0.001$). The genotype x environment interaction was non- significant for all the sampling dates (Table 8). Plant height means across environments ranged from 16.3cm to 42.9cm (Appendix 3). The tallest plants were recorded in genotype PI 567102B (42.9cm) while the shortest plants were recorded in genotype PI 416826A (16.3cm).

Table 8: Mean squares for plant height across environments at the four sampling dates

Source of Variation	Df	40 DAP	54 DAP	68 DAP	82 DAP
Environment	2	14141.1	19756.0	19788.7	20248.7
Genotypes	159	107.7	209.92***	150.3***	274.9***
Genotype × Env't	318	77.4	126.4	97.7	147.0
L.E.E	433	84.1	132.9	104.4	156.2

Values marked *** are significantly different at probability level 0.001; DAP- Days after planting; L.E.E- Lattice Effective Error

3.6.4.2 Soybean leaf area

There were significant differences in leaf area among the genotypes at 54 DAP, 68 DAP and 82 DAP ($P < 0.001$). There was no significant genotype $\times$ environment interaction at all the sampling dates (Table 9). The leaf area means ranged between 12.7-37.3 cm². The largest leaf area was recorded in genotype PI 628908 (37.3cm²) whereas the lowest leaf area was recorded in genotype PI 416826A (12.7cm²) (Appendix 3).

Table 9: Mean square for leaf area across environments for the four sampling dates

Source of Variation	Df	40 DAP	54 DAP	68 DAP	82 DAP
Environment	2	5278.9	3718.9	2271.3**	1919.0**
Genotype	159	122.73	197.43***	204.9***	254.6***
Genotype $\times$ Env't	304	103.09	98.36	80.61	85.59
L.E.E	438	110.6	104.5	93.3	93.3

Values marked *,*** are significant at probability levels 0.05 and 0.001 respectively, DAP- Days after planting.

3.6.4.3 Soybean grain yield

There were highly significant differences among genotypes in grain yield realized across environments at $P < 0.001$ (Table 10). However there was no significant difference in yield due to the environment $\times$ genotype interaction (Table 10). The highest yield across the three environments was by Namsoy 3 (530kg/ha) whereas the lowest yield was by PI 506764 (196kg/ha) (Table 10). In individual environments, the highest and lowest yielders were PI 567024 (574kg/ha) and PI 567059 (160kg/ha) in Iki Iki A, Namsoy 3 (626kg/ha) and 5.18 (159kg/ha) in Iki Iki B, and PI 626832 (647kg/ha) and PI 59172 (186kg/ha) in NaSARRI, respectively (Table 11). The 10 least GLM damaged genotypes had fairly higher yields ranging between 290-442kg/ha in comparison to yield from the most damaged genotypes that ranged between 200-389kg/ha. PI 615437 (442 kg/ha), which is one of the least damaged genotypes, yielded better than the highest yielder among the commercial varieties, Maksoy 5N (430 kg/ha) (Table 11).

Table 10: Mean square for yield across environments

Source of variation	Df	Yield (kg/ha)
Environment	2	405505*
Genotype	159	26473.1***
Genotype × Env't	318	9915
L.E.E	423	3521.2

Values marked *,*** are significantly different at 0.05 and 0.001 probability level respectively; Env't-environment

3.6.5 Relationship between leaf miner severity and the other traits evaluated across environments

The correlation results for GLM severity and the soybean traits of leaf area, plant height and grain yield are presented in Table 12. There was a negative significant correlation between GLM severity and plant height ($r = -0.182^*$), a positive significant correlation between GLM incidence and leaf area ($r = 0.247^{**}$) and plant height ($r = 0.158^*$). Plant height was positively and highly significantly correlated with leaf area ($r = 0.763^{***}$). There was significant positive correlation between yield and leaf area ($r = 0.187^*$) and plant height ($r = 0.176^*$).

Table 11: Correlation coefficients between GLM severity and plant parameters for the 160 genotypes across three environments over four sampling dates

Traits	GLM %Incidence	Leaf area (cm ²)	Plant height (cm)	GLM Severity	Yield (kg/ha)
%Incidence	1				
Leaf area (cm ²)	0.247**	1			
Plant height (cm)	0.158*	0.763***	1		
Severity	0.081	-0.095	-0.182*	1	
Yield (kg/ha)	-0.045	0.187*	0.176*	-0.058	1

Values marked *, **, *** are significantly different at 0.05, 0.01 and 0.001 probability level respectively

Table 12: Mean yields (kg/ha) across environments

Genotype	Yield (kg/ha)	Genotype	Yield (kg/ha)	Genotype	Yield (kg/ha)
PI 506764	196.9	BSPS 42	297.7	PI 628889	357.8
BSPS 47B	200.9	PI 644103	300.0	PI 605865B	358.3
PI 628863	206.0	PI 567104B	300.7	PI 417503	359.6
PI 417089A	206.5	BSPS 48A-5	301.2	BSPS 48A-19	360.3
PI 416826A	215.4	PI 628903	302.6	3.16	361.4
PI 416810	215.5	PI 628850	304.3	PI 287197	362.1
NGDT 2.15-4	220.7	PI 567123	306.2	PI 567102B	364.2
1882	225.5	PI 628811	307.1	NII GC 4.1-2	366.1
G 2043	235.1	Wondersoy	307.2	PI 628934	371.0
5.18	240.4	PI 628925	308.9	PI 628833	372.1
PI 59172	242.1	NGDT BLP 12.4	310.4	G 32	372.6
PI 200526	243.3	PI 567034	311.0	PI 567025A	376.0
PI 628918	244.7	BSPS 75B	311.1	PI 578457A	377.2
G 50	245.9	PI 628960	312.1	PI 567046A	379.7
12.17	249.9	BSPS 48C	312.4	G8586	380.6
PI 628905	251.4	PI 548360	314.2	PI 605854B	381.0
GC48702-26-3-1	254.1	7.11	315.4	PI 417126	381.3
8527	255.8	PI 605885B	316.9	Kab 1	385.4
PI 567059	257.3	PI 462312	317.1	SRE-B-15C	387.3
AGS 338	257.8	PI 606440A	319.0	PI 471904	387.3
BSPS 62C-1	259.5	PI 417132B	320.0	SCSI	387.9
Kuntz	259.8	BSPS 48A-1	320.3	Siesta	389.1
NGDT 8.11	260.8	BSPS 27A	320.3	PI 459025	391.5
GC 8901-13-13	265.0	PI 628887	320.6	Maksoy 1N	393.2
PI 200488	266.5	PI 417120	320.8	3.7	393.7
DXT 16.6-2	269.7	PI 567190	321.7	4.21	395.2
Maksoy2N	272.7	PI 628830	322.9	PI 628904	399.8
Serenade	274.9	13.2	323.3	3.17	404.5

PI 628812	275.8	PI 635999	326.2	SRE-C-14A	405.8
PI 628907	276.5	16.12	326.9	PI 626832	409.5
G 10427	276.8	Soprano	327.4	PI 628959	412.5
PI 628827	278.3	13.14	329.3	GC 84051-31-1	413.0
PI 628948	279.7	PI 605638	334.5	Santa	417.4
Nam 2	279.9	PI 567189A	336.7	Roan	418.1
BSPS 48A-21B	280.2	PI 606405	339.0	GC 487021-26-3-1	418.4
SRE-D-11-13	280.4	G 7955	339.3	SS 86045-23-2	420.7
PI 628855	280.9	G2843	342.6	PI 417132	426.1
Nam 4M	281.0	11.1	343.0	Nam1	429.2
Maksoy 4N	281.9	PI 506695	343.1	G57	429.3
PI 628915	283.5	PI 506695	343.1	Maksoy 5N	430.4
G 7959	285.3	Duiker	344.1	PI 628813	432.6
AGS 292	287.0	BSPS 24.2A-3	345.1	PI 615437	442.9
PI 628933	287.1	Maksoy 3N	346.9	PI 203398	446.9
PI 628919	288.8	PI 594538A	350.6	NG 14.1-6B	454.7
K-local	290.2	UG5	352.4	6.22	461.0
Nam II x GC 4.1-2	290.3	BSPS 48A-14	353.4	13.2A	462.2
PI 506491	290.8	Safari	354.2	PI 587056A	463.8
PI 476905A	292.4	1.19	354.6	PI 567024	467.5
NGDT 2.15-10	293.3	G 10428	355.4	GC 00138-29	478.7
Dinamri	294.0	10.41	355.4	GC 85037-2-3-54	479.0
PI 567053	294.7	PI 605823	355.8	PI 628908	497.4
PI 628932	295.1	PI 606397B	356.4	Solitaire	517.3
Gazelle	295.9	9.2	357.8	Namsoy 3	530.6
BSPS 182A	297.1				
Mean	333.4	Mean	333.4	Mean	333.4
LSD	113.1	LSD	113.1	LSD	113.1
CV%	29.9	CV%	29.9	CV%	29.9

The regression analysis results for %incidence with leaf area and plant height; and severity with leaf area and plant height are presented in Figures 3 and 4 below. The results showed that plant height and leaf area justified only 6.1% and 2.5% GLM incidence variation, respectively and 3% and 0.9% GLM severity variation, respectively.

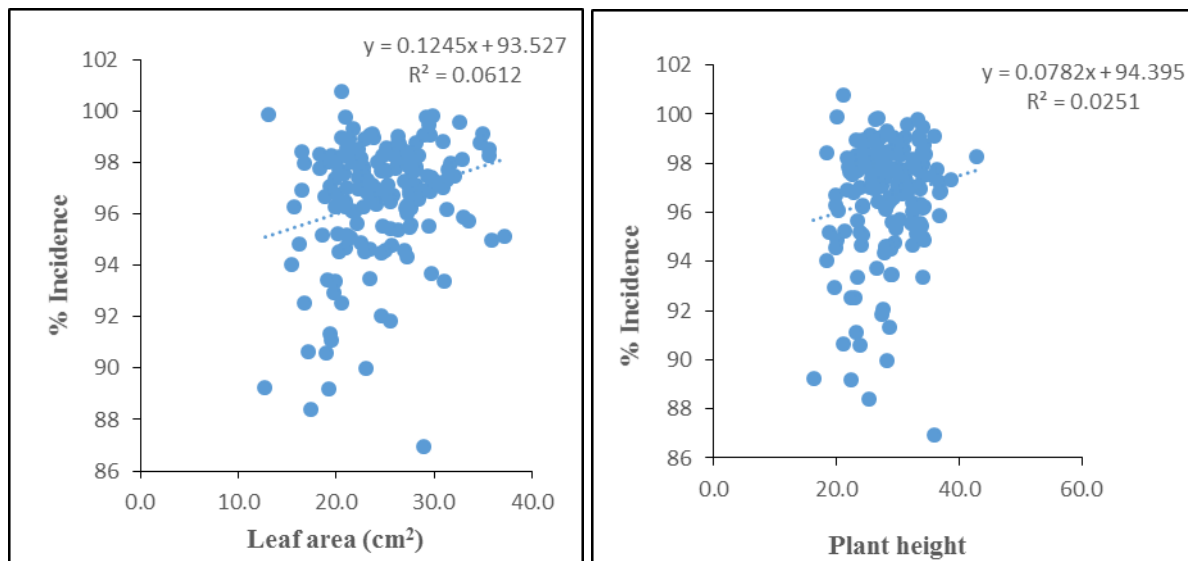


Figure 3: Regression analysis of GLM % incidence as affected by leaf area (left) and plant height (right)

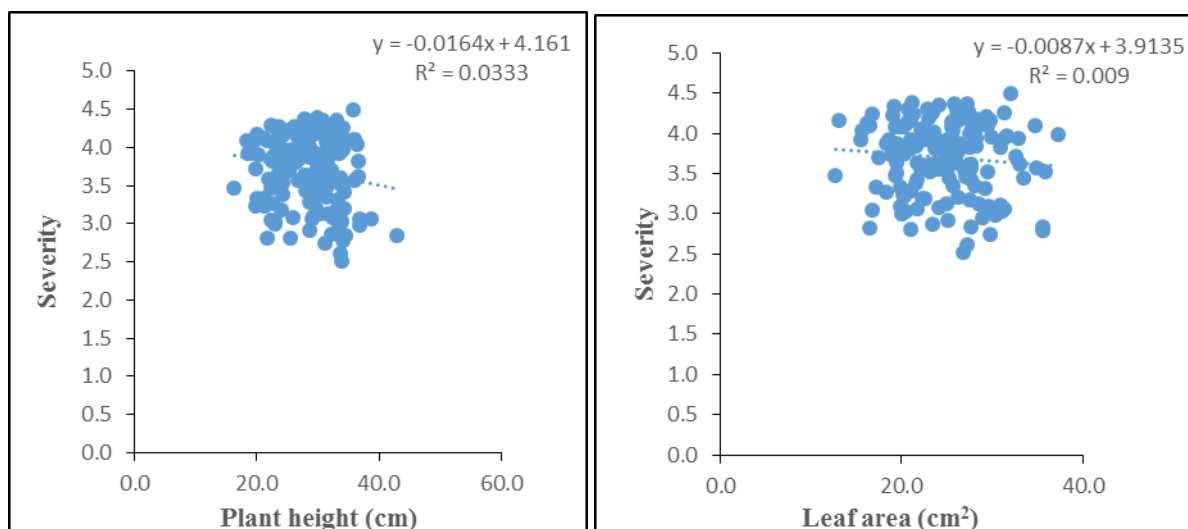


Figure 4: Regression analysis of GLM severity as affected by leaf area (left) and plant height (right)

3.6.6 Relationship of foliage parameters (trichomes, pubescence colour and leaf colour) with GLM severity

There was no statistically significant difference ($P < 0.05$) among genotypes with regard to presence of trichomes, leaf colour and pubescence colour (Table 13).

Table 13: T-test results for the relationship between GLM severity and foliage parameters; trichomes, pubescence colour and leaf colour, for the 160 genotypes evaluated across sampling dates and the 3 environments

Trait	Group	Severity	Variance	Tcalc	Tcrit
Leaf colour	Light green	3.6	1.27	0.37	1.98
	Dark green	3.7	1.16		
Pubescence colour	White	3.8	0.82	0.60	1.98
	Brown	3.7	1.33		
Trichome	Present	3.8	1.28	0.55	1.98
	Absent	3.7	1.10		

3.7 Discussion

None of the genotypes was resistant to GLM attack since all of them sustained mines on their leaves. The highly significant differences among the genotypes in terms of GLM severity and incidence, plant height and leaf area showed genetic variability among the soybean genotypes for these traits. This suggests that there is a possibility to genetically advance breeding for leaf miner resistance using the studied genotypes. These results support earlier reports of Ramani and Lingappa (1988) and Shirale and Uttamrao (2010) who identified soybean lines with varying degrees of GLM resistance, in India.

Pest severity as an indicator for resistance to GLM, using the Praveena et.al (2011b) categorization, showed that the Ugandan commercial varieties were either moderately resistant or susceptible and therefore incorporation of leaf miner resistance in these commercial varieties is very important so as to maintain their high yields. In addition, this grouping showed that there is

a good number of genotypes (11 genotypes) of Ugandan origin that are moderately resistant whose potential can be utilized to improve the susceptible varieties.

Groundnut leaf miner resistance that was exhibited by some of these genotypes was attributed to certain antibiosis or antixenosis mechanisms which were probably absent in the susceptible ones. Plant height and leaf area could have played a role in the resistance displayed by these genotypes because of the significant relationship that was observed between incidence and plant height, and leaf area; and plant height and severity. As such, ovipositing females responded to tall plants with bigger leaves; but severity of larvae damage was higher on shorter plants. This relates to findings of Ihsan-ul-Haq et al. (2003) who reported a positive correlation between soybean looper, *Pseudoplusia includens* (Walker) (Lepidoptera: Noctuidae) infestation with leaf area on soybeans. On the other hand, since severity wasn't correlated to incidence, then most likely, factors other than morphological might have contributed to the GLM resistance.

The non-significant genotype by environment interaction across the environments and sampling dates for severity, percentage incidence, plant height, and leaf area showed that the effect of genotypes wasn't dependent on the environment. Conditions at Iki Iki and NaSARRI had same effect on the genotypes. This implies leaf miner resistance stability among the studied genotypes in the area.

The results of the t-test showed significant difference in the mean GLM severity for the two planting dates. In the second planting at Iki Iki B, GLM reached peak earlier (54 DAP) as compared to first Iki Iki A (68 DAP), but the latter eventually manifested more damaged leaves. This is in contrast to findings by McPherson et al. (2008) and (Harish, 2008) who reported lower insect pest infestation in soybeans planted earlier than those planted later in the season. The higher GLM severity in the earlier planted soybeans is perhaps due to the prolonged favourable environment conditions since the trial was planted at the on-set of rains. However, the results are in line with Lewin et al. (1979), who reported that early sowing led to higher infestation of the GLM. Peak GLM severity during the reproductive stage may have affected the yield because it is reported that foliage feeders, of which the GLM is inclusive, can have a negative effect on yield

incase they cause excessive defoliation during the crop's reproductive stage because the crop is less able to compensate for stress and vegetative damage at this stage (OMAFRA , 2009).

The severity trends with days after planting in this study are somehow in line with the reports by Harish (2008) and Arunachalam and Zadda (2012). The pest severity trends were probably brought about by the prevailing weather factors of relative humidity, temperature and rainfall in the study environments as reported by Arunachalam and Zadda (2012).

The higher yields recorded in the resistant genotypes were most probably due to differences in GLM severity. These present findings are in line with (Harish, 2008) and Praveen et. al (2011b) who reported higher yields in the GLM resistant soybean and groundnut varieties, respectively. On the other hand, moderately high yields were recorded in some of the susceptible genotypes like siesta. This result could be attributed to GLM tolerance, as earlier reported by Rao (2000).

The positive significant correlation between yield and plant height; and yield and leaf area is in agreement with reports of Mansur et al. (1996), Maliki et al. (2007) and Maliki et al. (2011), though the correlation values recorded in this study are low compared to earlier reports by Maliki et al. (2007) and Shamsi and Kobrae (2012). This however contradicts Singh et.al (2000), Maliki et al. (2006) , (El-Badawy & Mehasen, 2012) and (Li, et al., 2013) earlier findings where they reported negative effects of plant height and leaf area on soybean seed yield.

The regression results showed that plant height and leaf area were not major components in GLM % incidence and severity variation. Other factors such as biochemicals which include alkaloids, glycosides, aromatics and acetogenins; biophysical characteristics like thickness or toughness of leaves, stems or roots, tichome type and density are said to be responsible for GLM resistance in groundnut (Sharma, et al., 2003; Mothilal, 2012).

3.8 Conclusions and future prospects

The results indicated a very high incidence of GLM regardless of genotypes. Using GLM severity as an indicator of resistance showed genotypes with appreciable levels of GLM resistance. The GLM resistance and stability portrayed by the high performing genotypes shows that crop improvement for GLM resistance on soybeans is achievable.

Genotypes PI 605638, PI 567056A, PI 506695, PI 605865B, and PI 567123 had relatively low severity scores (2-3) in all the three environments implying that they can be deployed in the breeding program as breeding lines or varieties. Some of the genotypes for example PI 615437 can also be used for yield improvement as they showed a higher yield potential than the Uganda commercial varieties.

Planting date had an effect on leaf miner severity with an initially higher pest incidence in the late planted trial though with more severity damage in the early planted genotypes.

3.9 Recommendations

Further studies should be done to clearly understand the mechanisms of resistance that are exhibited by the resistant genotypes and the heritability of the GLM resistance trait.

The highly susceptible genotypes that were identified can be used as checks or spreaders to increase the pest pressure under natural infestation in the field in case of need to do more screening.

In any further screening studies, either Iki Iki or NaSARRI can be selected for initial screening of the genotypes since both sites had high natural pest pressure.

CHAPTER FOUR

QUANTIFICATION OF YIELD LOSS CAUSED BY THE GROUNDNUT LEAF MINER ON SOYBEANS

4.1 Background

In Africa, GLM is known to occur in Uganda, Mozambique, Malawi, DRC and South Africa (Shanower, et al., 1993). It has been reported to cause severe losses of about 50-100% on groundnut in Mozambique and Uganda (Kenis & Cugala, 2006; Cugala, et al., 2010). Most of the losses caused by GLM have been reported on groundnut. The pest has become a problem on soybean and yet there is lack of information on the yield losses caused by GLM on soybean in Uganda. Therefore a study was done in Eastern Uganda, a key soybean growing area, on six commercial soybean varieties to quantify the yield losses caused by GLM on soybeans.

4.1.1 Study site and materials

Six local commercial soybean varieties, Namsoy 4M, Maksoy 1N, Maksoy 2N, Maksoy 3N, Maksoy 4N and Maksoy 5N were used in this study (Table 14). This study was conducted in season 2013B, in 3 environments namely, Iki Iki A and Iki Iki B, both in Iki Iki sub-county, Budaka district, and at National Semi-Arid Resources Research Institute (NaSARRI) in Serere town council, Serere district. NaSARRI is located at 1°31'N/33°27'E at an altitude of 1,139 m.a.s.l and receives mean annual rainfall and temperature of 1,972 mm and 24°C, respectively. Iki Iki lies at 1°06'N/34°00'E at an altitude of 1,156 m.a.s.l and receives mean annual rainfall and temperature of 1,200 mm and 24.7°C, respectively. In Iki Iki, the trial was repeated by staggered planting and thus Iki Iki A was the first planting (02/09/2013) while Iki Iki B was the second planting (10/10/2013). The staggering was because the pest is only reported to occur in the second growing season. This site was also considered a separate environment. The NaSARRI site was also planted on 10/10/2013.

Table 14: Commercial soybean varieties released in Uganda

Name	Pedigree	Year released
Maksoy 1N	Selection from Tgx 183510E	2004
Maksoy 2N	Duiker × Tgx 183510E	2008
Maksoy 3N	Duiker × GC 00138-29	2010
Namsoy 4M	Nam 2 × GC 00138-29	2004
Maksoy 4N	Duiker × GC 00138-29	2013
Maksoy 5N	Nam II × GC 00138-29	2013

4.1.2 Experimental design

A split plot RCBD was used, with the spray regime as the main plots and the varieties as the sub-plots. Two main treatment levels were used: protected (sprayed) versus un protected (unsprayed). A tank mixture of Cypermethrin (Cyperlacer 5EC), a contact insecticide, and Dimethoate (Tafgor 40EC), a systemic was used to spray the protected plots. This was 10ml of Cypermethrin + 20ml of Dimethoate in 10 litres of water. Spraying was started 14 DAP and continued at weekly intervals up to the crop's physiological maturity. Spraying was done during the morning hours (between 7:00-9:00am), using a knapsack sprayer. The 6 sub-plot treatments (varieties) were replicated 3 times and planted at a spacing of 60cm between rows and 5cm within rows, each with four rows measuring 5m. The replications were separated by an area of 1m apart and 1.8m between the main plots. The experiment was weeded twice, in each of the environments, first at 3 weeks and second at 6 weeks after planting. The experiment was conducted in the field under natural infestation.

4.1.3 Data collection

Severity of damage caused by GLM was recorded using a scale of 1-5 where 1= no damage, 2= 1-20% leaf damage, 3= 21-40% leaf damage, 4= 41-60% leaf damage and 5= 61-100% leaf damage (Praveena, et al., 2011b). The data was recorded from 40 days from planting (Ramani & Lingappa, 1988) and continued at an interval of 14 days for 4 consecutive times. Incidence, which was considered as the number of plants that were infested out of the 10 randomly sampled plants was also recorded. Total seed yield was recorded at harvest in grams per plot and converted to kilograms per hectare using the formula;

$$\text{Soybean yield (kg/ha)} = \frac{\text{Yield (grams)} \times 10,000}{\text{Area harvested (m}^2\text{)} \times 1,000}$$

Yield losses from the leaf miner were estimated as the difference between yield from protected plots versus the yield from un protected plots, expressed as a percentage (Cugala, et al., 2010).

$$\% \text{ Yield loss} = \frac{\text{Yield (protected plot)} - \text{Yield (unprotected plot)}}{\text{Yield (protected plot)}} \times 100$$

4.1.4 Data analysis

Data were subjected to analysis of variance using Genstat 13th Edition computer package and means were separated using Fisher's protected least significant difference (LSD) test at 5% probability level. Cost-benefit analysis was used to calculate the marginal returns (profitability) of the pesticide used following procedures outlined by Karungi et.al (2000) as:

$$\text{Marginal returns} = \frac{\text{Value of yield gain from insecticide treatment}}{\text{Cost of insecticide treatment}}$$

Marginal returns indicate the value of the yield gained from spraying in relation to the cost of the spray schedule. A marginal return value less than one indicates that the increase in soybean yield doesn't compensate the cost of spraying (Karungi, et al., 2000). The costs associated with the spray regime used are shown in Table 15 below.

Table 15: Cost of pesticide application used in calculation of marginal returns

No. of sprays	Item	Cost
1	Pesticide ^a	54,000
	Labour for spraying ^b	60,000
	Labour for harvesting and threshing additional grain	40,000
	Total cost	154,000
5	Additional pesticide	216,000
	Labour for 4 more sprays	240,000
	Labour for harvesting and threshing ^c additional grain ^d	160,000
	Total cost for one spray	154,000
	Total cost	770,000
7	Additional pesticide	324,000
	Labour for 6 more sprays	360,000
	Labour for harvesting and threshing ^c additional grain ^d	240,000
	Total cost for one spray	154,000
	Total cost	1,078,000

Adopted from: (Karungi, et al., 2000)

^aPesticide application rate was estimated at 1 litre per hectare

^bLabour calculated at 1 man-day per ha (this covered knapsack sprayer hire)

^cLabour for harvesting and threshing estimated/ha

^dValue of soybean at the time of research at 1500 Ugshs/kg

4.2 Results

4.2.1 GLM Severity

Across environment analysis showed significant differences among the main factor treatment of spray regimes at all the sampling dates ($P < 0.001$). There were no significant differences in GLM severity among the varieties, treatment by variety, and environment by variety interactions as shown in Table 16.

Table 16: Mean squares for GLM severity across the three environments at four sampling dates

Source of variation	Df	40 DAP	54 DAP	68 DAP	82 DAP
Environment	2	0.025	0.674	0.955	0.500
Treatment	1	97.3***	342.4**	387.2**	402.5**
Environment $\times$ treatment	2	0.025	0.674	0.955	0.500
Variety	5	0.099	0.101	0.030	0.026
Variety $\times$ treatment	5	0.099	0.101	0.030	0.026
Error	60	0.084	0.036	0.017	0.026

Values marked ** and *** are significantly different at 0.01 and 0.001 probability level respectively

There was a sharp increase in the mean GLM severity in the unprotected plots, from 40 DAP to 54 DAP (2.9 to 4.6) after which the rate of increase decreased. On the other hand, the protected plots barely showed any signs of pest infestation and thus had a mean score of 1.0 at all the scoring dates (Fig. 5 and 6).

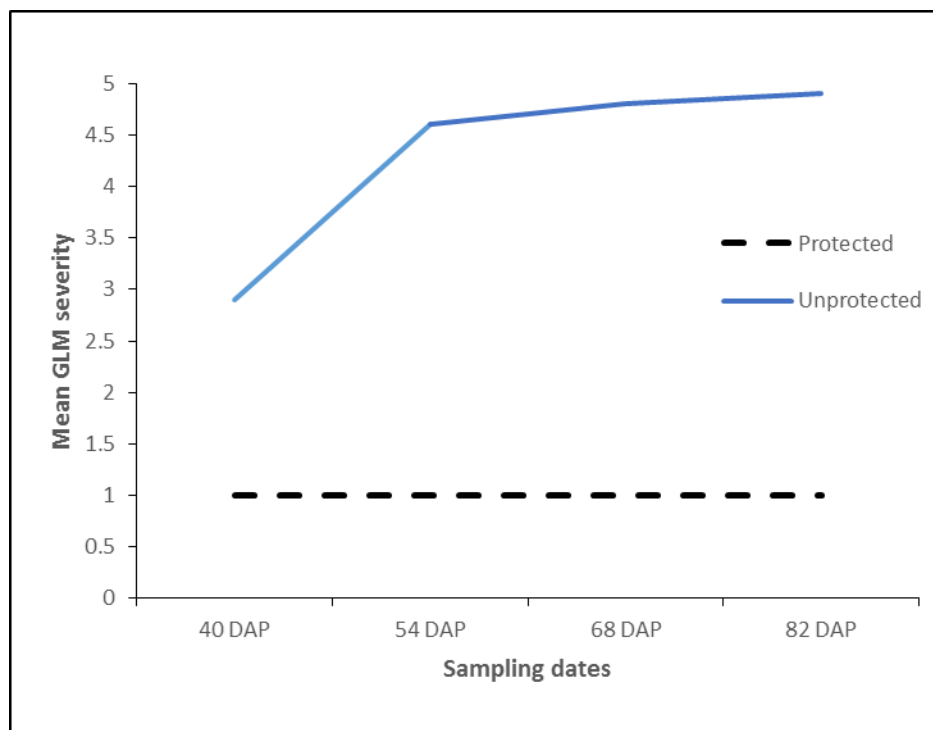


Figure 5: GLM severity means of protected vs. unprotected plots across environments for the four sampling dates (DAP= Days after Planting)



Figure 6: Unprotected (left) and protected (right) soybean fields at a leaf miner hot spot, NaSARRI, Uganda at 68 DAP

4.2.2 Leaf area

There were significant differences in leaf area among the genotypes at all the sampling dates ($P < 0.05$). There were no significant differences between treatments, environment by variety, and treatment by variety interactions. Highest variance among the varieties was recorded at 68 DAP (Table 17). On average, Maksoy 5N had the largest leaf area (38 cm^2) among all the varieties whereas Maksoy 4N had the least (26.9 cm^2) (Table 18).

Table 17: Mean squares for leaf area across the environments for the four sampling dates

Source of variation	d.f.	40 DAP	54 DAP	68 DAP	82 DAP
Environment	2	10201.2	12790.5	7553.6	11867.3
Treatment	1	32.0	91.6	133.4	4.2
Environment $\times$ treatment	2	90.4	151.0	229.8	150.2
Variety	5	469.5**	401.1*	341.4*	385*
Error	60	57.3	75.3	52.0	108.7

Values marked * and ** are significantly different at 0.05 and 0.01 probability level respectively

Table 18: Mean leaf area of varieties across environments for the four sampling dates

Variety	Sampling dates				Mean
	40 DAP	54 DAP	68 DAP	82 DAP	
Maksoy 4N	25.8	26.5	27.0	28.2	26.9
Maksoy 2N	25.9	28.3	28.8	31.1	28.5
Maksoy 3N	33.8	35.1	34.6	38.6	35.5
Maksoy1N	36	35.2	35.4	38.1	36.2
Namsoy 4M	34.7	34.2	37.9	35.9	35.7
Maksoy 5N	37.3	39.0	35.9	39.8	38.0
Mean	32.2	33.0	33.2	35.3	33.5
LSD	6.7	7.1	7.3	6.2	6.8
%CV	27.9	29.0	29.7	23.6	27.6

LSD is Least significant difference for varieties down column at 5% probability level

4.2.3 Soybean grain yield and %yield loss

Significant differences in yield were observed among the treatments, environments, environment by treatment interaction ($P < 0.01$), and environment by variety interaction ($P < 0.05$). There were no significant differences in yield among varieties and treatment by variety interaction (Table 19).

Table 19: Mean squares for yield for treatments and varieties across environments

Source of variation	Df	MS Yield
Environment	2	814188***
Treatment	1	2177586*
Environment $\times$ treatment	2	79913**
Variety	5	113994
Variety $\times$ environment	10	39147*
Environment $\times$ treatment $\times$ variety	10	11663
Error	60	23127

MS- mean square; Values marked *, **, *** are significantly different at 0.05, 0.01 and 0.001 probability level respectively

Maksoy 4N (451 kg/ha) gave the highest yield across the environments, whereas the lowest yielder was Maksoy 5N (388 kg/ha). The mean yield across environment from the protected and un protected plots was 568 kg/ha and 284 kg/ha respectively. The yield of protected plots was always higher than that from the unprotected plots (Table 20).

The highest yield was recorded in NaSARRI (788Kg/ha) on protected plants whereas the lowest yield was recorded in Iki Iki A (175.3kg/ha) on unprotected plants. Iki Iki A had both the least yields in the protected and un protected plots among the environments whereas NaSARRI had the highest yield both in the protected and un protected plots. Maksoy 5N had the lowest yield whereas Maksoy 4N gave the highest yield across environments (Table 20).

Table 20: Table showing the mean yield (kg/ha) from the protected versus unprotected plots between varieties and within each of the environments

Variety	Iki Iki A		Iki Iki B		NaSARRI		Overall mean yield (kg/ha)
	Prot	Unprot	Prot	Unprot	Prot	Unprot	
Maksoy 1N	406	144	593	222	618	407	398
Maksoy 2N	327	124	368	274	998	438	422
Maksoy 3N	395	186	530	294	769	516	448
Namsoy 4M	408	273	392	216	864	534	448
Maksoy 4N	594	152	537	269	822	333	451
Maksoy 5N	435	173	510	396	657	160	388
Mean	427.5	175.3	488.3	278.5	788.0	398.0	425.8
LSD	162.2	95.8	118.2	118.2	254.1	250.8	20.6
%CV	36.1	52.0	23.0	40.4	30.7	60.0	27.6

LSD is Least significant difference for varieties down column at 5% probability level; Prot = Protected

Protecting the soybeans with chemical treatments had an increasing effect on yield. There was yield increase of 53.1% in Iki Iki A, 39.8% in Iki Iki B, and 49.1% at NaSARRI. Average percentage yield losses ranged from 38.9-53.9% (Table 21). The highest yield loss across environments was recorded in Maksoy 4N (53.9%) and the lowest in Namsoy 4M (38.9%).

Table 21: Percentage yield losses among varieties within and across environments

Variety	% yield losses			Overall % Yield loss
	Iki Iki A	Iki Iki B	NaSARRI	
Maksoy1N	62.4	62.3	32.9	52.5
Maksoy 2N	58.6	23.2	56.1	46.0
Maksoy 3N	49.9	43.5	31.3	41.6
Namsoy 4M	34.9	42.2	39.8	38.9
Maksoy 4N	56.7	45.9	59.2	53.9
Maksoy 5N	56.0	21.7	75.4	51.0
Mean	53.1	39.8	49.1	47.3
LSD	17.8	27.8	31.6	19.4
%CV	32.0	66.6	61.3	39.0

LSD is Least significant difference for varieties down column at 5% probability level; Prot = Protected

The yield gain from the protected over the unprotected and marginal returns are shown in Table 22. Marginal returns from Iki Iki A, Iki Iki B and NaSARRI were 0.6, 0.68, and 1.1, respectively. As such, the marginal returns from chemical use were unprofitable in Iki Iki A and Iki Iki B (Table 22).

Table 22: Mean grain yields and marginal returns for the protected vs. unprotected for the three environments

Env't	Pesticide protection	Yield (kg/ha)	Yield gain over Control (kg/ha)	Value of yield gain (Ug shs)/ha	Cost of spray (Ug shs)/ha	Marginal returns/ Profitability
Iki Iki A	Unprotected	175.0				
	Protected	427.5	252.5	641,250	1,078,000	0.6
	LSD	50.8				
Iki Iki B	Unprotected	279.0				
	Protected	488.0	171.5	732,000	1,078,000	0.68
	LSD	57.3				
NaSARRI	Unprotected	398.0				
	Protected	788.0	390.0	1,182,000	1,078,000	1.10
	LSD	117.2				
Across Env't	Unprotected	284.0				
	Protected	568.0	271.4	852,000	1,078,000	0.8
	LSD	47.4				

LSD is Least significant difference; Env't is environment; Protected plots were sprayed 7 times in each of the environments

4.2.4 Correlation among the traits evaluated (Plant height, leaf area, grain yield, % Incidence and severity).

The results of correlation between GLM severity and other soybean traits are presented in Table 23. There was a highly significant positive correlation between severity and % incidence ($r = 0.985^{***}$), highly significant negative correlation between severity and grain yield ($r = -0.546^{***}$), and incidence and grain yield ($r = -0.557^{***}$). Significant positive correlation between plant height and leaf area ($r = 0.462^{***}$) and a significant negative correlation between leaf area and yield ($r = -0.207^*$) (Table 23).

Table 23: Correlations between GLM severity, % incidence, leaf area, plant height and yield for the six varieties for protected versus unprotected plots.

Traits	%Incidence	Severity	Leaf area (cm ²)	Plant height (cm)	Yield (kg/ha)
% incidence	1				
Severity	0.985***	1			
Leaf area (cm ²)	-0.048	-0.112	1		
Plant height (cm)	-0.015	-0.051	0.462***	1	
Yield (kg/ha)	-0.557***	-0.546***	-0.207*	0.146	1

Regression analysis results for yield with leaf area and plant height and yield with severity and incidence are presented in Figures 7 and 8 below. The results showed that leaf area and plant height accounted for 11.1% and 24.5% variation observed in yield respectively while GLM % incidence and severity accounted for 11.9% and 26.7% variation observed in yield.

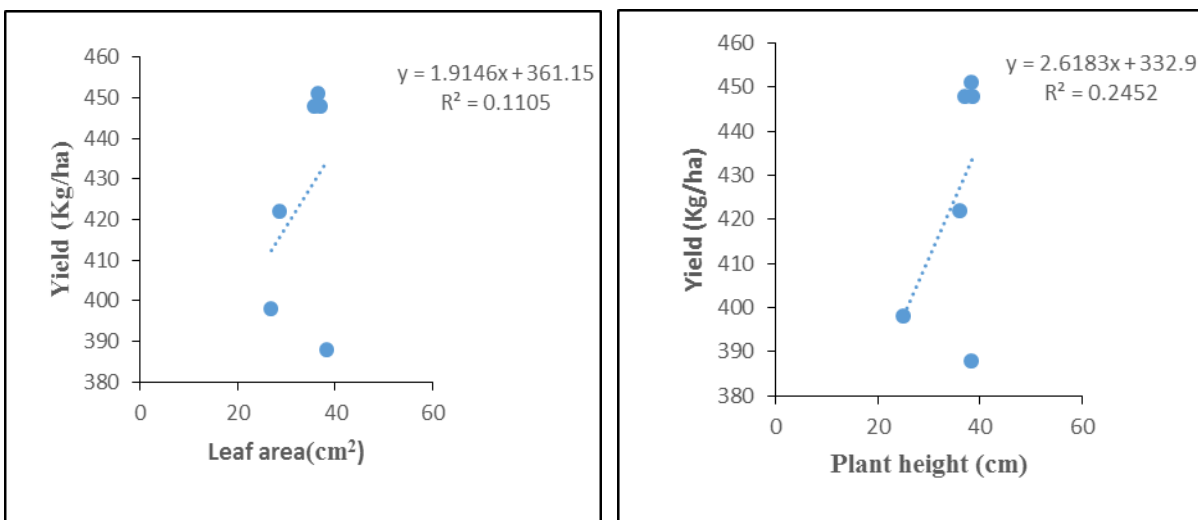


Figure 7: Regression analysis of yield as affected by leaf area (left) and plant height (right)

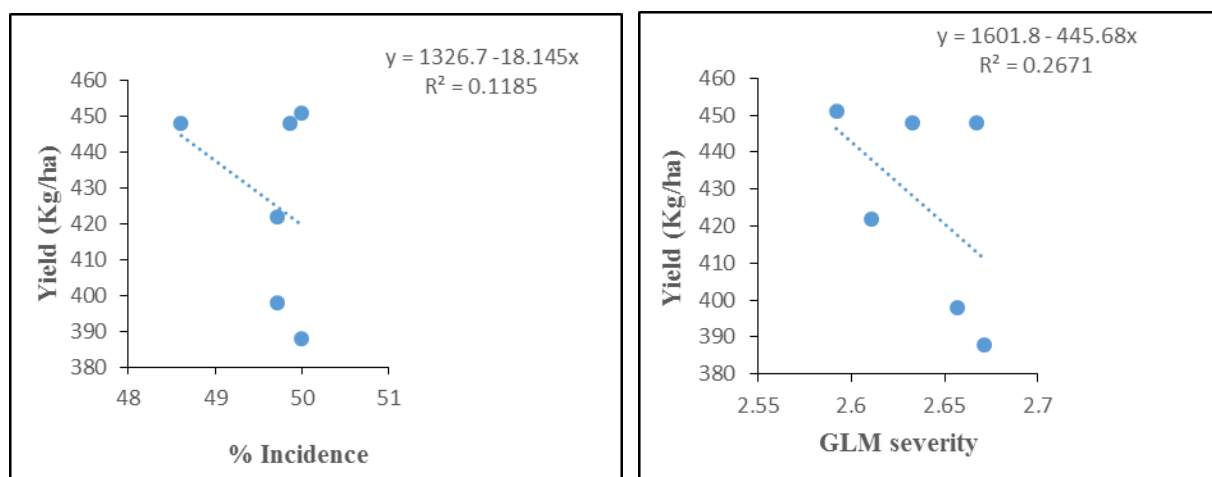


Figure 8: Regression analysis of yield as affected by GLM % incidence (left) and GLM severity (right)

4.3 Discussion

The significant differences among the varieties in terms leaf area across environments indicates genetic differences among the varieties. This variation among these genotypes is very important for soybean breeding and selection (Maliki, et al., 2011). Significantly higher GLM incidence and severity were recorded in the unprotected plots as compared to the protected plots. These results are in line with findings by Cugala et al. (2010) who reported low GLM populations in the cypermethrin protected groundnut plots as compared to the unprotected plots, and earlier by Umesh and Krishna (1997) who also reported significantly higher infestation level of GLM in the untreated soybean in relation to the treated soybean. Significantly higher yields were recorded in the protected plots as compared to the unprotected plots which concurs with Umesh and Krishna (1997). Shanower et al. (1995) and Marwoto et al. (1996) also reported higher yield in the treated groundnut as opposed to the untreated. Spraying a tank mixture of cypermethrin and dimethoate was effective in control of the GLM as severity was maintained at 1.0 (0% leaf damage) in this study. The absence of the GLM in the protected plots indicated effectiveness of the pesticide spray which kept the GLM population in the protected plots under check leading to a higher yield in the protected plots. Several other studies have reported the effectiveness of dimethoate and cypermethrin in the control of GLM on groundnut (Umesh & Krishna, 1997; Munyuli, et al., 2003; Epieru, 2004; Cugala, et al., 2010).

Results showed marginal returns 0.6, 0.65 and 1.1 at Iki Iki A, Iki Iki B and NaSARRI, respectively; from pesticide use suggesting that use of chemicals to control the GLM in this study was only cost effective at NaSARRI as per the guidelines of Karungi et al. (2000). However use of chemical spray in Iki Iki A and Iki Iki B wasn't cost effective. This implies that profitability from pesticide use in this study was environment dependent. This may be explained by the interaction between treatment and environment due to the differences in these environments and genotype response across these environments. Soil factors could have also played a role (Cox, et al., 2003). However, soil properties were not investigated in this study. In addition, number of sprays could be reduced and spraying done at the time when its mostly effective during the crop's growth stages in order to increase on profitability (Karungi, et al., 2000).

The high GLM severity scores and yield losses in all the varieties proved that GLM infestation can get to very high population densities causing serious economic damage to soybeans in the study area. All the available commercial varieties are prone to damage by the GLM albeit to varying degrees. The results showed that the varieties yielded differently across environments though each faced and maintained similar yield losses across environments. The yield losses obtained among the soybean varieties in this study were in the ranges of 38.9-53.9%, relatively low as compared to the 60% to 86.2% reported by Cugala et al. (2010) and Shanower et al. (1993) on groundnuts in Mozambique and India, respectively. This maybe explained by the genotypes used as well as the environmental conditions in the study environments. Though lower than reported on groundnuts, the level of loss is still quite high for successful soybean production and hence effective management strategies are critical to promote productivity.

The negative correlation between yield with GLM incidence and severity indicated that the pest caused substantial reductions in yield to justify interventions for control. This implied that the higher the severity and incidence, the lower the yield. These results are in line with Kalayanasundaram and Murugesan (1989) who reported a corresponding decrease in soybean yield ranging between 40% to 66% with an increase in *A.modicella* larval population.

The regression results showed that plant height, leaf area, GLM % incidence and severity were to some extent components in the soybean yield. Other yield componets like pods per plant, seeds per pod, seeds per plant, seed size, leaves per plant and plant biomass could have explained the rest of the variation but these were not measured in this study (Mehmet, et al., 2009; Maliki, et al., 2011; Li, et al., 2013; Ali, et al., 2013).

4.4 Sectional conclusion

The study showed that the GLM can cause upto 50% yield losses in the commercial soybean varieties in Uganda, thus the soybean breeding program has the task to address this constraint, so as to avoid these great losses. All the varieties used in this study sustained yield losses from GLM damage. This damage could be alleviated by treatment with a mixture of cypermethrin and dimethoate. In addition, higher yields were recorded from the protected plots compared to the unprotected plots.

4.5 Recommendations

Breeding should be directed to develop GLM resistant soybean varieties since all the available commercial varieties are susceptible.

The use of chemicals was very effective in controlling the pest, although costly, and thus can be included in integrated GLM management strategies. It is very necessary to identify the appropriate crop's phenological stage for pesticide application in order to ensure high marginal returns.

Groundnut leaf miner accounted for 38.9-53.9% yield variation hence other factors could be in play and should be investigated.

CHAPTER FIVE

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 General Discussion

Being an oligophagous pest on leguminous crops, GLM is moving from groundnut to soybean probably because of the intense spraying done to control this pest on groundnut. It has been proven that this pest can get to very high densities and cause severe damage that leads to significant yield losses in soybean as per the findings in this study. As such, interventions are needed in order to avoid total abandonment of the crop by the farmer due to the enormous crop losses incurred. Although use of chemicals was very effective in eliminating the GLM in the control experiment, the study showed that it can be associated with high costs making it unaffordable by the resource-constrained farmers as well as unprofitable if many sprays are to be used. In order to reduce the numbers of chemical sprays to profitable levels, integration with host-plant resistance could be a cheaper means to address this pest among the resource-constrained farmers. Breeding for resistance to GLM in soybeans is feasible since some moderately resistant and stable genotypes were identified in this study and thus can be utilized to introgress and improve GLM resistance in the already high yielding commercial varieties. Genotype performance in terms of resistance is dependent on different pest resistance mechanisms that range from antixenosis to antibiosis and thus can be exploited among these genotypes.

5.2 Conclusion

This study was conducted with an ultimate goal of contributing to development of soybean varieties with resistance to the GLM. The first experiment was aimed at identifying sources of resistance to the GLM among diverse soybean accessions. Results revealed that all the 160 genotypes screened in this study sustained damage from GLM. However, 43 moderately resistant genotypes were identified and these can be utilized to introgress resistance in the commercial varieties that were found to be susceptible to the GLM.

The second study was directed to identifying yield losses caused by the GLM among the commercial soybean varieties. Significant yield losses ranging from 38.9 -53.9% were recorded in

the unprotected plots and were attributed to GLM damage. These yield losses varied among the varieties.

Profitability of pesticide protection for GLM management was dependent on the environment in this study.

5.3 Recommendations

The moderately resistant varieties should be further screened to identify the tolerant ones that can be used to improve the commercial varieties

Studies to identify the mechanisms of resistance and mode of inheritance of GLM resistance among these genotypes should be done

Studies to develop options to integrate with chemical sprays to reduce number of sprays needed to control GLM could be explored

In addition, the stage of crop development at which the pest has the most effect on yield needs to be identified.

Studies to identify the behavior, seasonal occurrence and distribution of GLM should be conducted as this is very vital in managing and controlling the pest.

In case of further screening work, initial screening can be done in one of the environments since there was no significant G×E at the best scoring date that was identified to have the most variance among the genotypes at all the scoring dates.

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Appendix

Appendix 1: Mean GLM % Incidence and severity across the three environments for the four different sampling dates

Genotype	% Incidence					Genotype	Severity				
	40 DAP	54 DAP	68 DAP	82 DAP	Mean		40 DAP	54 DAP	68 DAP	82 DAP	Mean
BSPS 48A-1	99	82	83	83	87	BSPS 48C	1.9	2.5	3.0	2.7	2.5
S 5.18	88	93	84	88	88	4.21	1.9	2.6	3.3	2.7	2.6
Soprano	88	92	85	92	89	PI 615437	1.9	2.7	3.3	3.2	2.7
PI 416826A	69	97	92	100	89	PI 644103	2.0	2.6	3.1	3.4	2.8
SRE-C-14A	68	96	96	100	90	PI 605638	2.0	3.1	3.0	3.2	2.8
PI 605885B	84	88	90	100	91	PI 567034	1.9	2.7	3.4	3.3	2.8
8527	80	94	89	100	91	PI 567102B	2.0	2.6	3.5	3.2	2.8
SCSI	100	93	83	88	91	NII GC 4.1-2	2.0	2.7	3.4	3.3	2.8
PI 567123	76	89	100	100	91	PI 578457A	1.7	2.9	3.6	3.2	2.9
PI 567189A	77	96	94	100	92	PI 605865B	2.1	3.3	3.2	3.1	2.9
PI 417126	79	91	98	100	92	Namsøy 3	1.9	2.8	3.9	3.2	3.0
PI 416810	80	90	100	100	93	6.22	2.1	2.9	3.4	3.5	3.0
PI 417089A	86	92	92	100	93	AGS 292	1.9	2.9	3.7	3.6	3.0
G 2043	77	94	100	100	93	Maksoy3N	1.9	2.6	3.7	3.9	3.0
Maksoy3N	88	92	95	98	93	PI 416810	1.9	3.1	3.7	3.5	3.0
PI 567190	95	80	99	100	93	PI 417089A	2.1	3.0	3.4	3.7	3.1
S 10.41	80	95	98	100	93	Maksoy 5N	2.1	3.2	3.7	3.2	3.1
PI 587056A	81	96	96	100	93	PI 567046A	2.2	3.1	4.1	2.9	3.1
PI 628830	98	94	83	100	94	PI 628811	2.1	3.1	3.4	3.7	3.1
PI 506491	81	95	100	100	94	Nam 2	2.0	3.1	3.6	3.6	3.1
Siesta	90	87	100	100	94	PI 506695	2.1	3.1	3.5	3.7	3.1
SRE-D-11-13	86	92	100	100	95	12.17	2.1	3.6	3.6	3.1	3.1

PI 605854B	86	92	100	100	95	13.2	2.1	2.9	3.8	3.7	3.1
PI 626832	89	93	96	100	95	PI 628925	2.1	3.3	3.7	3.4	3.1
G 10427	88	92	99	100	95	BSPS 48A-21B	2.0	3.1	3.9	3.6	3.1
PI 605865B	80	99	99	100	95	BSPS 24.2A-3	2.0	3.3	3.7	3.7	3.2
PI 578457A	84	95	100	100	95	PI 628918	2.2	3.1	3.7	3.8	3.2
PI 628933	99	97	93	90	95	BSPS 75B	2.1	3.0	4.0	3.6	3.2
GC 84051-31-1	84	96	100	100	95	16.12	2.2	3.1	3.9	3.6	3.2
PI 200488	93	86	100	100	95	PI 605854B	2.0	3.4	3.8	3.7	3.2
BSPS 75B	96	84	99	100	95	PI 628903	2.1	3.3	3.9	3.6	3.2
UG5	90	93	97	100	95	AGS 338	1.9	2.8	4.2	4.1	3.3
PI 628813	85	95	100	100	95	PI 567053	2.2	3.3	3.9	3.7	3.3
PI 628908	84	97	100	100	95	BSPS 62C-1	2.0	3.1	4.1	4.1	3.3
Solitaire	96	94	90	100	95	8527	2.0	3.1	4.1	4.1	3.3
PI 506695	87	97	97	100	95	G 50	2.2	3.3	4.2	3.8	3.3
PI 628903	88	93	100	100	95	GC 84051-31-1	2.3	3.1	4.3	3.7	3.3
S 16.12	90	93	98	100	95	G 10428	2.1	3.2	4.0	4.2	3.4
NGDT 8.11	100	98	83	100	95	PI 628813	2.1	3.2	4.2	4.0	3.4
BSPS 24.2A-3	100	95	86	100	95	1.19	2.3	3.4	4.1	3.9	3.4
Kab 1	90	94	98	100	96	Nam1	2.2	3.4	4.2	4.0	3.4
NG 14.1-6B	85	98	99	100	96	G2843	2.1	3.4	4.2	4.1	3.4
S 13.2A	91	91	100	100	96	NGDT BLP 12.4	2.2	3.2	4.3	4.0	3.4
1882	90	99	95	98	96	PI 567025A	2.2	3.6	4.4	3.7	3.5
G2843	83	100	99	100	96	PI 416826A	1.8	3.4	4.4	4.3	3.5
G8586	88	98	98	100	96	Soprano	2.0	3.0	4.5	4.4	3.5
PI 567104B	87	97	100	100	96	PI 567059	2.2	3.4	4.3	4.1	3.5
PI 200526	93	94	98	100	96	UG5	2.1	3.4	4.5	4.0	3.5
Nam1	93	94	97	100	96	NG 14.1-6B	2.0	3.9	4.2	3.9	3.5
PI 567024	87	98	100	100	96	PI 462312	2.5	3.7	4.1	3.8	3.5
S 1.19	88	100	96	100	96	SRE-C-14A	2.4	3.6	4.3	3.9	3.5
PI 462312	93	93	99	100	96	Dinamri	2.4	3.5	4.3	3.9	3.5

PI 506764	91	94	100	100	96	G 10427	2.2	3.4	4.3	4.3	3.5
G 50	91	96	98	100	96	1882	2.3	3.6	4.2	4.1	3.5
NGDT 2.15-4	100	86	99	100	96	PI 606405	2.3	3.4	4.2	4.3	3.6
SS 86045-23-2	92	96	98	100	96	13.2A	2.9	3.6	4.2	3.7	3.6
S 4.21	98	88	99	100	96	Nam 2 x GC 4.1-2	2.3	3.7	4.4	3.9	3.6
Nam 2	93	94	98	100	96	GC 85037-2-3-54	2.4	3.7	4.2	4.0	3.6
Roan	94	92	99	100	96	SRE-D-11-13	2.1	3.4	4.3	4.5	3.6
PI 567053	92	96	98	100	96	PI 417503	2.3	3.4	4.2	4.5	3.6
GC 8901-13-13	94	97	96	100	97	3.17	2.3	3.3	4.5	4.3	3.6
PI 471904	89	97	100	100	97	NGDT 2.15-10	2.2	3.5	4.4	4.3	3.6
PI 59172	87	100	100	100	97	BSPS 48A-19	2.3	3.5	4.2	4.4	3.6
K-local	97	94	97	100	97	PI 417126	2.3	3.4	4.5	4.2	3.6
AGS 292	92	95	100	100	97	Santa	2.6	3.8	4.0	4.2	3.6
Serenade	96	92	100	100	97	PI 459025	2.6	3.6	4.1	4.2	3.6
BSPS 48A-21B	98	89	100	100	97	PI 587056A	2.5	3.6	4.0	4.4	3.6
S 3.7	90	97	100	100	97	G8586	2.5	3.6	4.2	4.2	3.6
BSPS 182A	91	97	99	100	97	SCSI	2.3	3.7	4.3	4.2	3.6
PI 567046A	90	99	99	100	97	BSPS 42	2.4	3.4	4.5	4.3	3.6
PI 567034	91	100	97	100	97	Gazelle	2.1	3.4	4.5	4.5	3.6
PI 203398	92	97	99	100	97	5.18	2.4	3.6	4.4	4.3	3.7
S 3.17	95	94	99	100	97	Kab 1	2.4	4.0	4.2	4.3	3.7
PI 628918	93	94	100	100	97	Maksoy 4N	2.5	3.8	4.5	4.1	3.7
PI 606405	91	98	100	100	97	PI 59172	2.5	4.0	4.4	4.0	3.7
PI 605638	89	99	100	100	97	PI 628855	2.5	4.1	4.2	4.1	3.7
S 13.2	99	90	99	100	97	Wondersoy	2.0	4.0	4.6	4.4	3.8
SRE-B-15C	100	93	94	100	97	PI 628905	2.1	3.7	4.6	4.7	3.8
G 7959	91	98	100	100	97	PI 567190	2.8	3.6	4.5	4.3	3.8
PI 628919	87	101	100	100	97	G 7959	2.6	3.7	4.6	4.4	3.8
Wondersoy	101	93	94	100	97	Duiker	2.3	3.8	4.6	4.6	3.8
S 6.22	100	91	98	100	97	Serenade	2.1	3.7	4.8	4.6	3.8

PI 567025A	94	97	98	100	97	Solitaire	2.4	4.1	4.7	4.2	3.8
S 9.2	95	95	100	100	97	Roan	2.6	3.7	4.6	4.4	3.8
Maksoy 5N	96	95	98	100	97	PI 606397B	3.0	3.8	4.4	4.2	3.8
PI 506695	90	99	100	100	97	PI 628889	2.4	3.8	4.7	4.5	3.8
BSPS 48A-19	96	97	97	100	97	PI 628919	2.1	3.8	4.6	4.7	3.8
PI 615437	92	98	100	100	97	Maksoy 1N	2.4	3.8	4.4	4.7	3.8
PI 605823	95	96	100	100	97	PI 594538A	2.4	4.2	4.8	3.9	3.8
Nam 4M	97	93	100	100	97	G 32	2.6	3.6	4.7	4.5	3.9
PI 628934	96	95	100	100	98	PI 567123	2.3	4.3	4.6	4.3	3.9
Santa	97	94	100	100	98	PI 628934	2.3	3.9	4.7	4.7	3.9
GC48702-26-3-1	97	97	97	100	98	PI 606440A	2.7	3.8	4.6	4.5	3.9
PI 287197	94	96	100	100	98	PI 635999	2.5	4.1	4.4	4.4	3.9
GC 85037-2-3-54	93	98	100	100	98	PI 628959	2.8	3.9	4.4	4.5	3.9
548360	95	97	99	100	98	PI 200526	2.5	3.9	4.6	4.5	3.9
PI 628855	99	93	99	100	98	PI 628887	2.2	3.9	4.7	4.7	3.9
S 13.14	94	99	98	100	98	548360	2.4	3.8	4.8	4.7	3.9
G 10428	93	97	100	100	98	PI 476905A	2.6	4.0	4.6	4.4	3.9
Dinamri	92	98	100	100	98	9.2	2.4	4.3	4.5	4.4	3.9
BSPS 27A	94	97	100	100	98	Safari	2.7	3.8	4.8	4.4	3.9
11.1	93	98	100	100	98	PI 506695	2.4	3.8	4.8	4.7	3.9
PI 628904	97	98	96	100	98	PI 506491	2.6	3.9	4.7	4.5	3.9
AGS 338	97	94	100	100	98	3.7	2.3	4.0	4.7	4.7	3.9
PI 417503	94	97	100	100	98	Maksoy2N	2.6	3.9	4.5	4.7	3.9
PI 628959	95	96	100	100	98	PI 417132	2.8	4.1	4.5	4.3	3.9
PI 628850	99	96	96	100	98	GC 487021-26-3-1	2.8	3.8	4.7	4.4	3.9
GC 00138-29	98	94	100	100	98	13.14	2.5	4.3	4.5	4.6	4.0
PI 417120	92	100	100	100	98	7.11	2.5	4.4	4.7	4.2	4.0
Duiker	93	99	100	100	98	GC 00138-29	2.8	4.1	4.7	4.3	4.0
BSPS 47B	98	96	98	100	98	GC48702-26-3-1	2.8	3.8	4.6	4.7	4.0
PI 628889	96	99	97	100	98	PI 628907	2.6	4.1	4.3	4.9	4.0

GC 487021-26-3-1	95	98	100	100	98	PI 628908	2.7	4.0	4.8	4.4	4.0
Gazelle	99	96	98	100	98	3.16	2.9	4.2	4.7	4.2	4.0
NGDT 2.15-10	96	96	100	100	98	PI 471904	2.6	4.0	4.8	4.7	4.0
PI 628833	95	98	100	100	98	PI 628812	2.2	4.1	4.9	4.8	4.0
BSPS 48A-5	95	99	98	100	98	PI 506764	2.5	3.9	4.9	4.8	4.0
PI 628887	93	99	100	100	98	BSPS 27A	2.7	4.2	4.7	4.5	4.0
PI 628863	94	99	100	100	98	BSPS 48A-5	2.6	4.3	4.7	4.7	4.1
PI 628905	95	100	99	100	98	PI 628904	2.4	4.3	4.9	4.7	4.1
PI 567102B	93	100	100	100	98	BSPS 182A	3.0	4.3	4.8	4.2	4.1
PI 594538A	97	97	99	100	98	G 2043	3.0	3.9	4.7	4.7	4.1
PI 628925	96	97	99	100	98	NGDT 8.11	3.0	4.2	4.7	4.5	4.1
PI 567059	94	99	100	100	98	SRE-B-15C	2.8	4.1	4.8	4.6	4.1
PI 606440A	99	94	100	100	98	PI 628863	2.9	4.1	4.7	4.6	4.1
PI 628812	96	97	100	100	98	PI 628827	2.9	4.3	4.7	4.5	4.1
BSPS 48C	94	99	100	100	98	DXT 16.6-2	2.6	4.5	4.7	4.6	4.1
S 3.16	98	97	98	100	98	G57	2.4	4.1	5.0	4.9	4.1
NII GC 4.1-2	99	96	98	100	98	BSPS 48A-1	3.0	4.5	4.7	4.3	4.1
PI 628811	95	98	100	100	98	PI 417132B	2.6	4.1	4.8	4.9	4.1
PI 628827	97	97	100	100	98	PI 200488	3.1	4.2	4.7	4.5	4.1
NGDT BLP 12.4	94	100	100	100	98	PI 567189A	2.7	4.5	4.8	4.7	4.1
PI 628915	99	94	100	100	99	PI 605823	2.7	4.6	4.9	4.5	4.2
PI 644103	96	98	100	100	99	SS 86045-23-2	3.0	4.3	4.7	4.5	4.2
PI 628907	96	98	100	100	99	G 7955	2.7	4.4	5.0	4.6	4.2
PI 628948	96	98	100	100	99	PI 628830	2.5	4.5	4.7	4.9	4.2
Safari	96	99	99	100	99	Kuntz	3.3	4.2	4.7	4.5	4.2
PI 628960	97	98	100	100	99	PI 628933	2.8	4.2	4.8	4.8	4.2
G57	97	98	100	100	99	11.1	2.9	4.5	4.6	4.7	4.2
PI 635999	96	98	100	100	99	GC 8901-13-13	2.9	4.7	4.7	4.5	4.2
PI 417132	96	99	100	100	99	PI 567104B	2.6	4.3	4.9	4.9	4.2
PI 606397B	96	99	100	100	99	PI 628960	3.0	4.4	4.8	4.6	4.2

PI 628932	97	100	99	100	99	PI 626832	2.9	4.2	4.8	4.9	4.2
Maksoy2N	99	98	99	100	99	PI 203398	2.8	4.3	4.9	4.9	4.2
PI 459025	98	99	99	100	99	PI 605885B	2.8	4.5	4.9	4.8	4.2
G 32	99	97	100	100	99	PI 628932	2.9	4.4	4.9	4.7	4.2
G 7955	98	98	100	100	99	PI 417120	2.6	4.6	4.9	4.8	4.2
BSPS 48A-14	100	96	99	100	99	BSPS 48A-14	3.2	4.1	4.9	4.9	4.3
S 12.17	98	99	100	100	99	PI 567024	3.2	4.3	4.8	4.7	4.3
Namsoy 3	97	99	100	100	99	PI 628850	3.1	4.8	4.8	4.4	4.3
Nam 2 x GC 4.1-2	99	98	100	100	99	PI 628833	2.8	4.6	4.9	4.8	4.3
Maksoy 1N	97	98	100	100	99	PI 628915	3.0	4.7	4.7	4.7	4.3
BSPS 42	98	99	100	100	99	PI 287197	3.1	4.6	4.8	4.6	4.3
DXT 16.6-2	100	97	100	100	99	NGDT 2.15-4	3.2	4.6	4.8	4.7	4.3
Maksoy 4N	98	99	100	100	100	10.41	2.8	4.3	5.7	4.5	4.3
BSPS 62C-1	100	100	99	100	100	BSPS 47B	3.1	4.5	5.1	4.8	4.4
PI 476905A	98	100	100	100	100	K-local	3.4	4.5	4.9	4.7	4.4
7.11	100	99	100	100	100	Siesta	3.2	4.6	4.9	4.8	4.4
Kuntz	100	99	98	100	100	PI 628948	3.2	4.5	4.9	4.9	4.4
PI 417132B	100	100	100	100	100	Nam 4M	3.3	4.7	5.0	5.0	4.5
Mean	93.0	96.0	98.0	100.0	96.8	Mean	2.5	3.7	4.4	4.2	3.7
LSD	23.0	9.8	9.8	6.0	12.2	LSD	0.6	0.6	0.6	1.6	0.9
CV%	12.0	9.0	8.8	5.3	8.8	CV%	20.7	14.9	12.3	14.3	16.0

LSD is least significant difference

Appendix 2: Table showing mean severity scores for the three different environments across the four different sampling dates

Environment	Iki Iki A				Iki Iki B				NaSARRI			
Genotype	40 DAP	54 DAP	68 DAP	82 DAP	40 DAP	54 DAP	68 DAP	82 DAP	40 DAP	54 DAP	68 DAP	82 DAP
GC 487021-26-3-1	2.0	3.9	4.7	4.6	3.2	4.2	4.6	4.3	2.9	3.3	5.0	4.4
BSPS 47B	2.8	4.6	5.2	5.0	3.5	4.4	4.8	5.0	2.8	4.2	5.0	4.4
K-local	2.5	4.3	4.9	4.9	4.1	4.8	4.6	4.6	3.3	4.3	5.0	4.8
PI 628915	2.6	4.8	4.8	4.4	4.0	5.1	4.6	4.7	2.7	4.4	5.0	5.1
PI 628904	2.4	4.4	4.7	4.4	2.5	4.5	4.7	4.9	2.1	3.9	5.0	4.8
PI 628905	2.1	3.2	4.3	4.5	2.3	3.7	4.3	4.5	2.0	4.0	5.0	5.0
PI 628863	2.0	4.0	4.2	4.6	3.7	5.0	4.9	4.9	2.7	3.2	5.0	4.6
NGDT 2.15-4	2.9	4.3	4.4	5.0	3.8	4.5	4.6	4.1	2.5	4.8	5.0	5.0
PI 628887	2.0	3.3	4.5	4.3	2.9	4.8	5.0	5.1	2.0	3.6	4.9	4.9
PI 628948	2.4	4.3	4.6	4.8	3.7	5.1	5.2	4.8	3.4	4.1	5.0	4.9
PI 578457A	1.8	3.0	3.8	2.9	1.5	2.7	2.8	2.9	2.0	3.1	4.2	3.8
GC 00138-29	2.3	3.1	4.1	3.4	3.1	4.8	4.9	5.0	2.9	4.3	5.0	4.5
PI 567046A	1.9	3.2	4.2	3.5	2.3	3.3	3.2	2.1	2.2	2.9	4.9	2.9
PI 567190	2.0	3.1	3.9	3.7	3.1	3.9	4.7	4.7	3.2	3.7	5.0	5.0
1882	1.9	2.7	4.2	3.4	2.8	3.9	3.7	4.2	2.5	4.2	5.0	4.8
PI 605823	2.4	4.6	4.7	4.4	3.4	4.8	4.8	4.1	2.2	4.3	5.0	5.0
9.2	2.2	4.1	4.2	3.4	2.7	4.6	4.6	5.0	2.2	4.1	5.0	5.0
G 7955	2.4	4.2	4.9	4.0	2.7	4.7	4.9	4.9	2.6	4.0	5.0	5.0
PI 416810	1.6	2.9	3.8	3.3	1.4	2.7	2.8	3.2	2.3	3.5	4.3	4.0
PI 605638	2.1	3.0	3.6	3.3	2.2	3.5	2.6	2.9	2.0	2.8	2.7	3.3
PI 628960	2.7	4.2	4.8	4.6	3.5	4.9	4.4	4.6	2.7	3.9	5.0	4.3
G 50	2.0	2.9	4.3	3.6	2.2	3.6	4.1	4.1	2.3	3.2	4.3	3.5
Safari	2.2	3.6	4.7	3.9	2.8	4.2	4.4	4.7	2.8	3.6	5.0	4.7
Santa	2.2	3.7	4.1	3.7	2.8	3.8	3.4	4.0	2.7	3.7	4.6	4.7
PI 628933	2.8	3.9	4.7	4.7	3.3	4.7	4.8	4.8	2.3	4.3	5.0	5.0
BSPS 48A-5	2.9	4.4	4.9	4.7	2.5	4.2	4.4	4.6	2.6	4.4	4.9	4.7
GC 84051-31-1	1.9	3.0	4.3	3.2	2.5	3.6	3.7	4.0	2.5	2.6	4.7	4.1

PI 200526	2.2	3.7	4.6	4.0	2.5	3.6	4.8	4.8	2.9	4.2	4.6	4.8
G 10428	1.8	2.6	3.7	3.9	2.4	3.5	3.7	3.7	2.2	3.5	4.9	5.1
PI 476905A	2.9	3.6	4.0	4.2	2.1	4.2	4.5	3.8	2.8	4.1	5.0	5.1
PI 628813	1.8	3.1	3.9	3.1	2.5	3.5	4.1	3.6	2.0	2.9	4.4	5.1
PI 417503	1.9	2.7	3.3	3.9	2.4	4.7	4.4	4.6	2.3	2.5	4.8	5.0
PI 567034	1.8	1.8	3.4	2.3	2.1	3.1	3.1	3.9	2.0	3.4	3.6	3.8
BSPS 48A-1	2.7	4.0	4.6	4.3	3.6	4.8	4.4	3.5	2.6	4.5	5.0	5.0
PI 628812	2.3	4.1	4.7	4.8	2.3	4.0	5.1	5.0	2.3	4.3	5.0	4.5
PI 506764	1.9	2.9	4.8	4.1	3.0	4.3	4.6	4.9	2.8	4.3	5.0	5.2
Nam1	1.9	3.2	3.7	3.3	2.4	4.2	3.9	3.7	2.2	2.7	4.9	4.9
PI 416826A	1.8	2.4	4.9	4.1	2.4	4.2	4.3	4.5	1.5	3.8	4.1	4.2
PI 567025A	2.1	4.0	4.6	3.9	2.7	3.6	4.0	4.0	2.1	3.4	4.8	3.2
PI 506695	2.2	3.1	3.7	3.9	2.1	3.7	3.8	3.8	2.1	2.7	3.2	3.2
PI 605865B	1.9	2.7	3.4	3.3	1.9	3.0	3.1	2.9	2.4	4.0	3.0	2.8
13.14	1.9	3.9	4.4	4.3	3.2	4.3	4.4	4.6	2.3	4.7	5.0	4.9
Dinamri	2.3	3.2	4.6	3.7	2.8	3.5	3.4	2.9	2.4	3.8	5.0	4.9
PI 628903	2.1	3.1	3.6	3.5	2.5	3.0	2.7	3.4	1.7	2.7	4.2	4.4
3.17	2.0	2.6	4.0	3.3	2.1	4.0	2.8	3.4	2.3	3.2	4.9	4.2
G 32	2.5	2.8	4.6	4.0	2.0	3.3	4.0	4.3	2.2	3.5	5.0	4.7
PI 628934	2.3	3.4	4.4	4.4	2.7	3.8	4.6	4.9	2.8	3.5	5.0	4.1
Roan	2.1	4.0	4.9	4.8	2.5	4.1	4.3	4.7	2.4	3.7	5.0	4.8
GC48702-26-3-1	2.6	2.9	4.6	4.4	2.4	4.1	4.5	4.3	2.6	4.0	5.0	4.7
BSPS 48A-19	3.3	4.3	4.8	4.7	2.6	4.0	4.3	4.5	2.6	3.3	5.0	4.7
Solitaire	2.4	3.4	4.2	4.4	2.1	3.2	3.2	3.7	2.5	3.6	5.0	5.0
PI 287197	2.1	4.0	4.6	4.6	3.1	4.6	4.8	4.1	2.2	3.8	4.7	3.6
BSPS 48A-14	2.9	4.7	4.7	4.7	3.3	4.1	4.7	4.5	3.2	4.7	5.0	4.6
NGDT 2.15-10	2.7	4.2	4.8	4.7	3.8	4.7	4.6	4.8	2.9	3.1	5.0	5.1
PI 606405	1.9	3.4	4.1	4.0	2.2	3.7	4.6	4.1	2.3	3.5	4.6	4.6
SRE-D-11-13	2.0	3.9	4.4	4.9	2.2	3.4	3.5	4.1	2.6	2.9	5.0	4.1
PI 506491	1.8	3.4	4.5	4.0	2.1	3.3	3.6	4.4	2.7	3.8	4.9	5.0
BSPS 48A-21B	2.3	4.0	4.6	4.7	3.2	4.1	4.5	3.9	2.5	3.7	5.0	4.9

PI 567104B	2.1	2.7	4.6	2.8	1.4	3.1	2.2	3.3	2.1	3.3	4.5	4.5
BSPS 182A	2.8	4.5	4.6	4.5	2.8	5.0	5.2	4.8	2.3	3.8	5.0	5.1
PI 635999	3.5	5.2	4.8	4.5	3.1	4.3	4.6	3.4	2.4	4.0	5.0	4.6
Kab 1	2.4	3.8	4.7	3.7	2.6	3.9	3.6	4.6	2.5	4.5	5.0	5.0
13.2A	2.0	3.7	4.0	3.9	3.0	4.1	3.8	4.4	2.4	4.4	5.0	4.7
4.21	2.2	3.5	4.0	3.4	2.5	3.8	3.5	3.1	4.0	3.4	4.9	4.4
PI 567123	1.4	2.1	3.1	2.7	2.1	2.8	2.6	2.2	2.3	2.9	4.0	3.0
13.2	2.1	4.2	4.6	4.1	2.9	4.4	4.4	3.7	2.1	4.4	5.0	5.0
PI 203398	1.9	2.4	3.7	3.6	1.8	3.1	3.5	3.5	2.4	3.2	3.8	3.8
Duiker	2.2	3.8	4.8	4.7	3.2	4.5	4.8	5.0	2.9	4.7	5.0	5.2
PI 417132B	2.4	3.7	4.7	4.4	2.3	4.3	4.2	4.5	2.3	3.4	4.9	4.9
PI 628850	2.3	4.3	4.5	4.8	2.7	4.5	4.8	4.9	3.1	3.5	5.0	4.9
BSPS 48C	2.8	4.6	4.8	4.7	3.4	5.1	4.2	3.4	3.0	4.6	5.0	5.0
PI 587056A	1.8	2.0	3.0	2.6	1.7	3.0	2.4	2.6	2.1	2.3	3.6	3.1
PI 628811	2.0	3.5	3.7	4.1	3.4	4.1	3.8	3.9	2.3	3.4	4.8	4.9
PI 567059	2.1	2.7	3.5	4.1	2.3	3.2	3.2	3.8	2.0	3.4	3.7	3.0
10.41	1.8	3.0	4.4	3.9	2.9	3.7	3.8	4.3	2.0	3.5	4.8	4.2
PI 628833	2.4	4.2	4.7	4.6	2.9	4.8	4.8	5.1	2.7	3.8	7.5	3.9
Maksoy2N	2.2	4.4	5.1	4.5	3.3	5.0	4.7	5.0	2.8	4.3	5.0	5.1
NG 14.1-24	2.3	3.5	4.2	4.3	2.8	3.8	4.1	4.5	2.8	4.1	5.0	5.0
PI 567189A	1.9	2.8	3.9	3.6	1.8	3.7	3.7	2.8	2.6	3.3	3.7	3.1
Kuntz	2.5	4.2	4.9	4.6	2.8	4.7	4.6	4.5	2.9	4.7	4.9	4.9
PI 628855	2.8	3.9	4.3	4.1	3.5	4.4	4.6	4.7	2.9	4.1	5.0	4.7
12.17	2.3	3.8	4.1	4.0	2.7	4.0	3.9	4.4	2.8	4.5	5.0	4.1
PI 567102B	2.1	3.1	3.2	2.9	1.9	3.7	3.2	2.4	2.3	3.9	4.4	3.8
PI 615437	1.8	2.6	3.5	2.9	2.2	2.7	3.0	3.7	2.1	2.5	4.0	2.8
PI 605885B	1.7	2.3	3.0	3.1	2.1	2.8	2.5	2.8	2.0	3.0	4.5	3.5
PI 594538A	3.0	4.5	4.8	4.9	2.9	4.1	4.8	4.7	2.5	4.6	5.0	4.9
BSPS 75B	2.5	4.2	4.8	4.6	2.3	4.1	4.5	3.2	2.4	4.4	5.0	3.9
Soprano	1.8	2.9	4.3	3.7	2.4	3.5	3.5	3.7	2.2	2.8	4.4	3.6
8527	1.8	2.7	4.3	3.7	1.9	3.2	4.3	4.5	2.2	2.9	5.0	5.1

5.18	1.9	2.8	4.3	3.8	2.1	3.5	3.4	3.6	2.1	3.1	4.7	4.9
Maksoy 1N	2.3	3.1	4.4	4.2	2.8	4.5	4.2	4.1	2.1	3.2	4.8	5.0
PI 628907	2.6	4.3	4.9	4.6	2.8	3.3	3.5	4.6	2.2	4.0	5.0	4.9
AGS 292	2.3	4.3	4.3	4.8	2.8	4.7	4.2	5.2	2.8	3.8	4.6	4.8
G 2043	1.9	2.6	3.5	3.6	1.9	3.0	3.2	3.7	2.0	3.0	4.6	3.5
548360	2.1	3.7	4.7	4.6	3.4	4.5	4.3	4.7	3.2	3.5	5.0	5.1
SCSI	2.2	4.1	4.6	4.3	2.7	3.4	4.5	4.6	2.4	3.8	5.0	5.0
PI 628919	2.4	3.3	4.4	3.7	2.0	3.4	3.4	3.7	2.6	4.4	5.0	5.0
PI 462312	1.9	3.3	4.3	4.7	2.2	4.4	4.8	4.9	2.3	3.8	4.9	4.6
Namsøy 3	2.4	3.6	4.1	4.3	2.4	3.4	3.7	3.2	2.4	4.3	4.8	4.1
PI 417126	2.2	2.6	4.0	3.1	1.4	2.8	3.2	3.5	2.2	3.0	4.1	2.9
PI 628959	2.4	3.1	4.3	3.7	2.4	3.8	4.1	4.7	2.4	3.2	4.9	4.2
BSPS 27A	2.9	4.0	4.9	4.8	3.4	3.7	3.4	3.3	2.5	4.1	5.0	5.0
Siesta	2.1	4.2	4.5	4.3	3.2	4.6	4.7	4.6	2.5	3.5	4.8	4.8
DXT 16.6-2	3.0	4.8	4.7	4.7	3.4	4.8	5.0	4.8	3.0	4.3	5.0	4.7
BSPS 24.2A-3	2.8	4.1	4.9	4.7	2.9	5.2	4.3	3.7	2.6	4.5	5.0	5.0
SRE-C-14A	1.8	3.2	3.6	3.6	1.5	3.6	3.0	4.1	2.4	2.9	4.6	3.6
PI 644103	2.9	4.0	4.7	4.1	2.1	3.9	3.6	2.9	2.3	2.9	4.4	4.4
PI 628908	1.7	2.5	3.4	3.2	2.0	3.1	2.5	4.0	2.4	2.2	3.5	3.1
Nam 4M	2.4	4.1	4.8	4.7	3.1	4.5	5.1	4.1	2.5	3.7	5.0	4.8
BSPS 62C-1	3.6	4.8	5.2	5.1	3.7	4.7	4.6	4.8	2.7	4.6	5.0	4.9
SS 86045-23-2	2.0	2.6	4.0	3.7	2.3	4.3	4.2	4.7	1.9	2.5	4.4	3.9
BSPS 42	2.7	4.3	4.7	4.6	4.2	4.8	4.4	4.1	2.5	4.2	5.0	5.0
PI 200488	2.3	2.6	4.4	3.9	2.3	3.5	4.2	4.3	2.7	4.3	4.9	4.9
PI 628827	3.0	4.4	4.1	4.5	2.9	4.2	4.7	3.8	3.4	3.9	5.0	5.1
SRE-B-15C	2.4	4.1	4.2	3.5	3.3	4.5	4.6	4.9	3.2	4.1	5.0	4.8
PI 628830	2.4	4.0	4.5	4.3	2.6	4.1	4.7	4.9	3.5	4.4	5.0	4.7
Wondersoy	2.2	4.5	4.6	4.8	3.4	4.5	4.9	5.0	2.2	4.5	5.0	4.9
NG 14.1-6B	1.9	4.4	4.9	4.4	2.5	3.8	4.0	3.9	2.0	3.9	4.9	4.9
PI 59172	2.3	4.2	4.9	3.6	2.7	4.4	4.0	3.9	1.6	3.4	3.9	4.0
GC 8901-13-13	2.2	4.1	4.4	3.6	2.9	3.9	3.8	4.1	2.3	4.0	5.0	4.6

BSPS 48A-27	2.3	4.7	4.8	4.7	4.4	5.2	4.2	3.6	2.2	4.2	5.0	4.9
Nam 2 x GC 4.1-2	3.1	4.3	4.8	4.2	2.1	3.4	3.3	2.8	2.2	3.6	5.0	5.1
PI 628918	2.1	3.2	4.5	3.9	2.5	4.4	4.4	4.4	2.1	3.8	4.4	3.5
G 10427	1.9	2.7	3.4	3.5	2.3	3.7	3.4	4.0	2.3	3.1	4.4	4.0
11.1	2.3	3.1	4.6	4.0	2.0	3.7	3.3	3.8	2.5	3.4	4.9	5.1
7.11	2.7	4.1	4.4	4.6	3.5	5.0	4.8	4.7	2.3	4.5	5.0	4.9
Nam 2	2.1	3.7	4.7	4.0	2.8	4.9	4.5	3.5	2.5	4.7	5.0	5.1
G8586	1.9	3.1	3.5	2.9	2.2	3.1	3.0	3.9	1.9	3.1	4.4	3.9
6.22	2.1	3.1	3.8	4.0	2.4	3.9	3.8	4.8	3.0	3.9	4.8	3.7
PI 506695	1.6	2.9	3.5	2.7	2.1	2.9	2.6	2.8	2.3	2.8	4.0	4.7
PI 628932	2.1	3.9	4.7	4.7	1.9	4.2	4.5	4.5	3.0	3.1	5.0	4.9
PI 459025	2.8	4.6	4.9	4.9	2.4	4.4	4.6	4.0	3.3	4.1	5.0	5.0
PI 628925	2.8	3.9	4.6	4.3	1.9	3.2	3.0	3.3	2.6	3.3	4.5	4.9
PI 567024	1.9	3.1	3.4	3.3	2.0	3.5	3.7	3.5	2.4	3.0	3.9	3.3
PI 606440A	2.9	4.0	4.9	4.5	3.3	4.3	4.6	4.7	3.1	4.6	4.9	4.9
PI 628889	2.5	3.5	4.4	4.3	2.3	4.5	4.6	5.1	2.9	3.6	5.0	4.2
Serenade	2.2	4.2	4.9	4.3	2.7	3.6	4.2	4.4	2.7	3.7	5.0	4.9
PI 417120	2.1	3.8	4.6	4.1	2.2	3.9	4.9	4.9	2.3	3.7	4.9	4.9
PI 606397B	2.2	4.4	4.6	5.1	3.4	4.9	5.2	4.5	2.1	4.5	5.0	4.8
Gazelle	2.8	3.6	3.9	3.7	2.9	4.0	4.4	4.0	2.9	3.8	4.9	4.8
PI 605854B	2.0	3.1	4.4	3.9	2.3	4.3	4.4	5.0	2.2	2.9	4.8	4.6
1.19	2.0	3.5	4.0	3.4	2.2	3.2	2.9	3.9	2.0	3.6	4.9	4.2
3.7	2.2	3.1	4.3	3.6	1.7	3.5	3.5	3.3	2.8	3.9	4.9	4.8
Maksoy3N	2.0	3.5	4.6	4.3	2.6	3.8	4.5	4.8	2.1	4.6	5.0	5.0
G 7959	1.9	2.4	3.6	3.1	1.9	3.2	3.6	4.3	2.1	2.5	4.0	4.3
PI 417132	2.4	3.5	4.6	4.0	2.0	4.2	4.5	4.8	3.3	3.3	4.9	4.8
UG5	2.2	3.8	4.2	3.7	3.2	4.8	4.2	4.5	2.8	3.6	5.0	4.9
NII GC 4.1-2	2.3	3.1	4.3	4.2	1.9	3.7	4.0	2.9	2.1	3.3	5.0	4.9
PI 567053	2.0	2.5	4.3	3.0	1.9	3.3	2.7	3.2	2.1	2.5	3.1	3.7
16.12	1.9	2.9	3.6	3.2	1.9	3.3	3.1	3.9	2.4	3.4	4.8	4.4
PI 471904	2.3	2.7	3.8	3.9	2.2	3.8	4.1	3.7	2.2	3.0	3.9	3.3

3.16	2.5	3.9	4.4	4.3	3.0	3.8	4.9	4.8	2.2	4.4	5.0	5.1
NGDT 8.11	3.0	4.4	4.9	5.0	3.1	4.8	4.3	3.8	2.5	3.4	5.0	3.8
G57	2.4	3.6	4.1	4.2	3.3	5.0	5.0	4.9	3.2	4.0	5.0	4.5
NGDT BLP 12.4	2.5	4.6	5.0	4.9	2.3	3.9	4.7	4.9	2.4	3.6	5.0	4.9
GC 85037-2-3-54	1.8	2.7	3.6	3.0	2.6	3.8	4.3	4.9	2.1	3.0	4.9	4.1
G2843	2.1	3.4	3.8	3.9	2.5	4.2	4.4	4.9	2.3	3.3	4.2	3.6
PI 626832	2.0	3.4	4.1	3.4	2.3	3.6	3.7	3.8	2.2	3.1	4.6	4.9
AGS 338	2.7	4.3	4.8	5.0	3.2	4.3	4.7	4.9	3.2	4.3	5.0	5.0
PI 417089A	2.0	2.7	4.6	3.9	2.1	2.9	3.7	3.7	2.0	3.0	4.4	4.6
Mean	2.3	3.6	4.3	4.0	2.6	4.0	4.1	4.1	2.5	3.7	4.7	4.5
LSD	0.7	1.2	0.8	1.1	1.0	1.1	1.2	1.2	0.9	1.1	0.8	0.8
%CV	15.4	16.7	9.1	13.2	19.2	14.4	14.7	14.9	19.0	15.7	8.7	9.2

LSD is least significant difference

Appendix 3: Mean plant height (cm) and leaf area (cm²) for genotypes across the three environments at four different sampling dates

Genotypes	Leaf area (cm ²)					Genotypes	Plant height (cm)				
	40 DAP	54 DAP	68 DAP	82 DAP	Mean		40 DAP	54 DAP	68 DAP	82 DAP	Mean
PI 416826A	15.2	13.3	13.1	9.3	12.7	PI 416826A	14.7	19.7	16.4	14.4	16.3
Kuntz	17.9	13.7	12.5	8.2	13.1	PI 628827	18.4	19.8	18.5	17.0	18.4
PI 506491	17.1	18.9	15.3	10.5	15.4	PI 506491	20.1	19.9	18.3	15.8	18.5
PI 506764	20.8	16.7	16.2	9.1	15.7	PI 506695	18.8	21.2	20.6	14.7	18.8
PI 200488	16.4	18.0	19.0	11.7	16.3	G 2043	20.9	17.9	20.3	19.3	19.6
PI 567034	20.2	16.8	18.0	10.9	16.5	PI 605854B	20.2	19.3	20.9	18.9	19.8
PI 628827	19.0	19.6	13.9	13.4	16.5	PI 59172	19.6	17.7	21.5	20.8	19.9
PI 417089A	16.7	19.3	17.5	13.5	16.8	G 50	20.2	20.1	21.4	18.2	20.0
PI 417120	18.8	17.8	18.7	11.8	16.8	PI 200488	21.0	19.8	18.5	20.9	20.0
8527	17.6	17.2	19.6	14.3	17.2	Kuntz	20.4	20.0	21.5	18.6	20.1
5.18	17.9	17.2	18.4	16.2	17.4	PI 200526	22.2	21.5	20.4	17.0	20.3
AGS 338	21.3	18.6	15.4	18.0	18.3	8527	20.1	21.3	22.5	20.4	21.1
PI 606440A	21.2	18.5	16.1	17.5	18.3	PI 417132B	21.3	21.2	21.9	20.1	21.1
PI 506695	19.8	17.3	20.2	17.1	18.6	PI 628903	19.7	23.6	20.8	20.9	21.3
PI 59172	20.8	20.4	26.3	7.9	18.8	PI 628863	20.8	22.3	22.3	21.3	21.7
PI 605885B	18.1	21.0	18.4	18.6	19.0	PI 567034	20.5	22.9	22.0	21.8	21.8
10.41	19.7	14.7	20.6	21.5	19.1	PI 417503	23.0	22.4	24.0	18.6	22.0
Soprano	17.8	20.3	20.4	18.7	19.3	PI 287197	22.1	23.0	22.0	22.1	22.3
Duiker	19.9	22.8	17.1	17.4	19.3	PI 417089A	20.6	22.9	23.1	22.7	22.3
SRE-B-15C	20.7	16.4	18.9	21.4	19.4	Soprano	19.4	23.5	24.2	22.2	22.3
PI 567123	17.5	17.9	17.3	24.9	19.4	Duiker	21.9	22.7	22.9	22.5	22.5
SCSI	21.5	14.0	20.2	22.3	19.5	PI 628934	22.7	23.3	22.3	21.8	22.5
PI 567059	21.3	21.0	16.6	19.1	19.5	PI 628889	22.6	21.7	22.9	23.0	22.5
G 2043	22.6	16.4	21.5	18.6	19.8	AGS 338	22.8	24.5	22.4	20.9	22.7
PI 506695	18.1	19.4	19.8	22.3	19.9	AGS 292	24.3	27.1	21.4	18.9	22.9

G 50	19.3	23.8	18.7	17.8	19.9	PI 628887	23.7	23.9	22.4	22.0	23.0
PI 567190	20.4	22.5	21.5	15.3	19.9	PI 416810	23.9	23.5	23.9	20.8	23
AGS 292	20.7	21.2	18.5	19.5	20.0	PI 628812	21.9	24.2	26.3	20.8	23.3
PI 628903	18.5	21.1	22.8	18.5	20.2	SCSI	21.0	23.6	24.3	24.4	23.3
PI 628863	20.9	19.8	23.1	17.2	20.2	PI 628932	23.5	23.8	24.2	21.8	23.3
PI 605854B	21.0	19.2	21.0	19.8	20.3	PI 628904	23.8	24.4	24.3	21.4	23.4
PI 628855	23.5	15.0	21.4	21.5	20.3	PI 567190	22.2	21.5	23.8	26.2	23.4
PI 416810	23.6	19.1	16.1	23.2	20.5	1882	23.5	25.0	23.5	22.1	23.5
PI 417132B	22.1	19.1	20.0	20.9	20.5	PI 628855	23.5	22.5	23.4	24.8	23.5
G 32	21.2	19.3	21.0	20.8	20.6	PI 628833	20.9	24.6	24.0	24.7	23.6
PI 287197	22.2	20.7	18.7	21.2	20.7	PI 567059	23.8	22.9	24.1	23.6	23.6
PI 628934	18.9	23.3	19.5	21.7	20.9	Solitaire	20.9	24.3	26.6	23.7	23.9
PI 628933	23.4	20.6	16.6	23.2	20.9	PI 605885B	22.4	25.1	25.1	22.9	23.9
PI 567053	21.2	20.6	22.3	19.7	21.0	PI 628918	24.6	23.8	24.3	23.2	24.0
PI 476905A	24.4	20.2	19.0	20.3	21.0	PI 628933	25.9	23.2	23.4	23.8	24.1
SS 86045-23-2	19.4	19.8	23.3	21.6	21.0	PI 462312	22.6	24.8	25.6	24.1	24.3
PI 605638	17.1	25.4	21.2	20.6	21.1	PI 628813	22.9	25.8	24.8	23.7	24.3
Solitaire	20.0	22.4	19.1	22.9	21.1	PI 459025	24.1	24.2	25.4	23.5	24.3
PI 628948	30.3	17.0	20.6	16.5	21.1	SS 86045-23-2	23.9	25.4	26.2	21.7	24.3
PI 628887	22.7	22.6	17.1	22.8	21.3	PI 628907	22.0	24.6	24.5	26.6	24.4
PI 628932	22.6	18.3	19.2	25.1	21.3	PI 594538A	23.6	26.7	25.2	22.3	24.5
PI 628813	20.2	19.2	23.3	23.4	21.5	PI 417120	22.8	26.3	25.0	25.2	24.8
PI 628889	19.9	24.2	23.5	18.8	21.6	G 32	23.1	26.3	25.7	25.1	25.0
Nam1	22.1	23.3	19.2	22.1	21.7	PI 628959	23.2	25.9	26.8	24.3	25.0
PI 628811	21.5	24.6	19.5	21.4	21.7	PI 628905	26.9	24.4	23.9	25.1	25.1
BSPS 42	22.5	20.9	22.7	21.0	21.8	5.18	21.0	23.8	28.7	27.9	25.4
PI 200526	26.9	21.2	21.5	18.0	21.9	PI 605638	23.5	27.5	25.1	25.8	25.5
BSPS 48A-5	22.8	23.6	19.5	22.7	22.1	Maksoy 1N	22.8	25.7	28.7	25.3	25.6
1882	22.7	21.2	21.5	23.2	22.2	GC48702-26-3-1	25.6	25.4	26.6	25.0	25.6
BSPS 48A-19	19.8	26.3	21.6	21.4	22.3	PI 506695	21.1	24.8	30.8	26.7	25.8

PI 628907	20.7	20.1	23.2	25.1	22.3	PI 628850	25.0	24.3	25.9	29.1	26.1
PI 628918	21.4	22.3	24.1	21.4	22.3	PI 606440A	25.1	27.3	26.8	25.5	26.2
PI 628904	24.1	21.1	20.3	24.2	22.4	PI 203398	25.3	27.0	28.0	24.6	26.2
NGDT 2.15-10	25.1	20.7	24.8	19.5	22.5	G 7959	22.3	25.7	29.6	27.8	26.3
BSPS 75B	23.0	22.3	21.0	23.8	22.5	PI 476905A	25.8	27.5	26.5	26.1	26.5
PI 417503	22.6	28.9	21.9	17.7	22.8	PI 606397B	24.6	30.5	25.5	25.6	26.5
GC48702-26-3-1	24.3	20.5	25.6	20.9	22.8	PI 628830	25.0	27.6	27.7	25.9	26.6
NGDT 2.15-4	20.0	23.9	22.6	24.8	22.8	PI 417132	23.8	28.2	27.6	26.8	26.6
Maksoy2N	26.9	23.8	20.7	20.2	22.9	PI 606405	25.1	27.8	27.5	26.7	26.8
PI 626832	23.7	21.1	23.0	24.0	22.9	Roan	25.1	29.9	25.7	26.6	26.8
SRE-C-14A	24.6	23.2	22.5	22.2	23.1	7.11	24.6	26.7	28.9	27.3	26.9
9.2	23.7	24.8	24.9	19.5	23.2	G 7955	26.2	26.6	31.4	24.5	27.2
3.7	24.4	20.4	26.8	21.2	23.2	9.2	25.6	27.9	28.7	27.2	27.4
PI 578457A	23.3	22.0	27.2	21.1	23.4	SRE-B-15C	27.6	26.5	26.6	29.0	27.4
BSPS 48A-14	25.0	23.6	22.2	22.8	23.4	548360	27.6	28.3	27.6	26.3	27.4
PI 587056A	21.2	24.7	21.5	26.2	23.4	PI 567189A	23.8	29.4	29.2	27.7	27.5
PI 471904	26.3	26.1	18.9	22.8	23.5	PI 417126	26.1	30.1	27.3	26.9	27.6
Maksoy 1N	21.9	21.5	27.2	24.0	23.7	Siesta	28.8	28.6	27.5	26.2	27.8
G 7959	22.1	24.0	24.2	24.7	23.7	3.16	26.0	28.4	29.2	27.7	27.8
PI 459025	27.8	22.9	23.2	21.4	23.8	Gazelle	27.0	25.6	28.9	29.9	27.9
PI 606405	24.0	23.1	24.3	25.2	24.1	BSPS 48A-5	21.1	29.6	30.2	31.0	28.0
Nam 2	20.9	24.3	26.9	24.5	24.1	PI 506764	57.6	20.8	19.1	14.4	28.0
BSPS 47B	24.6	23.7	24.8	23.7	24.2	G 10427	28.7	28.5	27.6	27.6	28.1
SRE-D-11-13	25.3	23.6	24.0	25.5	24.6	BSPS 48A-19	22.5	29.0	30.0	31.0	28.1
PI 417126	25.1	22.3	24.8	26.5	24.7	Nam1	25.2	28.5	28.9	29.9	28.1
548360	24.1	28.7	25.2	20.7	24.7	PI 626832	25.9	26.6	28.7	31.4	28.1
PI 594538A	22.0	25.7	26.8	24.6	24.8	BSPS 42	23.0	29.5	30.7	29.4	28.2
Kab 1	23.5	25.6	23.7	26.3	24.8	SRE-C-14A	26.8	30.0	28.4	27.9	28.3
BSPS 48A-21B	22.0	26.8	24.7	26.2	24.9	NGDT 2.15-4	21.8	29.6	31.2	30.8	28.3
Dinamri	22.3	20.6	27.9	29.0	24.9	NGDT BLP 12.4	24.2	29.5	31.1	29.2	28.5

PI 605865B	25.1	23.3	24.4	27.5	25.1	PI 605865B	26.1	30.3	29.7	28.2	28.6
GC 85037-2-3-54	26.2	23.0	27.7	23.6	25.1	PI 567053	25.6	29.0	30.7	28.9	28.6
Safari	25.8	24.9	24.1	25.9	25.2	PI 471904	27.9	29.7	29.3	27.9	28.7
Wondersoy	26.2	21.8	24.6	28.5	25.3	PI 567123	24.0	28.4	32.0	30.7	28.7
NGDT BLP 12.4	23.0	25.1	25.9	27.2	25.3	SRE-D-11-13	29.0	30.1	28.9	27.4	28.8
NGDT 8.11	26.1	28.7	23.5	23.7	25.5	PI 587056A	23.7	27.6	32.0	32.4	28.9
Roan	26.1	26.6	19.1	30.2	25.5	10.41	24.8	28.7	30.3	32.3	29.0
PI 567189A	23.4	28.4	21.0	29.3	25.5	13.2A	28.7	31.2	29.1	27.6	29.2
PI 628812	24.1	28.9	23.0	26.5	25.6	PI 628811	24.1	29.7	32.0	30.9	29.2
GC 84051-31-1	25.1	27.7	25.4	24.7	25.7	11.1	26.4	26.5	33.5	30.6	29.2
K-local	29.7	23.0	22.1	28.4	25.8	12.17	28.2	31.8	28.2	29.0	29.3
11.1	22.7	27.4	27.6	26.6	26.0	GC 8901-13-13	25.5	30.6	31.3	29.9	29.3
PI 628833	22.6	27.0	26.6	28.4	26.1	GC 84051-31-1	29.4	30.2	31.3	27.4	29.6
Gazelle	27.3	28.6	23.8	25.0	26.2	PI 628960	27.3	31.5	30.9	29.1	29.7
PI 628905	26.7	26.1	26.5	25.8	26.3	16.12	26.7	32.3	30.9	29.0	29.7
16.12	27.5	26.2	26.2	25.2	26.3	Santa	26.4	31.0	32.0	29.5	29.7
G 7955	24.8	25.5	31.2	23.7	26.3	3.7	27.4	30.1	31.2	30.6	29.8
PI 635999	23.3	26.1	22.1	34.0	26.4	PI 628948	37.6	28.0	28.1	25.8	29.9
PI 628960	25.5	28.3	23.6	28.1	26.4	Wondersoy	26.7	32.2	30.1	30.7	29.9
BSPS 48C	25.1	26.4	23.4	32.1	26.7	GC 85037-2-3-54	28.2	33.0	31.1	28.5	30.2
PI 628915	28.5	22.5	26.9	29.7	26.9	PI 635999	27.4	33.1	30.6	30.1	30.3
G 10427	24.6	24.1	35.0	24.1	26.9	Dinamri	28.9	28.3	32.3	31.8	30.3
PI 567025A	28.9	26.4	25.3	27.5	27.0	PI 628915	25.9	30.5	33.3	31.8	30.4
PI 462312	24.1	27.0	33.4	24.0	27.1	PI 628925	25.3	31.5	32.9	31.9	30.4
4.21	25.5	29.2	27.0	27.3	27.3	G2843	31.4	32.0	31.4	26.9	30.4
PI 567104B	24.8	29.0	26.0	29.4	27.3	K-local	32.1	31.4	28.3	31.0	30.7
Siesta	30.3	24.1	25.2	29.7	27.3	Safari	27.7	31.9	32.1	32.3	31.0
PI 628850	27.5	20.9	29.8	31.6	27.4	BSPS 48A-14	28.0	37.6	32.2	26.6	31.1
3.17	26.8	25.2	29.0	28.8	27.5	PI 615437	29.6	32.6	30.7	31.6	31.1
3.16	29.6	28.7	25.8	25.8	27.5	BSPS 182A	24.2	33.0	34.3	33.8	31.3

BSPS 24.2A-3	26.8	22.2	33.3	27.9	27.5	PI 567025A	27.7	34.7	29.3	33.7	31.4
Serenade	25.5	28.1	33.8	22.8	27.5	G 10428	28.4	32.5	33.4	31.3	31.4
NII GC 4.1-2	28.6	23.5	27.5	30.8	27.6	PI 628919	27.8	32.2	33.2	33	31.6
1.19	26.2	29.7	26.3	28.4	27.6	BSPS 48A-21B	23.6	30.5	33.9	38.2	31.6
13.2A	29.2	31.4	24.0	26.1	27.7	Maksoy 4N	28.3	29.9	34.5	33.9	31.6
Santa	23.2	30.4	29.8	27.5	27.7	Kab 1	27.1	34.4	33.8	33.6	32.2
BSPS 182A	28.1	35.6	24.8	22.9	27.8	PI 578457A	26.8	33.1	35.8	33.5	32.3
BSPS 27A	27.1	22.9	34.0	28.2	28.0	NGDT 2.15-10	28.6	33.3	34.1	33.5	32.4
G 10428	29.6	26.9	28.5	27.5	28.1	Nam 2	27.1	32.8	34.4	35.3	32.4
PI 628959	24.6	28.0	25.3	34.7	28.1	PI 567104B	24.0	30.7	36.8	38.3	32.4
PI 417132	25.8	28.6	30.4	28.2	28.2	PI 628908	32.4	34.5	32.7	32.4	33.0
PI 628919	29.2	29.1	25.4	29.2	28.2	BSPS 47B	27.8	33.4	34.9	36.1	33.0
GC 8901-13-13	28.5	28.7	28.3	28.2	28.4	BSPS 24.2A-3	28.1	33.5	36.0	34.8	33.1
PI 628925	27.3	27.7	25.6	33.3	28.5	BSPS 62C-1	31.2	33.9	34.2	33.6	33.2
BSPS 48A-1	27.0	28.7	24.9	35.1	28.9	13.2	27.4	33.8	37.4	34.5	33.3
Namsoy 3	30.0	26.5	28.6	30.7	28.9	13.14	28.4	34.1	36.5	34.3	33.3
BSPS 62C-1	26.4	29.4	28.0	33.2	29.2	Maksoy2N	28.7	32.9	37.3	34.9	33.5
PI 605823	35.7	21.1	31.3	29.0	29.3	Namsoy 3	27.4	32.0	36.7	37.8	33.5
PI 203398	30.6	27.0	29.6	30.4	29.4	4.21	29.3	34.4	36.1	35.1	33.7
DXT 16.6-2	30.9	27.5	24.0	35.5	29.5	3.17	31.9	35.5	33.9	33.7	33.7
NG 14.1-6B	24.6	24.9	32.9	35.6	29.5	NG 14.1-6B	26.2	33.3	39.0	36.5	33.8
PI 567046A	22.4	36.8	28.6	30.7	29.6	GC 487021-26-3-1	30.3	35.1	35.2	34.4	33.8
12.17	26.4	29.8	27.6	34.9	29.7	BSPS 48C	29.0	32.3	38.1	36.4	33.9
PI 628830	27.8	26.6	32.6	31.9	29.7	NGDT 8.11	29.1	34.0	36.4	36.3	33.9
PI 615437	27.3	32.6	29.2	29.7	29.7	PI 605823	38.6	31.5	36.9	29.1	34.0
7.11	25.2	38.3	33.3	22.8	29.9	Maksoy3N	29.7	34.8	35.8	35.7	34.0
6.22	28.8	31.6	29.3	31.8	30.4	PI 567024	29.7	37.6	34.7	34.3	34.1
PI 606397B	29.9	33.6	29.5	30.5	30.8	PI 644103	28.7	31.6	39.3	36.7	34.1
13.2	28.7	32.3	28.9	33.8	30.9	UG5	31.0	39.2	32.2	33.9	34.1
Maksoy3N	26.7	32.9	26.3	38.2	31.0	GC 00138-29	33.8	35.4	33.2	34.0	34.1

PI 567024	27.3	32.3	31.0	34.7	31.3	DXT 16.6-2	29.4	37.9	35.9	33.3	34.1
MAKSOY 5N	33.4	26.4	30.7	34.9	31.4	G57	34.5	35.1	34.1	33.1	34.2
13.14	26.5	36.6	32.1	30.7	31.5	1.19	27.9	40.7	35.1	33.5	34.3
GC 00138-29	33.5	31.6	27.7	33.8	31.7	BSPS 75B	26.9	35.2	38.4	37.0	34.4
Nam 4M	28.3	37.2	35.3	27.7	32.1	NII GC 4.1-2	28.4	33.2	36.6	39.5	34.4
MAKSOY 4N	29.2	40.2	25.8	35.3	32.6	Nam 4M	28.8	34.7	40.6	39.0	35.8
GC 487021-26-3-1	30.2	28.5	37.1	35.8	32.9	Nam 2 x GC 4.1-2	25.4	31.8	44.0	43.0	36.0
G8586	29.9	32.7	32.3	37.3	33.1	BSPS 48A-1	29.1	33.7	40.0	41.4	36.0
G2843	34.6	45.4	32.9	21.3	33.5	BSPS 27A	27.5	34.5	40.7	42.8	36.4
G57	34.9	37.0	30.0	36.8	34.7	G8586	30.7	38.2	38.4	39.6	36.7
Nam 2 x GC 4.1-2	31.0	35.1	28.8	44.7	34.9	Serenade	26.3	63.2	30.0	27.5	36.7
PI 567102B	33.1	33.0	33.6	42.6	35.6	6.22	32.2	38.5	38.5	38.4	36.9
PI 644103	31.8	40.7	33.6	36.5	35.6	PI 567046A	29.5	34.9	41.4	41.8	36.9
UG5	33.3	40.4	30.5	39.1	35.8	Maksoy 5N	31.0	38.9	42.3	42.6	38.7
PI 628908	31.6	42.4	35.2	39.7	37.3	PI 567102B	32.4	39.1	47.4	52.6	42.9
Mean	24.4	24.9	24.3	24.9	24.6	Mean	25.8	28.8	29.4	28.4	28.1
LSD	10.0	12.8	3.9	13.8	10.1	LSD	4.7	1.6	10.2	10.5	6.8
CV%	36.0	45.2	40.6	48.8	42.7	%CV	39.3	34.4	30.6	32.5	34.2

LSD is least significant difference

Appendix 4: Mean severity scores for Iki Iki A and Iki Iki B for 4 four sampling dates and genotype grouping according to GLM severity categories

GLM severity for Iki Iki A and Iki Iki B						Genotype grouping according to GLM severity categories			
Genotype	40 DAP	54 DAP	68 DAP	82 DAP	Mean severity	Genotype	Origin	Mean severity	Category
PI 587056A	1.8	2.6	2.6	2.5	2.4	AGS 292	AVRDC	3.0	moderately resistant
PI 567123	1.7	2.5	2.9	2.6	2.4	AGS 338	AVRDC	3.3	moderately resistant
PI 605885B	1.8	2.5	2.7	3.0	2.5	G8527	AVRDC	3.3	moderately resistant
PI 567034	1.9	2.3	3.2	3.1	2.6	G 50	AVRDC	3.3	moderately resistant
PI 578457A	1.6	2.8	3.3	2.9	2.7	GC 84051-31-1	AVRDC	3.3	moderately resistant
PI 506695	2.0	3.0	3.2	2.8	2.7	G 10428	AVRDC	3.4	moderately resistant
PI 416810	1.6	2.9	3.4	3.2	2.8	G2843	AVRDC	3.4	moderately resistant
PI 628908	1.8	2.8	3.0	3.6	2.8	SRE-C-14A	AVRDC	3.5	moderately susceptible
PI 615437	2.0	2.7	3.4	3.3	2.8	G 10427	AVRDC	3.5	moderately susceptible
PI 567053	1.9	2.8	3.5	3.1	2.8	G1882	AVRDC	3.5	moderately susceptible
PI 567102B	2.0	3.4	3.2	2.7	2.8	GC 85037-2-3-54	AVRDC	3.6	moderately susceptible
PI 605865B	1.9	3.0	3.4	3.2	2.9	SRE-D-11-13	AVRDC	3.6	moderately susceptible
G 2043	1.8	2.8	3.3	3.6	2.9	G8586	AVRDC	3.6	moderately susceptible
PI 605638	2.0	3.2	3.1	3.2	2.9	Gazelle	AVRDC	3.6	moderately susceptible
PI 567104B	1.9	3.0	3.5	3.1	2.9	G 7959	AVRDC	3.8	moderately susceptible
PI 417126	1.8	2.7	3.7	3.3	2.9	G 32	AVRDC	3.9	moderately susceptible
G 7959	1.9	2.6	3.6	3.6	2.9	G548360	AVRDC	3.9	moderately susceptible
PI 628903	2.3	3.1	3.1	3.4	3.0	GC 487021-26-3-1	AVRDC	3.9	moderately susceptible
G8586	2.1	3.1	3.2	3.5	3.0	GC 00138-29	AVRDC	4.0	moderately susceptible
PI 567189A	1.9	3.1	3.7	3.2	3.0	GC48702-26-3-1	AVRDC	4.0	moderately susceptible
PI 567046A	2.2	3.3	3.7	2.9	3.0	G 2043	AVRDC	4.1	moderately susceptible

PI 203398	1.9	2.8	3.7	3.6	3.0	SRE-B-15C	AVRDC	4.1	moderately susceptible
1.19	2.0	3.3	3.3	3.5	3.0	G57	AVRDC	4.1	moderately susceptible
3.17	2.0	3.3	3.4	3.4	3.0	SS 86045-23-2	AVRDC	4.2	moderately susceptible
16.12	2.1	3.3	3.5	3.4	3.1	G 7955	AVRDC	4.2	moderately susceptible
G 10427	2.1	3.1	3.4	3.7	3.1	SCSI	AVRDC	3.6	moderately susceptible
G 10428	2.0	3.0	3.6	3.7	3.1	GC 8901-13-13	AVRDC	4.2	moderately susceptible
3.7	2.0	3.2	3.7	3.4	3.1	BSPS 48C	Uganda	2.5	moderately resistant
SRE-C-14A	1.8	3.5	3.4	3.8	3.1	NII GC 4.1-2	Uganda	2.8	moderately resistant
PI 567059	2.1	3.0	3.3	4.0	3.1	Namsoy 3	Uganda	3.0	moderately resistant
PI 567024	2.0	3.4	3.6	3.5	3.1	Maksoy3N	Uganda	3.0	moderately resistant
PI 417089A	1.9	2.7	4.1	3.8	3.1	NG 14.1-24	Uganda	3.1	moderately resistant
5.18	1.9	3.2	3.8	3.8	3.1	BSPS 48A-21B	Uganda	3.1	moderately resistant
Soprano	2.1	3.1	3.8	3.6	3.2	BSPS 24.2A-3	Uganda	3.2	moderately resistant
PI 506695	2.1	3.3	3.6	3.9	3.2	BSPS 75B	Uganda	3.2	moderately resistant
PI 471904	2.3	3.2	3.8	3.8	3.3	BSPS 62C-1	Uganda	3.3	moderately resistant
PI 628813	2.2	3.4	4.1	3.5	3.3	Nam1	Uganda	3.4	moderately resistant
4.21	2.3	3.6	3.8	3.3	3.3	NGDT BLP 12.4	Uganda	3.4	moderately resistant
1882	2.3	3.3	3.8	3.7	3.3	UG5	Uganda	3.5	moderately susceptible
8527	1.8	3.0	4.3	4.0	3.3	NG 14.1-6B	Uganda	3.5	moderately susceptible
GC 84051-31-1	2.3	3.3	4.1	3.5	3.3	Nam 2 x GC 4.1-2	Uganda	3.6	moderately susceptible
Dinamri	2.5	3.4	4.0	3.4	3.3	NGDT 2.15-10	Uganda	3.6	moderately susceptible
Nam1	2.1	3.7	3.9	3.5	3.3	BSPS 48A-19	Uganda	3.6	moderately susceptible
PI 628919	2.2	3.4	4.0	3.7	3.3	BSPS 42	Uganda	3.6	moderately susceptible
PI 626832	2.1	3.5	4.0	3.7	3.3	Kab 1	Uganda	3.7	moderately susceptible
G 50	2.1	3.3	4.1	3.9	3.3	BSPS 48A-27	Uganda	3.7	moderately susceptible
PI 200488	2.2	2.9	4.2	4.0	3.3	Maksoy2N	Uganda	3.9	moderately susceptible
PI 506491	1.8	3.3	4.0	4.2	3.3	BSPS 27A	Uganda	4.0	moderately susceptible
11.1	2.1	3.4	4.0	3.9	3.3	BSPS 48A-5	Uganda	4.1	moderately susceptible
NII GC 4.1-2	2.1	3.5	4.2	3.6	3.3	BSPS 182A	Uganda	4.1	moderately susceptible
Namsoy 3	2.5	3.5	3.7	3.7	3.4	NGDT 8.11	Uganda	4.1	moderately susceptible

SS 86045-23-2	2.0	3.4	4.0	4.1	3.4	DXT 16.6-2	Uganda	4.1	moderately susceptible
Solitaire	2.2	3.4	3.8	4.1	3.4	BSPS 48A-1	Uganda	4.1	moderately susceptible
GC 85037-2-3-54	2.2	3.3	4.1	4.0	3.4	BSPS 48A-14	Uganda	4.3	moderately susceptible
G 32	2.3	3.1	4.3	4.1	3.5	NGDT 2.15-4	Uganda	4.3	moderately susceptible
Santa	2.5	3.8	3.7	3.9	3.5	BSPS 47B	Uganda	4.4	moderately susceptible
10.41	2.3	3.4	4.1	4.1	3.5	K-local	Uganda	4.4	moderately susceptible
PI 628925	2.6	3.7	4.0	3.8	3.5	Nam 4M	Uganda	4.5	moderately susceptible
PI 628811	2.6	3.7	3.7	4.1	3.5	PI 615437	USA	2.7	moderately resistant
6.22	2.2	3.5	3.9	4.4	3.5	PI 644103	USA	2.8	moderately resistant
13.2A	2.4	3.8	3.7	4.1	3.5	PI 605638	USA	2.8	moderately resistant
PI 567025A	2.2	3.7	4.2	4.0	3.5	PI 567034	USA	2.8	moderately resistant
PI 416826A	2.0	3.2	4.5	4.3	3.5	PI 567102B	USA	2.8	moderately resistant
PI 606405	2.1	3.6	4.4	4.1	3.5	PI 578457A	USA	2.9	moderately resistant
SRE-D-11-13	2.1	3.7	3.9	4.5	3.5	PI 605865B	USA	2.9	moderately resistant
PI 417503	2.2	3.8	4.0	4.2	3.6	PI 416810	USA	3.0	moderately resistant
PI 644103	2.4	3.9	4.2	3.6	3.6	PI 417089A	USA	3.1	moderately resistant
PI 628959	2.3	3.4	4.3	4.2	3.6	PI 567046A	USA	3.1	moderately resistant
PI 567190	2.5	3.5	4.3	3.9	3.6	PI 628811	USA	3.1	moderately resistant
Nam 2 x GC 4.1-2	2.6	3.9	4.2	3.6	3.6	PI 506695	USA	3.1	moderately resistant
12.17	2.4	3.9	3.9	4.1	3.6	PI 628925	USA	3.1	moderately resistant
GC 8901-13-13	2.6	4.0	4.0	3.8	3.6	PI 628918	USA	3.2	moderately resistant
PI 628918	2.3	3.7	4.4	4.1	3.6	PI 605854B	USA	3.2	moderately resistant
PI 605854B	2.1	3.6	4.3	4.5	3.6	PI 628903	USA	3.2	moderately resistant
PI 628905	2.2	3.5	4.4	4.5	3.6	PI 567053	USA	3.3	moderately resistant
PI 59172	2.3	4.2	4.4	3.8	3.7	PI 628813	USA	3.4	moderately resistant
PI 417132	2.2	3.8	4.4	4.2	3.7	PI 567025A	USA	3.5	moderately resistant
Maksoy 1N	2.6	3.8	4.3	4.0	3.7	PI 416826A	USA	3.5	moderately resistant
NG 14.1-6B	2.1	4.0	4.4	4.2	3.7	PI 567059	USA	3.5	moderately susceptible
Kab 1	2.5	3.9	4.2	4.2	3.7	PI 462312	USA	3.5	moderately susceptible
Gazelle	3.0	3.8	4.1	3.9	3.7	PI 606405	USA	3.6	moderately susceptible

G2843	2.5	3.9	4.2	4.3	3.7	PI 417503	USA	3.6	moderately susceptible
GC48702-26-3-1	2.6	3.5	4.4	4.3	3.7	PI 417126	USA	3.6	moderately susceptible
Serenade	2.3	3.8	4.5	4.4	3.7	PI 459025	USA	3.6	moderately susceptible
PI 476905A	2.6	3.9	4.4	4.1	3.7	PI 587056A	USA	3.6	moderately susceptible
PI 628907	2.5	3.7	4.1	4.6	3.7	PI 59172	USA	3.7	moderately susceptible
13.2	2.5	4.2	4.4	3.9	3.7	PI 628855	USA	3.7	moderately susceptible
PI 417120	2.1	3.8	4.7	4.5	3.8	PI 628905	USA	3.8	moderately susceptible
BSPS 27A	3.0	3.8	4.1	4.1	3.8	PI 567190	USA	3.8	moderately susceptible
Maksoy 5N	2.6	3.7	4.3	4.5	3.8	PI 606397B	USA	3.8	moderately susceptible
PI 200526	2.3	3.7	4.7	4.4	3.8	PI 628889	USA	3.8	moderately susceptible
Maksoy3N	2.3	3.7	4.5	4.5	3.8	PI 628919	USA	3.8	moderately susceptible
Nam 2	2.5	4.3	4.6	3.8	3.8	PI 594538A	USA	3.8	moderately susceptible
BSPS 75B	2.4	4.1	4.7	4.0	3.8	PI 567123	USA	3.9	moderately susceptible
PI 462312	2.0	3.8	4.5	4.8	3.8	PI 628934	USA	3.9	moderately susceptible
13.14	2.5	4.0	4.3	4.4	3.8	PI 606440A	USA	3.9	moderately susceptible
PI 417132B	2.3	4.0	4.5	4.5	3.8	PI 635999	USA	3.9	moderately susceptible
Roan	2.2	3.9	4.5	4.7	3.8	PI 628959	USA	3.9	moderately susceptible
SCSI	2.4	3.8	4.7	4.5	3.8	PI 200526	USA	3.9	moderately susceptible
9.2	2.5	4.4	4.4	4.2	3.9	PI 628887	USA	3.9	moderately susceptible
BSPS 48A-21B	2.7	4.0	4.5	4.3	3.9	PI 476905A	USA	3.9	moderately susceptible
Safari	2.6	4.0	4.6	4.2	3.9	PI 506695	USA	3.9	moderately susceptible
GC 00138-29	2.8	4.0	4.6	4.1	3.9	PI 506491	USA	3.9	moderately susceptible
PI 628889	2.5	3.9	4.4	4.6	3.9	PI 417132	USA	3.9	moderately susceptible
PI 628934	2.4	3.7	4.6	4.8	3.9	PI 628907	USA	4.0	moderately susceptible
UG5	2.8	4.4	4.3	4.0	3.9	PI 628908	USA	4.0	moderately susceptible
PI 506764	2.4	3.7	4.8	4.6	3.9	PI 471904	USA	4.0	moderately susceptible
PI 628932	2.1	4.1	4.7	4.6	3.9	PI 628812	USA	4.0	moderately susceptible
PI 628830	2.4	4.0	4.7	4.6	3.9	PI 506764	USA	4.0	moderately susceptible
3.16	2.7	3.8	4.6	4.5	3.9	PI 628904	USA	4.1	moderately susceptible
PI 287197	2.5	4.3	4.6	4.4	3.9	PI 628863	USA	4.1	moderately susceptible

PI 628887	2.4	4.0	4.7	4.7	3.9	PI 628827	USA	4.1	moderately susceptible
GC 487021-26-3-1	2.7	4.1	4.6	4.3	4.0	PI 417132B	USA	4.1	moderately susceptible
AGS 292	2.5	4.4	4.1	4.9	4.0	PI 200488	USA	4.1	moderately susceptible
SRE-B-15C	2.8	4.4	4.5	4.3	4.0	PI 567189A	USA	4.1	moderately susceptible
BSPS 48A-19	2.9	4.1	4.4	4.6	4.0	PI 605823	USA	4.2	moderately susceptible
548360	2.9	4.1	4.5	4.5	4.0	PI 628830	USA	4.2	moderately susceptible
BSPS 48A-5	2.6	4.2	4.5	4.7	4.0	PI 628933	USA	4.2	moderately susceptible
Nam 4M	2.8	4.2	4.7	4.3	4.0	PI 567104B	USA	4.2	moderately susceptible
BSPS 24.2A-3	2.7	4.6	4.5	4.3	4.0	PI 628960	USA	4.2	moderately susceptible
PI 628827	3.0	4.3	4.5	4.2	4.0	PI 626832	USA	4.2	moderately susceptible
PI 628812	2.2	4.0	4.9	5.0	4.0	PI 203398	USA	4.2	moderately susceptible
BSPS 48A-1	3.2	4.5	4.5	4.0	4.0	PI 605885B	USA	4.2	moderately susceptible
Kuntz	2.5	4.4	4.7	4.6	4.1	Kuntz	USA	4.2	moderately susceptible
G57	2.9	4.3	4.5	4.5	4.1	PI 417120	USA	4.2	moderately susceptible
Duiker	2.7	4.1	4.8	4.7	4.1	PI 628932	USA	4.2	moderately susceptible
AGS 338	2.8	4.2	4.6	4.8	4.1	PI 567024	USA	4.3	moderately susceptible
Siesta	2.8	4.5	4.7	4.4	4.1	PI 628850	USA	4.3	moderately susceptible
PI 628904	2.6	4.5	4.8	4.6	4.1	PI 628833	USA	4.3	moderately susceptible
PI 635999	3.3	4.5	4.7	4.0	4.1	PI 628915	USA	4.3	moderately susceptible
PI 628850	2.4	4.5	4.7	4.9	4.1	PI 287197	USA	4.3	moderately susceptible
BSPS 42	3.3	4.4	4.5	4.3	4.1	PI 628948	USA	4.4	moderately susceptible
NGDT BLP 12.4	2.4	4.3	4.9	5.0	4.2	Soprano	Zimbabwe	3.5	moderately resistant
PI 628855	3.4	4.2	4.6	4.4	4.2	Dinamri	Zimbabwe	3.5	moderately susceptible
PI 459025	2.7	4.5	4.9	4.5	4.2	Santa	Zimbabwe	3.6	moderately susceptible
G 7955	2.7	4.6	5.0	4.4	4.2	Duiker	Zimbabwe	3.8	moderately susceptible
PI 605823	2.9	4.7	4.8	4.3	4.2	Serenade	Zimbabwe	3.8	moderately susceptible
PI 628933	3.1	4.2	4.7	4.7	4.2	Solitaire	Zimbabwe	3.8	moderately susceptible
NGDT 8.11	3.1	4.5	4.6	4.5	4.2	Roan	Zimbabwe	3.8	moderately susceptible
Wondersoy	2.7	4.5	4.7	4.9	4.2	Safari	Zimbabwe	3.9	moderately susceptible

PI 606440A	3.2	4.2	4.8	4.5	4.2	Siesta	Zimbabwe	4.4	moderately susceptible
7.11	3.2	4.5	4.4	4.6	4.2	S 4.21	IITA	2.6	moderately resistant
BSPS 48C	3.1	4.9	4.6	4.1	4.2	6.22	IITA	3.0	moderately resistant
PI 628863	3.1	4.5	4.6	4.7	4.2	12.17	IITA	3.1	moderately resistant
PI 594538A	2.9	4.4	4.8	4.9	4.2	13.2	IITA	3.1	moderately resistant
Maksoy 4N	3.3	4.9	4.5	4.2	4.2	16.12	IITA	3.2	moderately resistant
BSPS 182A	2.8	4.6	4.8	4.7	4.2	1.19	IITA	3.4	moderately resistant
Maksoy2N	2.8	4.7	4.8	4.6	4.3	13.2A	IITA	3.6	moderately susceptible
BSPS 48A-14	3.1	4.5	4.7	4.7	4.3	3.17	IITA	3.6	moderately susceptible
PI 628833	2.8	4.6	4.8	4.8	4.3	5.18	IITA	3.7	moderately susceptible
PI 628915	3.1	4.8	4.6	4.6	4.3	9.2	IITA	3.9	moderately susceptible
NGDT 2.15-4	3.5	4.4	4.6	4.5	4.3	3.7	IITA	3.9	moderately susceptible
PI 628960	3.2	4.6	4.7	4.6	4.3	13.14	IITA	4.0	moderately susceptible
PI 606397B	2.8	4.7	4.9	4.9	4.3	7.11	IITA	4.0	moderately susceptible
NGDT 2.15-10	3.3	4.5	4.8	4.8	4.4	3.16	IITA	4.0	moderately susceptible
K-local	3.5	4.6	4.8	4.7	4.4	11.1	IITA	4.2	moderately susceptible
DXT 16.6-2	3.2	4.8	4.8	4.8	4.4	10.41	IITA	4.3	moderately susceptible
PI 628948	3.1	4.8	4.9	4.9	4.4	Maksoy 1N	IITA	3.8	moderately susceptible
BSPS 47B	3.2	4.6	5.1	5.0	4.5	Nam 2	IITA	3.1	moderately resistant
BSPS 62C-1	3.6	4.8	4.9	5.0	4.6	Wondersoy	IITA	3.8	moderately susceptible
Mean	2.4	3.8	4.2	4.1	3.6				
LSD	0.74	0.72	0.8	0.8	0.8				
%CV	21.6	13.6	13.6	13.9	15.7				

LSD is least significant difference

Appendix 5: Mean yield (kg/ha) across and within environments

Mean yield across environments					Mean yield across environments				
Genotype	(kg/ha)	Iki Iki A	Iki Iki B	NaSARRI	Genotype	(kg/ha)	Iki Iki A	Iki Iki B	NaSARRI
GC 487021-26-3-1	418.4	482.7	497.5	278.3	PI 628855	280.9	235.5	268.7	330.8
BSPS 47B	200.9	162.2	188.1	230.2	12.17	249.9	257.1	276.9	245.8
K-local	290.2	216.8	278.0	367.9	PI 567102B	364.2	417.0	366.3	297.9
PI 628915	283.5	187.8	200.0	457.0	PI 615437	442.9	490.6	401.4	435.9
PI 628904	399.8	306.1	377.5	510.3	PI 605885B	316.9	333.7	347.7	274.8
PI 628905	251.4	242.5	305.3	198.1	PI 594538A	350.6	207.5	245.7	590.0
PI 628863	206.0	180.9	189.5	238.0	BSPS 75B	311.1	265.4	302.8	368.5
NGDT 2.15-4	220.7	187.8	194.8	286.7	Soprano	327.4	251.4	300.9	419.3
PI 628887	320.6	300.6	304.1	379.6	8527	255.8	232.1	251.8	288.7
PI 628948	279.7	231.4	268.2	333.3	5.18	240.4	170.5	159.3	402.8
PI 578457A	377.2	308.7	367.8	458.5	Maksoy 1N	393.2	331.5	382.6	470.6
GC 00138-29	478.7	566.3	551.1	316.5	PI 628907	276.5	225.1	270.4	318.0
PI 567046A	379.7	268.1	323.2	541.7	AGS 292	287.0	306.4	357.0	211.0
PI 567190	321.7	284.5	344.1	336.1	G 2043	235.1	215.6	230.6	273.8
1882	225.5	214.3	243.3	212.3	PI 548360	314.2	302.7	340.0	303.3
PI 605823	355.8	266.6	321.9	474.1	SCSI	387.9	309.1	372.5	479.4
9.2	357.8	267.8	329.5	507.4	PI 628919	288.8	283.9	334.3	245.8
G 7955	339.3	314.9	357.6	350.6	PI 462312	317.1	309.9	312.6	332.5
PI 416810	215.5	196.3	209.0	241.9	Namsoy 3	530.6	482.2	626.8	494.5
PI 605638	334.5	247.9	318.5	422.2	PI 417126	381.3	287.8	374.2	474.5
PI 628960	312.1	288.0	348.9	300.7	PI 628959	412.5	337.6	414.1	491.4
G 50	245.9	192.2	233.9	310.9	BSPS 27A	320.3	297.4	365.3	284.7
Safari	354.2	311.3	362.4	389.2	Siesta	389.1	336.0	425.8	399.0
Santa	417.4	393.7	521.1	367.5	DXT 16.6-2	269.7	210.5	222.0	373.6

PI 628933	287.1	259.4	302.3	306.7	BSPS 24.2A-3	345.1	309.1	311.1	401.4
BSPS 48A-5	301.2	283.1	283.7	323.8	SRE-C-14A	405.8	359.3	460.8	390.7
GC 84051-31-1	413.0	346.9	323.6	552.4	PI 644103	300.0	272.0	342.2	274.6
PI 200526	243.3	230.2	253.0	259.9	PI 628908	497.4	444.6	422.2	645.9
G 10428	355.4	294.9	327.6	448.9	Nam 4M	281.0	210.9	234.5	388.0
PI 476905A	292.4	298.7	355.4	211.7	BSPS 62C-1	259.5	197.9	243.5	322.2
PI 628813	432.6	346.0	419.5	535.3	SS 86045-23-2	420.7	399.6	517.1	331.2
PI 417503	359.6	374.8	485.9	207.6	BSPS 42	297.7	216.7	241.1	444.6
PI 567034	311.0	324.1	395.0	211.1	PI 200488	266.5	202.8	217.3	386.7
BSPS 48A-1	320.3	276.4	333.3	344.5	PI 628827	278.3	240.0	276.1	327.9
PI 628812	275.8	293.3	290.2	239.1	SRE-B-15C	387.3	342.1	379.3	436.6
PI 506764	196.9	197.5	197.9	190.1	PI 628830	322.9	326.6	273.4	372.5
Nam1	429.2	330.9	399.4	564.3	Wondersoy	307.2	320.1	282.3	340.1
PI 416826A	215.4	200.2	235.6	191.0	NG 14.1-6B	454.7	362.5	478.2	515.0
PI 567025A	376.0	412.4	405.6	309.0	PI 59172	242.1	228.8	288.1	186.8
PI 506695	343.1	329.8	417.8	268.8	GC 8901-13-13	265.0	226.3	244.1	340.4
PI 605865B	358.3	373.1	337.3	358.3	Maksoy 4N	281.9	244.8	288.2	306.7
13.14	329.3	255.6	328.9	402.6	Nam II x GC 4.1-2	290.3	262.1	302.8	295.5
Dinamri	294.0	243.5	278.3	359.6	PI 628918	244.7	227.6	239.4	278.8
PI 628903	302.6	229.4	272.0	437.4	G 10427	276.8	249.5	295	314.7
3.17	404.5	287.3	357.4	591.3	11.1	343.0	275.0	316.7	447.2
G 32	372.6	336.1	417.3	371.7	7.11	315.4	328.6	348.1	296.5
PI 628934	371.0	278.5	330.8	502.9	Nam 2	279.9	251.5	262.6	330.6
Roan	418.1	400.7	534.6	303.3	G8586	380.6	356.8	405.7	400.1
GC48702-26-3-1	254.1	215	226.7	330.6	6.22	461.0	491.4	448.4	432.6
BSPS 48A-19	360.3	330.2	401.2	344.9	PI 506695	343.1	327.4	410.3	278.0
Solitaire	517.3	453.7	503.6	583.8	PI 628932	295.1	235.7	272.8	363.0
PI 287197	362.1	272.2	353.1	438.5	PI 459025	391.5	353.5	436.2	379.9
BSPS 48A-14	353.4	331.2	371.8	342.2	PI 628925	308.9	209.1	232.8	471.4
NGDT 2.15-10	293.3	238.4	266.6	381.9	PI 567024	467.5	572.0	574.7	244.6
PI 606405	339.0	352.3	435.6	243.8	PI 606440A	319.0	267.2	316.2	365.8

SRE-D-11-13	280.4	225.4	268.6	377.5	PI 628889	357.8	316.7	379.2	387.2
PI 506491	290.8	310.1	374.1	195.2	Serenade	274.9	234.2	269.5	311.4
BSPS 48A-21B	280.2	237.8	227.6	367.8	PI 417120	320.8	331.3	411.5	220.2
PI 567104B	300.7	276.3	298.1	329.0	PI 606397B	356.4	359.5	414.3	280.5
BSPS 182A	297.1	270.3	312.9	296.7	Gazelle	295.9	267.2	304.3	327.8
PI 635999	326.2	321.4	400.8	249.5	PI 605854B	381.0	269.2	305.4	563.4
Kab 1	385.4	347.3	428.1	395.5	1.19	354.6	286.7	349.3	422.3
13.2A	462.2	426.8	552.2	399.6	3.7	393.7	325.4	430.1	421.6
4.21	395.2	387.0	307.7	496.5	Maksoy3N	346.9	331.9	295.5	426.5
PI 567123	306.2	244.4	267.0	410.3	G 7959	285.3	276.1	300.0	283.3
13.2	323.3	260.3	347.7	351.9	PI 417132	426.1	425.2	537.8	299.1
PI 203398	446.9	447.0	503.6	393.5	UG5	352.4	259.6	307.1	476.2
Duiker	344.1	235.9	259.0	551.5	NII GC 4.1-2	366.1	332.0	402.8	366.8
PI 417132B	320.0	249.3	281.6	434.7	PI 567053	294.7	242.1	266.8	380.4
PI 628850	304.3	265.2	324.8	349.8	16.12	326.9	290.2	335.3	339.1
BSPS 48C	312.4	285.6	336.8	312.4	PI 471904	387.3	386.3	493.6	279.8
PI 587056A	463.8	387.6	486.5	531.5	3.16	361.4	282.7	310.0	495.0
PI 628811	307.1	242.3	280.4	384.2	NGDT 8.11	260.8	212.9	236.6	332.7
PI 567059	257.3	160.2	167.3	471.5	G57	429.3	407.8	460.8	448.0
10.41	355.4	348.7	320.2	427.5	NGDT BLP 12.4	310.4	210.2	250.6	451.0
PI 628833	372.1	347.2	338.1	408.5	GC 85037-2-3-54	479.0	475.6	474.8	485.9
Maksoy2N	272.7	229.8	268.4	309.3	G2843	342.6	241.7	281.8	498.9
Maksoy 5N	430.4	476.9	433.9	361.0	PI 626832	409.5	275.5	316.8	647.8
PI 567189A	336.7	335.2	408.7	261.6	AGS 338	257.8	250.5	291.2	224.1
Kuntz	259.8	188.8	225.1	361.6	PI 417089A	206.5	201.3	218.9	200.7
Mean	333.4	296.4	336.6	367.4	Mean	333.4	296.4	336.6	367.4
LSD	113.1	193.3	227.9	235.1	LSD	113.1	193.3	227.9	235.1
CV%	29.9	33.0	34.3	32.4	CV%	29.9	33.0	34.3	32.4

LSD is least significant difference

