Beetle Pests in Sri Lanka: Current Challenges, Knowledge and Emerging Threats to Agriculture and Biodiversity

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Abstract

Beetles represent a significant portion of Sri Lanka's biodiversity, with 115 families (ca. 3,033 species) documented, making them the largest faunal group on the island. The larval and adult phases of about 75% of beetle species are phytophagous and considering their significant damage to economically important crops for agriculture. Substantial agricultural yield is lost each year due to rapid insect infestations could significantly impact national food availability. It is extremely necessary to document insect pests in the country fundamental to pest management strategies. This review focuses on enhancing the understanding of major beetle pest species that affect crops such as vegetables, fruits, grains, coconut, rubber, rice and tea. The review encompasses 60 species from 14 families, with a predominant presence of pests from the Chrysomelidae, Scarabaidae, Curculionidae, Cerambycidae and Meloidae families. Recent field observations suggest significant damage to cashew plants in Wanathawilluwa. Phytophagous beetles significantly impact vegetable crops in the Solanaceae and Cucurbitaceae families by feeding on soft tissues. Larvae contribute to damage by attacking roots and stems, causing necrosis. Within families Coccinellidae, Carabidae, and Cicindelidae, many beetles exhibit predatory behaviours, while some demonstrate phytophagous tendencies as opportunistic feeders. Beetle pests in families Curculionidae, Cerambycidae, and Scolytidae are predominantly associated with woody crops. Understanding the economic pest status of these beetles and their sporadic population dynamics is crucial due to past outbreaks in neighbouring countries, highlighting potential risks to agriculture and ecosystems.

Keywords: Beetle, Pests, Agriculture, Crops, Phytophagous

I. INTRODUCTION

Coleoptera commonly known as Beetles are the most diverse group of animals on earth. They encompass almost 25% of all defined animals (Powel, 2009; Sharma, et al., 2019). The diversity of beetles is very wide with a cosmopolitan distribution; they are found in all habitats with a few in marine settings, except in extreme environments (Banerjee, 2014; Springer, 2009). Sri Lanka, a tropical island exhibiting remarkable biological diversity thus is designated as one of the world's biodiversity hotspots along with the Western Ghats of India (Myers et al., 2000). According to the numerical records, 3,033 species of coleopterans belonging to 115 families are documented from Sri Lanka (Bambaradeniya, 2006).

The larval and adult phases of about 75% of beetle species are phytophagous (Gullan & Cranston, 2010). Since most beetles are herbivores, and then considering their significant damage to economically important crops for agriculture, forestry, and household settings, are often deemed as one of the most destructive groups of pests worldwide (Gilliott, 1995; Patole, 2017; Kailash, et al., 2015). The percentage of beetle species that are pests is relatively low. However, they are particularly significant in tropical countries like Sri Lanka, where the environment and cropping conditions favor their development. The country's agricultural sector accounts for approximately 7% of the national Gross Domestic Product (GDP), with more than 30% of the country's population employed within the agriculture sector (ITA, 2024). Addressing the increasing food demand driven by population growth is a paramount global concern, but the substantial agricultural yield is lost each year due to rapid insect infestations (Bandara & Harshana, 2019). Insect pests inflict damage on crops at different growth stages, leading to annual losses ranging from 25% to 30%, which could significantly impact national food availability (Bandara & Harshana, 2019). Thus, research must focus on major insect pests and their outbreaks which is fundamental for the implementation of pest management strategies (Bandara & Harshana, 2019).

The fall armyworm (*Spodoptera frugiperda*) (Order Leoidoptera) was the worst pest infestation in the country's history which led to a substantial yield loss in 2018 over six months in corn (Hettiarachchi, et al., 2024; Wijerathna, et al., 2021; Perera, et al., 2019). Over 50% of the cultivation (54,416 hectares) has been infested in Uva, Eastern, and North Central provinces (Perera, et al., 2019). In 2020, a sporadic increase in crop-damaging yellow-spotted grasshoppers (*Aularches miliaris*) was recorded in the North Western Province in coconut and rubber cultivations (Rodrigo, 2020). A similar outbreak was reported on coconut plantations in Gampaha, Kegalle, Kandy, Kalutara, Colombo, Kurunegala, Ratnapura, Puttalam, and even the southern province of *Aleurodicus dispersus* (Spiralling whitefly) in 2019, resulting in considerable net yield loss (Silva, 2022). Rice, the primary food crop grown in Sri Lanka, is predominantly affected by the brown plant hopper (*Nilaparvata lugens*), leading to annual imports of milled rice ranging from 20,000 to 600,000 tonnes (Bandara & Harshana, 2019). There is an equal tendency to spike the beetle population to an endemic proportion in terms of past experience with the sudden emergence of some beetle species and the sporadic increase of the population in regional countries during past decades. Nevertheless, this scenario is expected to further intensify mainly due to climate change (Bentz et al., 2010; Jakoby et al., 2019). Recent researches have shown that such outbreaks have increasingly challenged traditional responses, and highlight the need for a more comprehensive management framework (Hlásny et al., 2021). Therefore, it is extremely timely and necessary to document insect pests in the country, starting with a particular class or order and then expanding to other classes and orders. This review focuses on efforts made to understand some of the major coleopteran pests in the country, providing detailed accounts of their host plants, distribution, and the nature of the damage they cause.

II. COLEOPTERAN PESTS OF MAJOR CROPS

The faunal communities within the Chrysomelidae, Cerambycidae, and Curculionoidae families are frequently deemed pests, primarily targeting agriculturally vital vegetable crops. Beetles of the family Scarabaeidae exhibit phytophagous tendencies with a diverse array of feeding behaviors. For instance, Dynastinae primarily feed on stems or roots, Cetoniinae consume sap, fruit, and flowers, Rutelinae target foliage, fruit, and flowers, while Melolonthinae feed on foliage. The soil-dwelling larvae of chafers predominantly consume live roots and have the potential to kill seedlings, mature plants by reducing the drought tolerance (Jackson & Klein, 2006). The prevailing observation indicates that the majority of species in coleopteran families, Coccinellidae, Carabidae, Cicindelidae primarily engage in predation, preying upon other insects and associated organisms serving as natural enemies. While numerous species exhibit phytophagous tendencies, many are opportunistic feeders, consuming a diverse array of food sources, damaging by sucking the sap from the flowers, buds, pods, tender shoots and reduce the market value of the products (Carvalho, et al., 2010; Cornelisse, et al., 2013).

A. Coleopteran Pests of Vegetables, Fruits, and Grains

Leafy vegetables constitute a vital element of the Sri Lankan diet and have been subjected to commercial cultivation. Flea beetle, *Chaetocnema* spp. (Chrysomelidae) has been recorded as an economically significant pest of green leaves (Table 01), serving as a primary threat to Mugunuwanna (*Alternanthera sesilis* L.) (Wahundeniya et al., 2005; Marasinghe and Nishantha, 2018). Flea weevil, *Tachyerges* spp. (Curculinoidae), has been identified as a new pest of leafy vegetables, Mukunuwenna (Hackston, 2020). This pest has been identified as an occasional threat to leafy vegetables across three districts, with particularly high leaf damage observed in the Gannourwa area during July-August 2017. Laboratory studies show that it can also damage various other leafy vegetable crops (Table 01) (Kumari, et al., 2022). A sweet potato flea beetle, *Chaetocnema confinis* Crotch. (Chrysomelidae) was discovered, causing extensive damage to Kankun (*Ipomoea aqutica*) in the Gannoruwa area during January-February 2018, reaching 100% crop loss. The damage initially appeared as whitish streaks on the leaves, progressing to yellow and brown discoloration, ultimately resulting in the complete destruction of the crop. Feeding studies confirmed that this species did not damage Mukunuwenna. These findings validate the existence of the invasive flea beetle species, *C. confinis*, within Sri Lanka, that not previously been documented (Kumari, et al., 2022).

Mohamedsaid (1979), studied the taxonomy of blister beetles (Meloidae) together with seasonal and geographic distribution and compared the meloid fauna of the island with rnainland India. *Mylabris pustulata* (Thunberg) is recorded as the most commonly collected species of Meloidae in Sri Lanka (Mohamedsaid, 1979). The species are geographically distributed throughout the island with the greatest abundance in regions receiving between 50-100 inches of rainfall annually, with peaks of abundance in April, June, and August (Mohamedsaid, 1979). According to Singh, et al., (1968) adult beetles recorded as a serious pest of cucurbitaceous crops and soybeans. Bhagwat (1995), surveyed Pigeon pea variety pests in Sri Lanka, covering six districts in farmers' fields and on Mahailluppallama research station and observed *Mylabris* sp. and Jewel beetles (*Sphenoptera* sp.) (Buprestidae) damaging pigeon pea stems seriously. Thuvaraka and Pakeerathan (2023), studied on eco-friendly management of hadda beetle, (*Henosepilachna* spp.) (Coccinellidae) which is a significant insect pest in brinjal cultivation across northern Sri Lanka. This polyphagous pest targets economically vital crops of the Solanaceae and Cucurbitaceae families (Table 01). *Epilachna vigintioctopunctata*, another phytophagous coccinellid, commonly known as the Epilachna beetle or cucurbit beetle, is a significant pest of cucurbitaceous and solanacaeous crops in Sri Lanka. Both the adult and larva of this beetle feed on the epidermal tissues of leaves, often stripping them down to the midrib, which can lead to the death of the plant (Karunaratne & Arukwatta, 2009). Mayadunnage, et al. (2007), conducted an extensive survey of predatory coccinellid beetles in vegetable-growing areas in the Mid Country, Sri Lanka, and recorded 15 different species belonging to 12 genera.

Abeywardhana and Dangalle (2021), conducted a survey on Arboreal Tiger Beetles (Cicindelidae) in Lowland Crop Cultivations in Sri Lanka, marking the first documentation of such beetles in crop cultivations in the country. Among the notable findings, *Derocrania scitiscabra* was the most commonly encountered species in betel leaf cultivation in the dry zone of Aralaganwila. Additionally, other species of the genus *Derocrania* were found in fruit farms in Vellankulam, and were observed in cinnamon and pepper cultivations in Waulpane (Table 1). Furthermore, observations by Jaskula (2013), indicate that tiger beetles may exhibit vegetarian feeding behavior during periods of low prey availability, admitting both suitable prey and vegetarian food sources. Additionally, reports indicate that species of the *Neocollyris* and *Tricondyla* genera lay their eggs on young branches of Arabic coffee and Liberian coffee trees, suggesting a potential reliance on specific plant species in Sri Lankan crop cultivations for their life cycle completion (Abeywardhana, et al., 2021). The larval stage of *Holotrichia serrata,* (sugarcane white grub), is recognized as a significant threat to sugarcane crops in Sri Lanka. In September 2012, an epidemic of this beetle was noted in soybean, cotton, and pigeon pea environments in Vidarbha, India (Dadmal, et al., 2013). Besides sugarcane, it poses a significant threat to various vegetables (Table 1). Observations in Sri Lanka have revealed that the grubs feed on the tap roots of teak seedlings, causing affected plants to wither and eventually perish, widely recorded from Sabaragamuwa province (Bandara, 1990; Bunalski, 1995). *Holotrichia reynaudi*, *Holotrichia rufoflava,* species of dung beetles recorded from the island, especially from Western and North Western provinces, and is considered as major pests on Peanuts, *Arachis hypogaea* in India (Kumar, et al., 2020; Bunalski, 1995). *Adoretus versutus*, commonly referred to as the rose beetle, originates from Oriental regions and is prevalent in numerous Asian countries, including Sri Lanka. The larvae of these beetles pose a threat to the roots of wild turmeric. Capable of triggering outbreaks, this pest can cause extensive defoliation across various crops (Table 01). A notable case occurred in Vanuatu, where the rose beetle was introduced in 1982 on Efate Island and inflicted significant damage in 1988 and 1989 on Espiritu Santo Island (Beaudoin, 1992). The Sri Lankan weevil, *Myllocerus undecimpustulatus* *undatus* Marshall (Curculionidae), native to Sri Lanka, was initially recognized as causing damage to the leaves of winged bean, *Psophocarpus tetragonolobus* (Shanthichandra et al., 1990). The weevil considered as a pest of more than 20 crops. The larvae feed on plant roots for approximately one to two months. It is unclear which plants serve as hosts for the larvae, but they have been successfully reared in laboratory conditions using pepper, eggplant, cotton, carrot, and sweet potato roots. The leaf-feeding adults exhibit a wide host range, including native, ornamental, vegetable, and fruit species (Neal, 2013) (Table 01). Another *Myllocerus* species, *Myllocerus viridanus*, grey weevils, (Curculionidae), constitute a significant pest native to Sri Lanka and India, with a broad spectrum of host plants (Table 01) (Butani, 1979). Thangavelu et al. (1974), documented severe outbreak on *Corchorus olitorius* L., a type of green leaves used in Ayurveda, originating from Tamil Nadu. Additionally, it has been established as a pest of Moringa (*Moringa pterygosperma* Gaertn) (Kotikal & Math, 2016).

B. Coleopteran Pests of Coconuts

The coconut is an economically significant crop that plays a crucial role in social and cultural activities in Sri Lanka. It is cultivated in 92 countries globally, with Sri Lanka ranked as the fourth-largest producer (Winotai, 2014). Beetle pests have emerged as a significant threat to coconut cultivation by damaging flowers, feeding on nuts, roots, and seedlings (Table 01). The coconut leaf miner (*Promecotheca cumingii*) (Hispidae), first recorded as a beetle pest of coconuts in Sri Lanka in 1970 (Perera, 1979), was initially observed in Dehiwala but soon spread to other areas in the Western, Southern, and Northwestern Provinces. Although it is controlled by natural enemies, occasional outbreaks have been recorded. Apart from coconuts, *P. cumingi* has been reported to attack arecanut, swamp palm, sago palm, royal palm, and oil palm, although in Sri Lanka it has only been detected on coconut, oil palm, and royal palm (Perera, 1979) The Plesispa beetle, scientifically known as *Plesispa reichei* (Chrysomelidae), was first reported in 1997 from Badalgama in Gampaha District, and it has since become widespread throughout the coconut triangle (CRI, 2006). The Red Palm Weevil was first discovered in the early 20th century in South and Southeast Asia. In Sri Lanka, it is a significant pest that causes severe damage to young coconut palms aged 3–10 years. Reports indicate that around 10% of young coconut palms in the country are lost each year due to its attacks (Table 01) (Kumara, et al., 2015). The *Oryctes rhinoceros*, (Scarabaeidae), commonly known as the rhinoceros beetle or coconut black beetle, targets developing fronds of tropical palms across Asia (Kumara, et al., 2015).

C. Coleopteran Pests of Tea

Xyleborus fornicatus Eichh., a twig-boring ambrosia beetle (Scolytidae), was first documented as a tea pest in 1868. It inflicts two types of damage: primary injury through the construction of galleries in stems, which can cause branch breakages, and secondary injury from wood rot, ultimately weakening the tea plants (Walgama, 2012). *Euwallacea perbrevis* Schedl, known as the shothole borer (Curculionidae), has been a significant pest of tea in Sri Lanka and India for more than a century. It is also economically important as a pest of avocado. Since the early 1900s, Sri Lankan tea growers have been plagued by this insect, which creates galleries inside the wood of the terminal branches of the tea crown (Liao, et al., 2023).

D. Coleopteran Pests of Rubber

The larvae of the Cockchafer beetle, *Melolontha* spp. (Scarabaeidae), pose a significant threat to rubber cultivation by feeding on rubber roots. Grub infestation reached endemic propotions during 2002 in Awissawella area destroying young rubber clearings which have spread to the Ratnapura, Kegalle and Kalutara districts presently. They consume lateral roots and can also damage the cortex of the taproot, leading to shoot dieback (Gurusinghe, 2019).

E. Coleopteran Pests of Rice

According to Perera and Karunaratne (2015), grain losses during storage, primarily caused by various agents of grain deterioration, range from 4% to 6%. Among these losses, 80% are attributed to insect infestations (Table 1). In Sri Lanka, rice weevil (*Sitophilus oryzae*), grain moth (*Sitotroga cerealella*), and red flour beetle (*Tribolium casteneum*) are identified as highly damaging pests of stored paddy and rice, and *Sitophilu* spp., is recognized globally as the most significant pest affecting stored paddy and rice (Perera & Karunaratne, 2015) which two species have been recognized in Sri Lanka (DOA, 2024). Pathak and Khan (1994), listed *Coccinella repanda*

(Thunberg) (Coccinellidae), a ladybird beetle as feeding on rice plants in Sri Lanka (Table 01).

Table 01: Coleopteran pests of major Agricultural crops in Sri Lanka

Species Name	Family	Host Plants	Nature of Damage	Reference
Protaetia alboguttata (Vigors)	Scarabeidae	Karonda (*Carissa carandas),* Star fruit (*Averrhoa carambola),* Brinjal	Feed on the flesh of the fruit by gouging with the horn in the front of the head and burying 3/4th of mouth parts into the fruit, Feed on tender shoots, flowers and flower buds during early morning,	(Jayanthi, et al., 2017)
Red pumpkin beetle *Aulacophora foveicollis* (Lucas)	Chrysomelidae	Cucumber, Bitter gourd, Sponge gourd, Ash gourd, Pumpkin, Melon	Feed on the leaf blade, perforate giving appearance of lace, eventually defoliated, Flowers and fruits are eaten and cut, larvae attack the roots and stems causing necrosis	(Khursheed and Raj, 2020)
Coccinella transversalis	Coccinellidae	Beans, Cotton, Mustard, Brinjal, Groundnut, Cabbage	Adults and nymphs cause damage by sucking the sap from the flowers, buds, pods, tender shoots	(Mayadunnage, et al., 2007), (Rajan, et al., 2018)
Rose beetle *Adoretus versutus*	Scarabeidae	Cashew, Taro (*Colocasia esculenta*), *Citrus* sp., Ginger, Cowpea, Radish	Perforate the leaf lets starting from the middle without destroying the ribs, make depressions in the border of the areas eaten, feed in the early hours of the night	(Beaudoin, 1992)
Mango ash weevil *Myllocerus discolor*	Curculionidae	Maize, *Citrus* sp., *Sorghum bicolor,* Brinjal, Soyabean	Feed on leaves, nibbling the leaves from the margins and eaten away small patches of leaf lamina	(Das and Das, 2016)
Myllocerus subfasciatus	Curculionidae	Brinjal	Damage leaves forming characteristic leaf notch symptoms, The grubs are subterranean and cause root damage resulting in wilting, drying and death	(Shanmugam, et al., 2018)
Apogonia blanchardi	Scarabeidae	Greengram, Cocova	Feed on the leaf from the peripheral region	(Calcetas, et al., 2021)
Pulse beetle *Callosobruchus chinensis*	Chrysomelidae	Bean, Black gram, Chickpea, Pigeonpea, Pea, Cowpea	Lay eggs on green pods and the larva bore through pod and feed on the developing seed, the insects continue to feed, emerge to adults and cause further infestation in harvested yields	(Arora, 1977; Singhal, 1986; Sirinivasan, et al., 2008)

Xyleborus perforans	Curculionidae	Jackfruit, Citrus spp., Cashew, Coconut	Bore into the xylem of the plant, and carry with them symbiotic fungi which grow in the galleries, and upon which the adults and larvae feed	(Rabaglia, et al., 2020; Winotai, 2014)
Scymnus latemaculatus	Coccinellidae	Mustard, Cabbage, Cauliflower, Potato, Turnip, Bottle gourd, Brinjal, Okra, Wheat	Both grubs and adults feed on upper surface of the leaves	(Janakiraman and Booth, 2021), (Ali, et al., 2018)
Henosepilachna septima	Coccinellidae	Bitter gourd , Ribbed gourd, Bitter Melon	Both grubs and adults feed on leaves, stem and fruit throughout the crop stages and results in skeletonizing the leaves	(Naz and Inayatullah , 2013), (Ganga, et al., 1985)
Sri Lankan weevil *Myllocerus undecimpustulatus undatus Marshall*	Curculionidae	*Citrus* sp., Pepper, Strawberry, Eggplant, Cotton, Carrot, Sweet potato	Feed on leaves inward from the leaf margins causing the typical leaf notching. When the leaf material is almost completely defoliated, where the weevil has fed along the leaf veins	(Neal, 2013)
White grub *Holotrichia serrata*	Scarabaeidae	Peanut, Pegion pea, Arecanut, Potato, Jack fruit, Soybean, Sugarcane, Tobacco, Rubber, Rice	Feed on plant roots, causing yellowing, do not show immediate symptoms of damage resulting lifespan yield losses	(Bhattacharyya *et al.*, 2017)
Grey weevil *Myllocerus viridanus*	Curculionidae	Cashew, Ranawara *(Cassia auriculata L.)*, Tora (*Cassia tora* L.), Key lime (*Citrus aurantifolia)*, Sweet Potato, Drumstick, Curry leaves, Eggplant	Feed on leaves nibbling the margin and eating away small patches of leaf lamina and larvae feeds on the fibrous rootlets of the host plant	(Rajan and Ghosh, 2019) (Butani, 1979)
Flea beetle *Chaetocnema spp.*	Chrysomelidae	Mugunuwanna, (*Alternanthera sessilis linn*.) Thampala (*Amaranthus candatus*), Nivithi (*Spinacia oleracea*), Koora thampala	Damage upon the leaves by chewing, resulting formation of small round holes which appears as windows due to the presence of epidermis	(Kumari, et al., 2022).
Flea weevil *Tachyerges spp.*	Curculinoidae	Mugunuwanna, Thampala, Koora thampala	The adult prefers younger leaves for feeding, while the larvae create mines in mature leaves	(Kumari, et al., 2022)
Flower feeder *Mylabris pustulata*	Meloidae	Wax gourd , Field pumkin, Chinese Okra, Sponge Gourd (*luffa aegyptiaca*), , Peanuts, beans, Pumpkin, Okra, Zea mays, Mango	Feeding on buds, flowers, fruits, pollen tender leaves which leads to affect the fruit setting	(Rao, 1954), (Sharma and Singh, 2016), (Raju, et al., 2016) (Joshi and Gaur, 2019)

Mylabris thunbergii	Meloidae	Okra, peanut, Pigeon pea, Ceylon spinach (*Talinum fruticosum),* Blackgram (Vigna mungo), Cowpea (*Vigna unguiculata*), Greengram	Feeding on leaves, floral parts; petals, pollen, stigma secretions, and tender developing pods	(Durairaj and Ganapathi, 2003)
Hadda beetle *Henosepilachna vigintioctopunctata* F.	Coccinellidae	Tomato, Potato, Eggplant	Both the adult and larval stages feed on the epidermal tissues of leaves, flowers, and fruits	(Jamwal *et al.*, 2017) (Thuvaraka and Pakeerathan, 2023)
Cashew-tree borer *Plocaederus ferruginea*	Cerambycidae	Cashew	Grubs feed on cambium tissues stopping sap flow	(Wijetunge, et al., 2016)
Stem boring grey beetle *Apomecyna saltator*	Cerambycidae	Minor pests of cucurbitaceous vegetable crops	Grubs bore the stems and make tunnel inside, Adults feed on the soft portions of the stem	(Fernando & Abhayawardena, 1991; Kumar, et al., 2022)
Mango stem borer *Batocera rufomaculata*	Cerambycidae	Mango, Durian, Jackfruit, Mulberry, Papaya, Apple	Grubs enter stems, creating tunnels that dry shoots and entire trees, resembling burned foliage in severe cases, significantly reducing yield	(Atapattu, 2015; Magar, et al., 2022)
Banana pseudostem weevil *Odoiporus longicollis* Oliver	Curculionidae	Monophagous pest of Banana plants	Larvae feed on pseudostem by tunnelling. In most of the cases the larvae goes deep into the pseudostem, adults are found to feed under the leaf sheaths	(Justin, et al., 2008)
Cherry stem borer *Aeolesthes holosericea* Fabricius	Cerambycidae	Cherry, Mulberry Apricot, Crab apple, Guava, Peach, Pear, Plum and Walnut etc.	Newly hatched grubs consume bark and create zigzag galleries before boring into and feeding on the sapwood.	(Patole, 2017)
Derocrania scitiscabra	Cicindelidae	Coconut cultivation mixed with pepper, Betel cultivation	Exhibit vegetarian feeding behavior during periods of low prey availability	(Abeywardhana, et al, 2021; Jaskula, 2013)
Derocrania concinna *Derocrania schaumi* *Tricondyla granulifera*	Cicindelidae	Fruit farm consisting of Mango and Cashew		Abeywardhana, et al, 2021)
Coffee stem borer *Xylotrechus quadripes* Chevrolat	Cerambycidae	Coffee	The larvae bore into the coffee stem, killing the young plants	(Patole, 2017)
Coffee-berry borer *Hypothenemus hampei* Ferrari	Scolytidae	Robusta and Arabica Coffee	Adult female attacks coffee berries and bore a hole into the coffee berry and then make galleries in the seeds where the eggs are deposited	(Patole, 2017)

Adoretus celogaster	Scarabaeidae	Coconut	Attack seedling leaf	(Winotai, 2014)
Phyllognatus dionysius F.	Scarabaeidae	Coconut	Attack mature plant leaves	(Winotai, 2014)
Oryctes rhinoceros L.	Scarabaeidae	Coconut, Oil palms, Date palms, Screwpine (*Pandanus*), Ornamental palms	Mature plant leaf eaters, reduced leaf area which influences nut production, with attack greater on tall, mature trees, from about 5 years of age onwards.	(Kumara, et al., 2015; Winotai, 2014)
Rhabdoscelus obscurus	Curculionidae	Coconut	Bore into the stem	(Winotai, 2014)
Asiatic red palm weevil *Rhynchophorus ferrugineus* Olivier	Curculionidae	Serious pest of Coconut, oil palms, date palms, sago, other species of Palmae	Feeding larvae bore into the crown of coconut and destroy it, outer leaves turn chlorotic and die, this gradually spreads to the innermost leaves, the trunk becomes tunneled and weakened	(Kumara, et al., 2015; Winotai, 2014)
Coconut leaf palm hispid *Plesispa reichei*	Chrysomelidae	Minor pest of coconut	Attack young palms around 3-4years old. both adults and larvae feed on young unopened leaflets and make feeding scars paralleled to the main vein, attack the tips of recently unfolded leaflets of mature plants	(Winotai, 2014)
Coconut weevil *Diocalandra frum enti* Fabricius	Curculionidae	Coconut palm, Date palm, Oil palms and Sorghum	The grubs attack all parts of the coconut palm particularly the roots, the leaves, and fruit stalks. As a result there is premature fruit fall	(Patole, 2017)
Rice root weevil *Echinocnemus oryzae*	Curculionidae	Rice	Both grubs and adult consume rice plants, grub stage reduce production by feed on roots. Adults in flooded or unflooded rice fields feed on young paddy leaves, leaving distinctive scars that run nearly parallel to the leaf veins.	(Mahala, et al., 2022)
Paddy black beetle *Heteronychus lioderes*	Scarabaeidae	Rice, Maize	Adult eat the subterranean stems and roots, impacted plants wilt and pass away. Upland rice is severely under attack.	(Mahala, et al., 2022; Sarkar, et al., 2014)
Rice Hispa *Dicladispa armigera*	Chrysomelidae	Rice	Grubs tunnel towards the leaf sheath, Adults initially remove chlorophyll in parallel white streaks along the main leaf	(Mahala, et al., 2022)

			axis, starting from the leaf tips. Mature beetles prefer the leaf's upper surface, each adult consume approximately 25 mm² of leaf daily.	
Coccinella repanda Thunberg	Coccinellidae	Rice pollen, panicle	In the absence of prey, feed on leaves, panicle, leaving small chewed areas, and frequently damage developing grains.	(Pathak and Khan, 1994)
Grain weevil *Sitophilus granerius* *Sitophilus oryzae*	Curculionidae	Rice, Grain products	Infestation starts in the field. Eggs laid on rice seeds, hatch into tiny grubs which feed the grain	(DOA, 2024)
Red flour beetle *Tribolium castaneum*	Tenebrionidae	Grain products	Secondary pests, feed on dust and fines of stored grains by constructing tunnels	(Wijayaratne and Egodawatta, 2021)
Cowpea weevil *Callosobruchus maculatus*	Chrysomelidae	Grain products, Stored legumes and seeds	Infestation starts in the field, larvae bore into the pulse grains and feed on endosperms	(Anuradha, et al., 2023)
Rusty Grain Beetle *Cryptolestes ferrugineus*	Laemophloeidae	Barley flour, Oats, Sorghum, Wheat flour, Maize, Corn	Both larvae and adults feed on stored nuts by boring inside, spreading fungal infection	(Thube, et al., 2017; Bharathi, et al., 2023)
Cigarette Beetle *Lasioderma serricorne*	Anobiidae	Stored Tea, Herbal Products, Arecanut	Larvae feed directly on nuts and in severe infestation nuts can be pulverized. Infestation of this pest can be detected by noticing larval cocoons, dead adult beetles in stored products	(Wijesinghe, et al., 2016; Thube, et al., 2017)
Coffee bean weevil *Araecerus fasciculatus*	Anthribidae	Coffee berries, Cocoa, Arecanut	Recorded from fresh stored nuts containing moisture, Both adult and grub damage the nuts by making holes of 1.5-2.5 mm diameter	(Thube, et al., 2017)

III. CASE STUDY OF A BEETLE OUTBREAK IN A CASHEW PLANTATION IN WANATHAVILLUWA, SRI LANKA

Severe leaf damage to cashew plants was reported in Wanathawilluwa in late 2023. Sampling of adult beetles was carried out in two different sites (Acre 2 Area and Acre 10 Research Area) in the Cashew plantation, Wanathawilluwa in December 2023. Beetles were captured using two UV-light traps from dusk to sunrise (6:00 pm to 7:00 am). Beetles that were attracted to the light traps were stopped by transparent polystyrene plates and fell into a container where they were preserved (96% ethanol).

Approximately 500 adult beetle specimens were collected from two sites and identified majority as *Apogonia* sp. (ca. 432 specimens) (Figure 02), *Sophrops* sp (ca. 27 specimens) and few Sericini chafers (Figure 01). The damage was observed as eating of the cashew leaves from the edges, resulting in round-shaped margins (Figure 02). Fortunately, the population increase does not significantly affect cashew production in the area (personal communication).

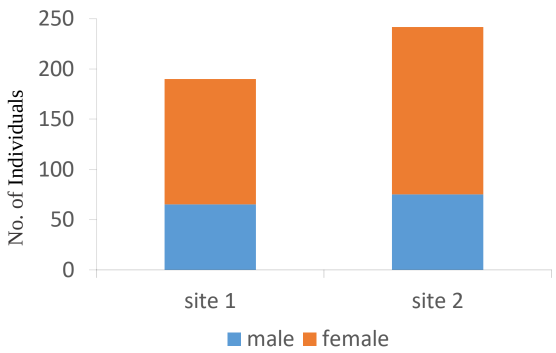

Figure 01: Beetle individuals sampled from site 1 and site 2

Figure 02: **A**, Cashew leaf damage displaying distinctive round-shaped margins due to feeding, **B**, *Apogonia* sp. collected from Wanathawilluwa

IV. CONCLUSIONS

The review documents 60 beetle species from 14 families that are significant pests in Sri Lanka's agriculture, affecting crops like vegetables, fruits, grains, coffee, tea, rubber, and coconut. Notable families include Curculionidae (12 species), Scarabaeidae (9 species), Chrysomelidae (7 species), Coccinellidae (6 species), and Cerambycidae (5 species), along with Meloidae, Scolytidae, Cicindelidae, Anthribidae, Buprestidae, Anobiidae, Laemophloeidae, Tenebrionidae, and Hisphidae. Vegetable crops from the Solanaceae and Cucurbitaceae families are particularly vulnerable, while Curculionidae, Cerambycidae, and Scolytidae primarily target woody crops like cashew, fruits, coconut, tea, and stored grain products. A specific case study highlighted an outbreak of beetles in a cashew plantation in Wanathavilluwa, where the majority of identified pests were *Apogonia* species, followed by *Sophrops* species, and a few Sericini chafers. Beetles occur frequently in crop cultivations, highlighting their significant ecological role in the agricultural landscapes of Sri Lanka. Therefore, understanding their dynamics within these ecosystems is essential. Although most beetle genera are documented, the gaps in knowledge regarding their status as economic pests and the patterns of their sporadic population increases remain significant. This knowledge gap is particularly concerning given the tendency for beetle populations to spike to endemic proportions, as evidenced by past outbreaks in regional countries over recent decades. Thus, further research is crucial to develop effective management strategies and mitigate potential economic impacts on crop production in Sri Lanka.

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Effects of Fertilizer and Irrigation on the Growth and Yield of Bush Pepper (*Piper nigrum* L.) Intercropped under Coconut

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Abstract

This research was conducted at the Intercropping and Betel Research Station of the Department of Export Agriculture, Sri Lanka, to assess the impact of different irrigation levels (6 L or 8 L per day) and amounts of inorganic fertilizer mixture (660 kg, 1320 kg, or 1980 kg per ha) consisting of Urea, MOP, and Eppawala Rock Phosphate, on the growth and yield of bush pepper planted under coconut. The study was a factorial experiment in a randomized complete block design with three replicates. Data on growth and yield were collected for five years. The findings didn't reveal significant differences in canopy diameter or branching. However, after 20 months, plants irrigated with 8 L per day exhibited a higher percentage of flowered plants, indicating that increased irrigation can accelerate flowering. Nevertheless, more spikes were observed under low fertilizer application, suggesting that low nutrient supply positively influences the anthesis of bush pepper. Although the increased irrigation and fertilizer application improved the spike filling rate, it showed a decrease in spike production. Nonetheless, no interaction between the two factors has been identified. Moreover, the decline in yield from the third to the fifth year was observed which can be attributed to the mutual shading of growing plants. However, these results do not support the feasibility of field cultivation of bush pepper, as the dry yield achieved in this experiment (maximum 660 kg/ha/year) falls short when compared to traditional climbing pepper.

Keywords: Bush pepper, Flowering, Fertilizer, Growth and yield, Irrigation

V. INTRODUCTION

Black pepper (*Piper nigrum* L.) is an important spice crop for Sri Lanka, with a significant contribution to the country's economy and the livelihoods of small-scale farmers. In 2022, the black pepper extent in Sri Lanka was 42,152 ha and production reached 24,029 MT. Pepper exports in 2022 were 11,416 T valuing Rs. Million 23,464 (Raby & Hettiarachchi, 2023). Black pepper is grown as a climbing vine, which requires stakes or support structures for vertical growth. However, propagating black pepper plants using plagiotropic branches (fruiting/side branches) results in bush-shaped plants, commonly known as "bush pepper" which is mostly suitable for pot cultivations. According to some studies, a bush pepper pot plant produces about 1.5 kg of green (fresh) pepper in 2-3 years, under average management conditions (TNAU, 2022; Priyadarshani et al., 2018). It is common in houses as an ornamental plant which delivers black pepper for family requirements (Kavindi, 2013).

The compact growth habit of bush pepper plants allows for higher plant densities and more efficient use of space. Additionally, bush pepper plants are easier to maintain than climbing pepper plants, as it needs no support or trellises, require less labour, and are quick to produce yield (Thankamani et al., 2002; Ngawit, Wangiyana, & Farida, 2022). However, Bhattacharya (2017) has reported that bush pepper plants of some varieties did not reach to bearing stage until 3 years.

According to these details, bush pepper can be considered as a potential intercrop for small-scale coconut farmers in Sri Lanka. Adopting bush pepper cultivation under coconut could increase land productivity, diversify income and improve resilience to changing climate. Research conducted by Priyadarshani et al., (2018) in Sri Lanka under coconut identified 1.8 m x 1.2 m as the suitable spacing for bush pepper which results in around 3000 plants per ha. Moreover, this study confirmed the potential of achieving nearly 750 kg/ha/year of dry pepper yield from the fifth year onwards but also notes the superiority of orthotropic plants (climbing pepper) in long-term results. Further, considering the possible differences in the root system and growth habits, bush pepper management should differ from climbing pepper. However, as most of the bush pepper studies are confined to pot experiments, the effect of agronomic practices like irrigation and fertilizing under field conditions remains unclear. Thankamani & Ashokan, (2011) showed 8 L drip irrigation during October – May is best for bush pepper under coconut in Kerala. Indian Institute of Spice Research has recommended the application of NPK at 10, 5, 20 g per bush at three months interval for field-grown bush pepper while recommending a lower dose for potted plants.

In Sri Lanka, the Department of Export Agriculture (DEA) recommends an annual application of 2380 kg/ha of a fertilizer mixture for climbing pepper vines. This mixture consists of Urea, Eppawala Rock phosphate (ERP), Muriate of Potash (MOP), and Kieserite in a 4:5:3:1 weight ratio. Additionally, DEA advise a seasonal application of 1400 kg/ha/year of the same mixture, applied twice a year (Anon, 2019). Yet, there is no specific fertilizer mixture recommended for bush pepper in Sri Lanka. Therefore, this research aimed to identify the effects of irrigation and inorganic fertilizer application on bush pepper plants grown under coconut in Sri Lanka.

VI. METHODOLOGY

This research was conducted at the Intercropping and Betel Research Station of the Department of Export Agriculture, Narammala, which is situated in the Low Country Intermediate Zone (IL1a) of Sri Lanka (7°24'19.0"N, 80°12'15.2"E). Annual average rainfall during the study period of 2016 to 2020 was 1904.8 mm. A coconut field over 20 years old was selected as the research site and divided into five blocks. The whole field was being managed according to the recommendations of the Coconut Research Institute, Sri Lanka, including the application of 3.3 kg of APM-W fertilizer mixture with 1 kg dolomite per palm once a year during September to October. Bush pepper plants were prepared from two-nodal cuttings of plagiotropic branches. After approximately four months, during the 2015-16 Maha season, these potted plants were planted into five blocks, with three plants per plot at 1.8 x 1.2 m spacing, following the previous research outcome (Priyadarshani et al., 2018). The experiment was conducted as a two-factor factorial experiment in a randomized complete block design with three replicates.

After establishment, the application of treatments was started. Treatments include two levels of irrigation and three levels of inorganic fertilizer. Two irrigation levels of 6 L and 8 L thrice a week were selected (Thankamani & Ashokan, 2011). The irrigation was halted during rainy days until the soil became visibly dry.

Since there was no specific recommendation for bush pepper in Sri Lanka, three levels of a fertilizer mixture used by some farmers in the Kurunegala district were selected. This fertilizer mixture, applied once in three months, consists of Urea, Eppawala Rock Phosphate (ERP), and MOP in a 2:5:4 ratio (w/w). The tested amounts were 660 kg/ha/year, 1320 kg/ha/year, and 1980 kg/ha/year, corresponding to 55 g, 110 g, and 165 g per plant every three months. These amounts were selected considering the DEA recommendations for pepper cultivation.

Table 02: Treatments of the experiment

Treatment	**Irrigation Amount**	**Fertilizer application (kg/ha/year)**	**Fertilizer (g/plant/3**
T1	6 L	660	55
T2	6 L	1320	110
T3	6 L	1980	165
T4	8 L	660	55
T5	8 L	1320	110
T6	8 L	1980	165

The Growth data like canopy diameter, number of plagiotropic branches, and number of spikes in a bush, were collected in monthly intervals throughout the study period. Further, the yield data including the fresh and dry weight of peppercorn, and fruit filling rate were recorded at irregular intervals depending on the availability of mature spikes.

The collected data were statistically analysed using the SAS OnDemand for Academics statistical application. Data were tested for normality, then the Kruskal-Wallis test was performed for nonnormal data, while analysis of variance was conducted for normally distributed data which includes, canopy diameter, percentage of flowered plants and spike filling rate. Mean separation was done using Duncan's Multiple

Range test. The analysis revealed no interaction effect between irrigation and fertilizer levels in this experiment. Thus, the results are discussed as single-factor effects.

VII. RESULTS & DISCUSSIONS

The statistical analysis of monthly records confirmed that none of the treatments had any significant effect on the canopy diameter of the plants during the study period, except 15 months after planting (MAP) between three different fertilizer levels, as shown in Table 02.

Table 03: Canopy diameter of bush pepper plants N=90

Dose of fertilizer	Canopy diameter (cm)		
	09 MAP	15 MAP	18 MAP
165 g	58.1 [a]	83.4 [ab]	92.2 [a]
110 g	56.0 [a]	77.5 [b]	86.5 [a]
55 g	64.5 [a]	90.1 [a]	92.5 [a]
CV %	35.78	24.70	26.44

Note: The means followed by the same letters are not significantly different at α = 0.05. MAP = months after planting.

This finding contradicts the majority of previous studies, which have highlighted the effect as well as the interaction between irrigation and fertilization in relation to plant growth and yield. Since, there were no significant differences in the most of canopy diameter data, indicating plants in this experiment have not suffered water or nutrient stress, the 55 g fertilizer and 6 L irrigation level is adequate for comparable growth of bush pepper plants. Therefore, further research is necessary with lower doses of fertilizer and irrigation to identify the optimum amounts for the growth of bush pepper plants.

No significant difference in the number of plagiotropic branches was identified. Also, the coefficient of variation of these data was over 50% which minimises the certainty of results. Therefore, it can be suggested that these irrigation or fertilizer application levels had no significant effect on the branching of bush peppers.

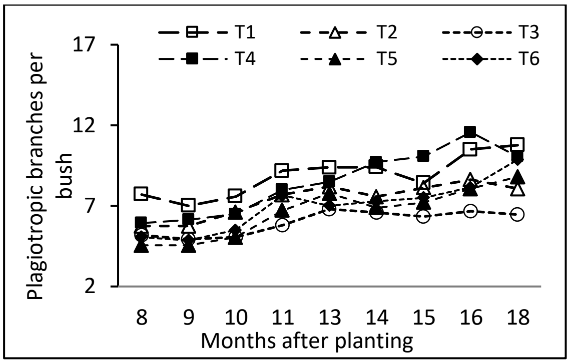

Figure 01: Plagiotropic branch formation of bush pepper under different irrigation and fertilizer levels. T1 to T6 denote daily irrigation and quarterly fertilizer application levels.

The results also showed that the percentage of plants with flowers was higher in 8 L irrigation compared to those irrigated with 6 L. The difference was statistically significant up to 20 months after planting. However, flowering under three fertilizer levels was not statistically significant (Table 03).

Table 04: Percentage of plants with flowers, 20 months after planting (MAP)

Dose of fertilizer	Plants with flowers (%)	Irrigation level	Plants with flowers (%)
165g	85.1 [a]	8 L	94.2 [a]
110g	80.0 [a]	6 L	77.9 [b]
55g	93.7 [a]		
CV %	22.52		

Note: Means followed by the same letters are not significantly different at α = 0.05

According to the results, higher irrigation levels can advance the flowering of plants even when the growth of plants remains unchanged. Unclear changes due to better water and nutrient availability might have caused this progress in 20 months. These results are consistent with previous research which has shown that irrigation can significantly influence the growth and development of pepper plants (Thankamani & Ashokan, 2011). The absence of significant differences between the three fertilizer levels is not consistent with previous studies that have reported a positive effect of fertilizer on flowering in pepper plants (Swarnapriya, 2020). Thus, while these results emphasise the importance of soil moisture for early flowering, further investigation is required to evaluate the effect of fertilizer on bush pepper flowering.

The data in Figure 02 represents the number of spikes in bush pepper plants, which measures the potential yield. It shows that the use of 55 g of fertilizer has resulted in a higher spike production in bush pepper plants. However, based on the data analysis, neither irrigation level nor fertilizer amount have significant effects on spike production.

Flowering can be enhanced either by high amounts of fertilizer which promote vegetative growth at the expense of spike production or insufficient fertilizer levels that trigger flowering as described by Wada & Takeno (2010). As no significant impact had been observed on plant growth, flowering of bush pepper might have been induced by fertilizer imbalance after the initial growth stage. This indicates the fertilizer level sufficient at the early growth stage may not be adequate at the latter stages, especially after anthesis. Hence, more studies should be conducted to determine the nutrient requirements at different stages of the bush pepper plant.

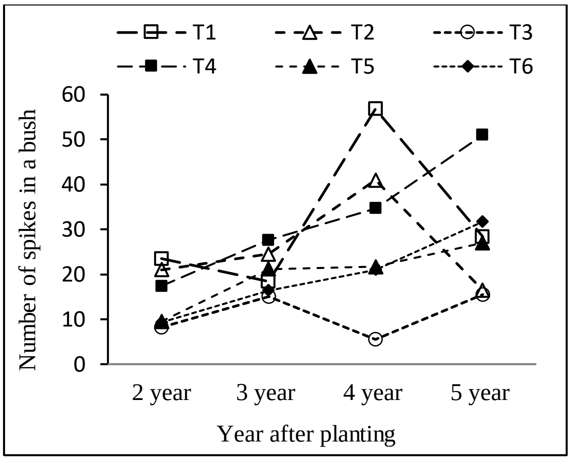

Figure 02: Number of spikes in a bush pepper plant.

The data on spike filling show the increase in the amount of fertilizer and water applied to the plants leads to a higher filling rate of bush pepper spikes (Table 04). This indicates that proper fertilizer application plays a crucial role in the growth and development of pepper fruits. Thus, emphasizing the importance of providing more water and fertilizer to the plants after flowering.

Table 04: Filling percentage of bush pepper spikes after 4 years of planting

Fertilizer level	**Spike filling rate (%)**	**Irrigation**	**Spike filling rate (%)**
165 g	78.3 [a]	8 L	76.6 [a]
110 g	73.2 [ab]	6 L	68.1 [b]
55 g	66.8 [b]		
CV	16.82		

Note; Means followed by the same letter are not significantly different. T1 to T6 denote daily irrigation and quarterly fertilizer application levels

Nevertheless, the spike length of bush pepper has been consistent through the treatments. Data shows that 84.1% of spikes had a length greater than 10 cm, while 19.5% had a length higher than 14 cm. Thus, nearly two-thirds of spikes had a length between 10 to 14 cm with an average of 11.9 cm.
According to the data in Table 05, which shows yield from the third year to the fifth year under different fertilizer and irrigation levels, bush pepper yield shows a reduction with time. Thus, it needs to be evaluated further in the field for a longer cultivation period. Also, the yield of bush pepper compared to traditional pepper is not adequate.

Table 05: The yield of bush pepper (dry yield kg per ha per year) under different irrigation and fertilizer levels

Treatment	**3rd year**	**4th year**	**5th year**
Fertilizer			
165 g	456.2 [a]	323.9 [a]	231.5 [a]
110 g	447.2 [a]	418.3 [a]	216.3 [a]
55 g	661.2 [a]	511.0 [a]	266.3 [a]
Irrigation			
8 L	520.7 [a]	319.3 [b]	247.3 [a]
6 L	547.0 [a]	555.1 [a]	227.7 [a]
CV	73.29	75.01	84.32

Note; Means followed by the same letter are not significantly different.

This kind of decline or fluctuation in yield is common in some bush pepper experiments (Priyadarshani, et al., 2018; Bhattacharya & Bandyopadhyay, 2017). Therefore, it can be a typical characteristic of black pepper plants of plagiotropic origin. But also, the effect of mutual shading of growing plants cannot be underestimated. Bush pepper plants naturally produce overlapping branches due to limited vertical growth. Its uncontrolled growth can reduce photosynthetic efficiency affecting the yield over time. Hence, pruning of bush pepper plants can be beneficial for a consistent yield for a long period. Therefore, further research on appropriate punning practices must be conducted.

In addition, the fertilizer formula used here (Urea: ERP: MOP; 2: 5: 4) is different from the recommended fertilizer mixture for black pepper in Sri Lanka (Urea: ERP: MOP: Kieserite; 4: 5: 3: 1). Therefore, plant growth and yield might have been affected by the imbalance of nutrients. Further, this demonstrates that applying fertilizer overdoses is pointless, thus emphasising the importance of providing a proper fertilizer recommendation for bush pepper in Sri Lanka. Since bush pepper has a comparatively small root system, its efficiency in nutrient uptake may not be similar to climbing pepper plants. Hence, bush pepper will be benefitted by providing readily available fertilizer mixtures. Therefore, replacing Eppawala rock phosphate (ERP) with more soluble triple super phosphate fertilizers should be considered in future bush pepper research (Srinivasan et al., 2008).

In conclusion, irrigation with 6 L or 8 L per bush thrice weekly or 660, 1320, and 1980 kg/ha/year of fertilizer mixture at three-month intervals shows no significant difference in the growth of bush pepper plants as measured by canopy diameter and number of plagiotropic branches. However, 8 L irrigation can bring plants into the flowering stage earlier than 6 L, though it can affect the production of spikes and final yield. Under these conditions, no interaction between fertilization and irrigation was observed. According to the results of this experiment, the use of 660 kg/ha/year of fertilizer has provided the plants with an adequate amount of nutrients for growth. Yet, the spike filling rate can be improved with higher irrigation and fertilizer application. Bush pepper in this experiment has produced around 660 kg/ha/year dry pepper yield at best, which is not satisfactory compared to about 5000 kg/ha/year yield of traditional climbing black peppers.

Finally, further research with irrigation and fertilizer levels less than 660 kg/ha/year, and changing with the growth phase of the bush pepper plants i.e., increased amount after the flowering, can be recommended.

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Cost-Effective Potting Media for Efficient Betel (*Piper betle* L.) Propagation

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Abstract

Betel (Piper betle L.) is a popular intercrop with coconuts in Kurunegala and Gampaha districts, mainly grown as a cash crop. To ensure selection of high quality, vigorous plants, growers often use potted betel plants for transplanting. The traditional potting media for betel consists of equal parts topsoil (TS), sand (S), cow dung (CM) and coconut flour (CD). However, due to the high cost and limited availability of sand and coir dust, using partially burned paddy husk as a substitute is a more economical option. A study was conducted to determine the cost-effective potting mixture using a combination of different potting materials. Seven treatments included the combinations of top soil, sand, cattle manure, coir dust, and partially burned paddy husk (PBPH). The poly bags were filled with a plotting mixture and three nodal cuttings were planted. A propagator was used to raise the plants for 21 days. The small plants were then kept in 70% shade. According to the results, the highest root dry weights were in the T2(TS:CM:S:CD:PBPH 2:1:1:1:3) and T7 (TS:CM:PBPH, 1:1:3). The highest shoot dry weight, shoot length, and number of leaves were all observed in T4 (TS:CM:S:CD 2:1:1/2:1:1). Therefore, treatments T4, T2, and T7 can be recommended for betel propagation. The cost per plant in the T4, T2, and T7 treatments was Rs 13.50, Rs 11.50, and Rs 9.30, respectively, which is lower than the cost of the conventional potting mixture at Rs 18.00.

Keywords: betel,Cost effective potting media, paddy husk

I. INTRODUCTION

Betel (*Piper betle*) is a perennial climbing plant from the Piperaceae family that is widely cultivated and highly valued for its economic and cultural significance in South and Southeast Asia. The leaves of the betel plant are commonly chewed with areca nut and slaked lime, a traditional practice across several Asian countries (Rani & Singh, 2017). Successful cultivation of betel requires specific soil and climatic conditions, making the selection of a suitable potting mix crucial for effective propagation and growth (Manjunatha, 2016). Betel is particularly popular as an intercrop in coconut plantations, serving as a significant cash crop in regions like Kurunegala and Gampaha districts of Sri Lanka (Silva et al., 2018). Many growers prefer to use potted betel plants for transplanting, as this allows them to select high-quality, vigorous plants for field planting (Senanayake & Wijesundara, 2019). In producing these potted plants, the cost, applicability, and availability of the potting media are key factors to consider (Das et al., 2020).

The conventional potting mixture used for raising betel planting materials typically contains a mixture of topsoil, sand, cow dung, and coir dust in a 1:1:1:1 ratio (V/V/V/V) (Wijeratne et al., 2017). However, the use of sand and coir dust has become increasingly uneconomical due to rising costs and limited availability (Kumar et al., 2018). A cost-effective alternative is the substitution of sand and coir dust with partially burned paddy husk, which offers a more affordable and accessible option. To address this, a study was conducted to determine a more economical potting mixture using a combination of different growing materials.

II. METHODOLOGY

The experiment was carried out from July to November 2020 at the Dampellessa Intercropping and Betel Research Station Narammala, located in the low country intermediate zone of (IL1a) of Sri Lanka (7°24'19.0"N, 80°12'15.2"E). Five different potting materials were used: topsoil (TS), cow dung (CM), sand (S), coir dust (CD) and partially burnt rice husks (PBH). These materials were combined in different ratios to create seven potting media mixture treatments (Table 01) with each treatment forty replicates.

Table 01 The different combinations of potting materials (Volume basis)

Treatment	TS	CM	S	CD	PBPH
T1 (Control)	1	1	1	1	0
T2	2	1	1	1	3
T3	1	½	1	1	1
T4	1	1	½	1	1
T5	1	1	1	½	1
T6	1	1	1	0	2
T7	1	1	0	0	3

Healthy semi-mature orthotropic three-node betel branches were obtained from the same variety of mother plants maintained at Narammala Intercropping and Betel Research Station. The potting mixture was filled in polythene bags 20 cm ×12 cm in size, which had perforated at the bottom for drainage. After watered hourly and selected cuttings were planted in polyethylene bags and watered. Stem cuttings were dipped in copper-based fungicide solution before introducing them into the potting mixture to prevent fungal infection at the cut end.

Isolated stem cuttings were placed in a humidity chamber to minimize air circulation and provide 70% shade. After 21 days, the cuttings were transferred from the humidity chamber to a net house with 60% shade, where moisture levels were maintained. Pest and disease control measures were applied as needed. Five plants were randomly selected from each replicate. Starting 35 days after planting, data on the number of shoots, number of leaves, shoot length, number of

roots, root length, shoot dry weight, and root dry weight were collected biweekly.

Data was recorded at two weeks intervals at 35 days after planting. The number of shoots, the number of leaves, the shoot length, the number of roots, the root length, the shoot dry weight and the root dry weight were recorded. Newly emerged shoots were separated from the plant and placed in paper bags. The shoot samples were oven-dried at 70°C until a constant weight was achieved, and the weight was recorded using an analytical balance. The vines were uprooted and thoroughly washed. Afterward, the roots were separated from the plant, placed in paper bags, and oven-dried at 70°C until reaching a constant weight. The weight was also measured using an analytical balance. Roots were carefully washed and separated using surgical scissors. Root samples were spread over a 1 cm grid, and root length was measured by counting the number of root intersections with the grid lines, following the method of Tennant (1975)._The data were analyzed using ANOVA and statistical analysis was performed with Minitab 17 software. The least significant different (LSD P = 0.05) was used to compare the treatment means.

III. RESULTS & DISCUSSIONS

Table 02. The growth parameters of betel plant under different potting media

Treatment	Root dry weight (g)	Shoot dry weight (g)	Root length (cm)	Shoot length (cm)
T1	0.08^{c}	0.64^{bc}	83.38^{c}	27.07^{c}
T2	**0.16^{a}**	0.75^{b}	120.04^{ab}	$27.96b^{c}$
T3	0.09^{ab}	0.56^{c}	98.69^{bc}	$28.44b^{c}$
T4	0.12^{ab}	**1.04^{a}**	112.63^{ab}	**44.60^{a}**
T5	0.10^{ab}	0.65^{bc}	100.46^{bc}	33.80^{b}
T6	0.11^{ab}	0.72^{b}	113.04^{ab}	$30.28b^{c}$
T7	**0.16^{a}**	0.75^{b}	**131.81^{a}**	$31.20b^{c}$
CV %	27.31	20.95	14.59	18.93

Note: means followed by the same letters are not significantly different

The highest root dry weights were observed in treatments T2 and T7 (0.16 g), which was significantly higher than T1 (0.08 g) but not significantly different from T3, T4, T5, and T6. The root dry weights of the treatments followed the order of T7=T2>T4>T6>T5>T3>T1 and treatment T1 being the lowest. There was no significant difference between treatments T_7 and $T_{2.}$

According to the statistical analysis, there were significant differences ($p<0.05$) between treatments with respect to shoot dry weight. The highest shoot dry weight was recorded at T4 (1.04 g), which was significantly higher than the other treatments and T_3 had the lowest. Shoot dry weights followed the order as T_4>T_2 =T_7 >T6>T5

$>T_1$ $>T_3$ respectively. Treatment T_4 was the highest.

The higher root and shoot dry weights in treatments T2, T4, and T7 can be attributed to the optimal combination of organic components, which provided adequate nutrients and improved soil structure. The high root dry weight in T2 and T7 (with higher proportions of PBPH) suggests that PBPH may enhance root biomass by improving soil aeration and moisture retention. Hossain and Islam (2020) reviewed various agricultural waste residues and concluded that materials like partially burnt paddy husk can improve soil physical properties, including aeration and moisture levels, thereby benefiting root growth and overall plant health. Research indicates that the application of rice husk ash improves soil structure by reducing soil compaction and increasing porosity, which leads to enhanced root growth due to better aeration in maize(Channabasappa et el. 2002*)*.

T7 had the longest root length (131.81 cm), significantly longer than T1 (83.38 cm), which had the lowest. Root length followed the order as T_7 $>T_2$ $>T_6>T_4>T_5>T_3$ $>T_1$ There were no significant differences among the treatments T_2, T_6, T_4, T_5 and T_3. There were significant differences ($p<0.05$) among treatments for shoot length. T4 had the significantly longest shoot length (44.60 cm). Shoot length followed the order of as T_4 $>T_5>$ T_7 $>T_6>T_3>T_2>T_1$ respectively.
There was no significant differences among treatments T_1,T_7,T_6,T_3 and T_2.(Figure.1) here was no significant different among treatments. Treatment T_4 had the highest average number of leaves with respect to other treatments. T_3 had the least average number of leaves.

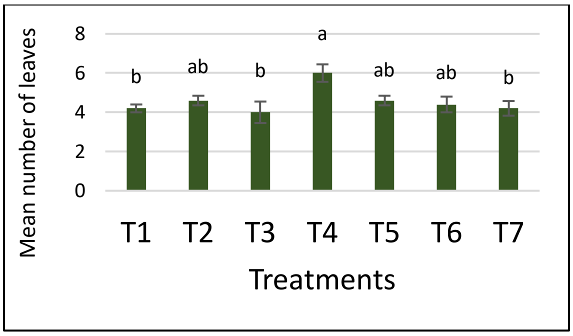

Figure 01. Effects of potting media on the number of leaves of betel plants during 60 days after plating.

Note: means followed by the same letters are not significantly different

T7 exhibited the longest root length, indicating that a higher proportion of PBPH in the mixture may promote root elongation. PBPH is known for its excellent aeration and drainage properties, which can facilitate deeper root growth. T4, with the longest shoot length, suggests that a balanced mixture of coir dust and sand can significantly enhance shoot development.

The positive effects of organic amendments like cattle manure and coir dust on plant growth have been well-documented. The cattle manure significantly improve soil fertility by increasing organic matter content and microbial activity, leading to enhanced plant growth (Ribeiro et al.2016). Similarly, coir dust, a by-product of the coconut industry, has been recognized for its high water-holding capacity and ability to improve soil aeration, which benefits root and shoot development (Awang et al. 2009).

The role of PBH in promoting root growth aligns with findings by *De Costa et al.* (2012), who reported that PBH enhances soil physical properties, such as porosity and permeability, thereby facilitating better root penetration and growth.

Though the sand and coir dust are traditional components of potting mixtures, their high cost and limited availability can be prohibitive. PBPH is a cost-effective alternative with good aeration properties. Studies have shown that PBPH can improve root growth due to its porous nature, which facilitates better oxygenation and drainage

For instance, research by Reddy et al. (2018) found that the incorporation of burnt paddy husk into soil significantly increased root biomass and plant growth by enhancing soil porosity and water management. Additionally, Sharma and Kumar (2020) highlighted that the use of paddy husk in soil amendments led to better oxygenation, which is critical for healthy root development and reduces the risk of root diseases.

The study revealed that different potting mixtures significantly influence the growth parameters of Betel. Treatment T4, comprising a mixture of topsoil, cattle manure, sand, and coir dust, showed superior performance in shoot dry weight and shoot length, indicating its potential as an effective potting mixture for Betel propagation. The maximum production cost (Rs. 18.00) was observed in the T1. Other treatments T2, T3, T4, T6, and T7 cost of production were Rs.11.50 ,Rs. 17.75, Rs.13.50, Rs.17.80, Rs. 15.75 and Rs 9.30. The cost of a plant in the T2, T4 and T7 treatments were Rs.11.50, Rs.13.50, Rs. 9.30 respectively lower than the cost of the conventional potting mixture (T1) Rs18.00.

IV.CONCLUSION

The findings indicate that the inclusion of partially burnt paddy husk (PBPH) in potting mixtures enhances the growth of betel plants, with mixtures containing higher PBPH levels (T2 and T7) demonstrating significant increases in root biomass and length. Additionally, the mixture with a reduced proportion of sand and coir dust (T4) was found to optimize shoot growth. Among the tested combinations, the T4 mixture (1:1:0.5:1:1) emerged as a cost-effective option for betel propagation, providing a balanced blend of nutrients and physical properties that support both root and shoot development. Further research should investigate the long-term impacts of these potting mixtures on plant health and productivity, as well as their cost-effectiveness for large-scale betel cultivation.

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Morphological and Yield Performance of Chinese and Rangoon Ginger (*Zingiber officinale* Roscoe) Accessions Cultivated as Intercrops under Coconut Cultivation in the Low Country Intermediate Zone of Sri Lanka

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Abstract

Ginger (Zingiber officinale) belongs to the family Zingiberaceae. Chinese, Rangoon and Local are the commonly cultivated ginger types in Sri Lanka. Local ginger is rich in fiber, uses in Indigenous and Ayurveda medicinal purposes, and amount of yield is comparatively low. Chinese and Rangoon are moderately in pungency, amount of yield is comparatively high and use in beverage industry likes for production of ginger beer and for culinary purposes also. Ginger can be grown either as a mono-crop or inter-crop under coconut plantation. This research was carried out at Inter-cropping and Betel Research Station, Narammala where the area belongs to Kurunegala district is under the coconut triangle. Coconut plants are generally spaced in 26 ft x 26 ft, hence 75% of area under the coconut plants are remaining unproductively. Underutilized area is high when the age of the coconut plants is below 5 years and over 20 years. Climatic conditions in Kurunegala district is more favourable for ginger cultivation. After the three years field experiment, the highest fresh yield of rhizome per clump for Chinese ginger accessions was given by the accession of G33 (949.2 g/clump) in Low Country Intermediate Zone under coconut cultivation. The highest fresh yield of rhizome per clump for Rangoon ginger accessions was given by the accession of G28 (754.2 g/clump) in low country Intermediate zone under coconut cultivation. The G28 and G33 accessions can be used to cultivate under coconut plantation as an intercrop to increase the productivity of coconut lands.

Keywords: Chinese ginger accessions, Rangoon ginger accessions, Evaluation

I .INTRODUCTION

Ginger is scientifically known as *Zingiber officinale* Roscoe and belongs to the order *Zingiberales* and the family *Zingiberaceae.* It is common in Southeast Asian countries and primarily cultivated in India. Ginger is a perennial herbaceous plant. The true stem of the plant lies underground and the above ground part is called the pseudo stem.

There are three main types of ginger grown in Sri Lanka: Chinese ginger, Rangoon ginger and native ginger. In addition, different types of ginger are cultivated around the world. Local ginger is high in pungency, rhizome is rich in fiber, uses in Indigenous and Ayurvedic medicinal purposes, and yield is comparatively low. Chinese and Rangoon are moderately in pungency, amount of yield is comparatively high and are often used in beverage industry likes for production of ginger beer and for culinary purposes.

Total cultivated extent of ginger in year 2022/2023 was 2,383 ha and the total production was 19,375 mt. Kurunegala, Gampaha, Kandy, Badulla and Rathnapura were the major growing districts of ginger in year 2022 / 2023 cultivated extent of these districts were 774, 280, 188, 142 and 129 ha respectively .Ginger production in the districts of Kurunegala, Gampaha and Kandy were 7,352, 2,662 and 1,692 ha respectively (Anonymous, 2023). Ginger can be grown either as a mono-crop or inter-crop under coconut plants. Coconut plants use a large volumes of air space and it limits to increase the crop density. Efficient utilization of air space is important. Coconut palms are generally spaced 8 m x 8 m resulting in 75% of area remaining unproductive. Underutilized area is high when the age of the coconut palm is below 5 years and over 20 years. Therefore, coconut based intercrops farming systems is important to increase the productivity of the land (Liyanege *et al.*, 1986).

There were no identified high yielding ginger accessions. For that cultivation of Chinese and Rangoon ginger is more profitable due to high yield rather than that of Local ginger.

The objectives of the study were to evaluate the morphological characteristics and identify high-yielding accessions of Chinese and Rangoon ginger (*Zingiber officinale* Roscoe) for cultivation as intercrops under coconut cultivation in the Low Country Intermediate Zone of Sri Lanka.

II. MATERIAL AND METHOD

A. Collection of ginger accessions-

Field surveys were done to collect ginger accessions and survey information like farmers' details, information on crop management practices were recorded on questionnaires. Different accessions of ginger were collected from the districts of Kurunegala, Gampaha, Kalutara, Galle, Matara, Hambantota, Monaragala, NuwaraEliya, Matale, Kegalle, Jaffna, Ampara, Kandy, Badulla, Rathnapura, Anuradhapura, Polonnaruwa, Puttalam and Colombo. Germplasm were collected from the different Extension Officers' rangers level within the district.

B. Multiplication of ginger accessions-

Collected ginger accessions were established in the research field, at Intercropping and Betel Research Station (IBRS), Department of Export Agriculture, Dampelessa, Narammala, Sri Lanka for further growth of ginger rhizomes. It is situated in Low country Intermediate zone, agro-ecological region IL1a Longitude is 80.22^0E and Latitude is 7.43^0N. Elevation is 63m from mean sea level. Average day time temperature is 28-30^0C. Narammala typically receives about 1900 mm of precipitation and has around 192 rainy days annually. Mean humidity is 76.8% (Weather and Climate, 2020).

C. Evaluated ginger accessions-

1) Evaluated Chinese type ginger accessions-

Altogether there were 14 Chinese type ginger accessions were collected by field surveying. One wild type ginger accession was also found. That was more or less similar to Chinese type ginger. Out of the collected all Chinese ginger accessions, 5 accessions were considered for the evaluation. Because of the amount of the rhizomes of the rest of the Chinese type ginger accessions, were not sufficient for establishment of a 3 replicates of field experiment. These Chinese type ginger accessions were numbered as G1, G2, G3, G17 and G33.

2) Evaluated Rangoon type ginger accessions-

Altogether there were 18 Rangoon type ginger accessions were collected by field surveying. Out of the collected all Rangoon ginger accessions, 7 accessions were considered for the evaluation, because the amount of the rhizomes of the rest of the Rangoon type ginger accessions were not sufficient for establishment of a 3 replicates of field experiment. These Rangoon type ginger accessions were numbered as G6, G9, G27, G28, G29, G30 and G34.

D.Establishment of ginger accessions evaluation fields and management practices- .

This research was carried out during the period of 2015-2023, at Intercropping and Betel Research Station (IBRS), Department of Export Agriculture, Dampelessa, Narammala, Sri Lanka. Evaluation for ginger was done as an intercrop under the coconut cultivation. Experimental design for evaluation field was Randomized Complete Block Design (RCBD) with 3replicates. The field was ploughed up to 35 cm-40 cm in depth and tilling of soil was done. Raised beds of 3.05 m x 1.22 m (10 ft x 4 ft) were prepared. Field establishment was done in *Yala* season in month of April. Five Chinese type ginger accessions, and seven Rangoon type ginger accessions were taken for the evaluation. These considered accessions had sufficient amount of rhizomes for 3 blocks. There is no any recommended ginger accessions given by the Department Export Agriculture for cultivation. Thirty grams of rhizomes weight for each accession was used for planting of Rangoon ginger and 40g of rhizomes weight from each accession was used for planting of Chinese ginger . Spacing between rows and between plants were 25 cm x 25 cm. Sprinkler irrigation was practiced for ginger cultivation. Department recommended management practices were followed for evaluation. One hundred kilograms of Triple Super Phosphate was applied as basal dressing per hectare. Eighty two kilograms of Urea and 42 kg of Muriate of Potash were applied for a hectare, at 45 days after establishment of ginger rhizomes. Eighty two kilograms of Urea and 42 kg of Muriate of Potash were applied for a hectare, at 90 days after establishment of ginger rhizomes. Always ginger beds were covered by using a mulch. Harvesting was done at nine months after the planting when the leaves become like straw.

E. Collection of ginger data-

Both morphological and yield data were collected. Height of the pseudo-stems, number of pseudo-stems per clump, number of leaves per pseudo-stem, leaf length and leaf width were measured at the 8 month after the planting. Nine month old matured fresh ginger rhizomes of each accessions were used for the weight evaluation. Cross sections of rhizomes were compared for colour using a Munsell Colour Chart (Plant). Fresh yield for each accessions was taken by randomly selecting 10 clumps per each replicates.

F. Analyzing of data-

Three consequent years, yield and morphological data were countered. Three year mean values were taken for the analysis. Mean separations were practiced using Statistical Analyzing Software (SAS) package. Leased Significant Difference (LSD) technique was used for the mean separation of the treatments.

III. RESULTS AND DISCUSSION

A. Evaluation of morphological characters-

Morphological characters of height of the pseudostem, no. of pseudostem per clump, no. of leaves per pseudostem, leaf length and leaf width were measured at the 8 month after the planting. Height of the pseudostem was measured from bottom of the plant to the top of the plant. Number of pseudostems per clump was taken by the counting. Number of leaves per pseudostem was also taken by the counting. Leaf length was measured from base to tip of the leaf. Maximum width of the leaf was taken as the leaf width.

1) Morphological characters of Chinese ginger

Mean values of morphological characters of Chinese ginger are shown in Table 01.

If the height of the pseudo-stem is higher it has more advantage, to capture penetrated sunlight through the coconut plants. The highest significant mean value for height of the pseudo-stem was recorded by the Chinese type ginger accession of G3 (59 cm) and the lowest value recorded by the accession of G17 (32.7 cm). There were no significant differences among the ginger accessions of G1 (33.8cm), G2 (32.8cm), G17 (32.7cm) and G33 (33.7cm) for height of the pseudo-stem.

Normally if a clump has higher number of pseudo-stems it will enhances the level of photosynthesis. There were no any significant differences among the accessions for number of pseudo-stems per clump. Number of pseudo-stems per clump varied from 7 to 5. Although they were not significant the highest value for number of pseudo-stems per clump was recorded by the Chinese ginger accession of G3 (7) and the lowest value recorded by the Chinese ginger accessions of G2 and G17 (5). According to a study done by Hossain *et al* (2019) higher number of pseudo-stems per clump during harvesting was observed in "deshi" variety (V1) (4.19) and lower number of tiller per plant was observed in china variety (V2) (3.70).

Number of leaves per pseudo-stem varied from 18 (G3) to 8 (G2). The highest significant number of leaves per pseudo-stem was given by G3 (18). There were no significant differences among the other accessions of G1, G2, G17 and G33.

Leaf lengths of Chinese ginger accessions varied from 21cm (G3) to 12cm (G1 and G33). There are no any significant differences of leaf length among the accessions of G1, G2, G17 and G33. The reason may be the these accessions are genetically somewhat similar.

Table 01: Mean values of morphological characters of Chinese ginger (At 8 months after the planting)- Means within a column with the same letter are not significantly different at $P<0.05$

Accession No.	Pseudostem height (cm)	No. of Pseudostems/ clump	No. of Leaves / Pseudostem	Leaf length (cm)	Leaf width (cm)
G6	35.2^{bc}	**10**^{ab}	9^{b}	14b^{c}	1.9^{cd}
G9	38^{b}	5^{b}	**16**^{a}	12^{c}	1.8^{d}
G27	32^{bc}	2^{b}	9^{b}	13.3^{bc}	**2.2**^{ab}
G28	28^{c}	3^{b}	10^{b}	14^{bc}	2^{bcd}
G29	36.2^{b}	**11**^{ab}	**15**^{a}	16.5^{b}	2.1^{bc}

G30	32.7[bc]	**15**[a]	10[b]	13.2[c]	2[bcd]
G34	**55.2**[a]	**15**[a]	**15**[a]	**21.2**[a]	**2.4**[a]
CV%	17	44	26	19	10

Leaf width varied from 2.5cm to 1.9cm . The highest significant different value for leaf width was indicated by the accession of G3(2.5 cm) and the lowest leaf width was indicated by the accession of G2 (1.9 cm).

If the leaf length and leaf width are higher values, leaf area of the accession is also high. Among the considered Chinese accessions, G3 was the most predominant accession for the morphological characters.

2) Morphological characters of Rangoon ginger- Mean values of morphological characters of Rangoon ginger are shown in Table 02.

Table 02: Mean values of morphological characters of Rangoon ginger (At 8 months after the planting)- Means within a column with the same letter are not significantly different at P<0.05

Accession No.	**Pseudostem height (cm)**	**No. of pseudostems per clump**	**No. of leaves / pseudostem**	**Leaf length (cm)**	**Leaf width (cm)**
G1	33.8[b]	**6[a]**	10[b]	12[b]	2[b]
G2	32.8[b]	**5[a]**	8[b]	14[b]	1.9[b]
G3	**59[a]**	**7[a]**	18[a]	**21[a]**	**2.5[a]**
G17	32.7[b]	**5[a]**	9[b]	14[b]	2[b]
G33	33.7[b]	**6[a]**	9[b]	12[b]	2[b]
CV%	21	43	22	16	11

The height of the pseudo-stem was varied from 55.2cm to 28cm. The highest significant different value for height of the pseudo-stem was recorded by the Rangoon type ginger accession of G34 (55.2 cm) and the lowest value recorded by the accession of G28 (28 cm).

Number of pseudo-stems per clump varied from 15 to 2. The highest value for number of pseudo-stems per clump was recorded by the Rangoon ginger accession of G30 and G34 (15). But there were no any significant differences among the accessions of G6, G29, G30 and G34.The lowest value recorded by the Rangoon ginger accessions of G27 (2). Number of leaves per pseudo-stem varied from 16(G9) to 9 (G6 and G27). Leaf lengths of Rangoon ginger accessions varied from 21.2cm (G34) to 12cm (G9). Leaf width varied from 2.4cm (G34) to 1.8cm (G9). Among the considered Rangoon accessions, G34 was the most predominant accession for the morphological characters. Normally Chinese ginger has, higher pseudostem height and less number of pseudostems per clump than that of Rangoon ginger.

B. Evaluation of the colour of the rhizomes of ginger accessions -

Nine month matured fresh ginger rhizomes were used for the evaluation. Cross sections of rhizomes were compared with a Munsell Colour Chart (Plant) (Figure 01).

Figure 01: Cross Sections of Rhizomes of Ginger Accessions

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Table 03 shows the Munsell colour notations for rhizome of Chinese ginger accessions and Table 04 shows the Munsell colour notations for rhizome of Rangoon ginger accessions.

Table 03 : Munsell colour notations for rhizome of Chinese ginger accessions

Accession No.	Colour notation of the rhizome [according to Munsell Colour Chart (Plant)]
G6	5Y 8/6 to 8/8
G9	5Y 8/4
G27	5Y 8/4 to 8/6
G28	5Y 8/6 to 8/8
G29	5Y 8/8
G30	5Y 8/6 to 8/8
G34	5Y 8/6 to 8/8

Water, protein, lipids, fibres, starch, minerals and vitamins are the components of ginger rhizomes (Ginger, 2015).
Normally, the ginger rhizome is pale yellow in colour. A study was done for identify, what are the compounds that responsible for the yellow colour. In this study, 62 kinds of ginger rhizomes originating from different cultivars or different cultivation locations were collected for analysis of yellow pigment compounds. Ultra-performance liquid chromatography profiles at 420 nm for each sample were used for principal component analysis. Curcumin, demethoxy curcumin, and 6- dehydrogingerdione were identified as the main common compounds contributing to the yellow colour (Yoko I. *et al*, *2014*).
Commonly cross sectional colour of core area of rhizome of Chinese ginger is bright yellow. All the colour notations of Chinese ginger accessions were differ from each other. That means their pigment compositions were differing from each other.
Commonly cross sectional colour of core area of rhizome for Rangoon ginger is light yellow. Most of the Rangoon ginger accessions (G6, G28, G30, G34) show 5Y 8/6 to 8/8 colour notation for cross section colour of rhizome.

Table 04 : Munsell colour notations for rhizome of Rangoon ginger accessions

Accession No.	Colour notation of the rhizome [according to Munsell Colour Chart (plant)]
G1	5Y 8/8
G2	5Y 8/6
G3	5Y 8/4 to 8/6
G17	5Y 8/8 to 8/10
G33	5Y 8/6 to 8/8

C. Evaluation yield of ginger accessions-

1) Fresh yield of the Chinese ginger-

Mean values of fresh yield of Chinese ginger is shown in Table 05.

Table 05: Mean values of fresh yield of the Chinese ginger

Accession no.	Fresh weight of the rhizome /clump (g)			
	1st year cultivated ginger	2nd year cultivated ginger	3rd year cultivated ginger	Mean values of 3 years
G1	**1265.5a**	**877.2a**	546.1d	896.3b
G2	1219.8abc	723.8ab	596.5c	846.7c
G3	1245.5ab	697ab	557.2d	833.2c
G17	1113.6c	565.3b	648.5b	775.8d
G33	1113.5c	627.7b	**1106.4a**	**949.2a**
CV%	30.4	13.9	20.3	13.5

Means within a column with the same letter are not significantly different at $P<0.05$

In first year, the highest fresh yield was given by the accession of G1 (1265.5 g/clump). But it was not significant different with the accessions of G3 (1245.5 g/clump) and G2 (1219.8 g/clump). The lowest fresh yield was given by the accession of G33 (1113.5 g/ clump).

In second year, fresh yield for all the accessions were lower than the yield of first year. It is may be the unfavourable weather condition of the second year. The highest fresh yield was given by the accession of G1 (877.2 g/clump). But it was not significant different with the accessions of G2 (723.8 g/clump) and G3 (697.0 g/clump). This is more or less similar to first year yield. The lowest fresh yield was given by the accession of G17 (565.3 g/ clump).

In third year, the significant highest yield was given by the accession of G33 (1106.4 g/clump). The lowest yield was given by the accession of G1 (546.1 g/clump). Besides the yield of G33, yields of the rest of the accessions in the third year, were lower than that of first year. The reason may be the weather conditions gave a negative impact on the yield of the accessions of G1, G2, G3 and G17 but not an adverse effect on the yield of G33, in third year due to some genetical reason.

Three year mean values for fresh yield of rhizome varied from 949.2 to 833.2 g per clump. When considered three years average yield of Chinese ginger, G33 accession gave the highest yield of 949.2 g/clump (10,441 kg/Ac). Therefore G33 accession is more suitable for cultivate under coconut plants as an intercrop.

The vegetative growth and development of ginger are divided into two phases. First phase is the rapid growth phase, that is increased growth rate of plant height followed by rhizome development phase. Throughout the second phase, enlargement and expansion of ginger rhizome is happened (Soni J. K., *et. al*.,2022).

Although the predominant vegetative growth was indicated by the Chinese accession of G33, the highest fresh yield was given by G33 accession. The reason for this type of situation may be the large amount of synthesized food was utilized for vegetative growth, and remaining only a small amount of synthesized food for the storage in rhizome.

Table 06: Mean values of fresh yield of the Rangoon ginger

Accession no.	Fresh weight of the rhizome /clump (g)			
	1st year cultivated ginger	2nd year cultivated ginger	3rd year cultivated ginger	Mean values of 3 years cultivated ginger
G6	**749.4[a]**	538.5[d]	538.8[d]	608.9[d]
G9	671.8[b]	543.3[d]	552.8[d]	589.3[d]
G27	681.4[ab]	703.3[abc]	720.2[b]	701.6[b]
G28	**729.5[ab]**	**801.3[a]**	731.8[b]	**754.2[a]**
G29	696[ab]	**764.3[ab]**	**749.8[a]**	**736.7[ab]**
G30	**690[ab]**	644.3[bcd]	589.1[d]	641.1[c]
G34	**684[ab]**	590.3[cd]	658.6[c]	644.3[c]
CV%	35.4	11.7	20.6	11.7

Means within a column with the same letter are not significantly different at $P<0.05$

2) Fresh yield of the Rangoon ginger

Mean values of fresh yield of Rangoon ginger is shown in Table 06

In first year, the highest fresh yield was given by the accession of G6 (749.4g/clump). But it was not significant different with the accessions of G27, G28, G29, G30 and G34. The lowest fresh yield was given by the accession of G9 (671.8 g/ clump).

In second year, the highest fresh yield was given by the accession of G28 (801.3 g/clump). But it was not significant different with the accessions of G29 (764.3 g/clump) and G27 (703.3g/clump). The lowest fresh yield was given by the accession of G6 (538.5 g/ clump).

In third year, the significant highest yield was given by the accession of G29 (749.8 g/clump). The lowest yield was given by the accession of G6 (538.8 g/clump).

Mean fresh yield of rhizome varied from 754.2 to 589.3g per clump. When considered three years average yield of Rangoon ginger, G28 accession gave the highest yield of 754.2 g/clump (4,977.7kg/ ac).

Commonly Chinese ginger yield is higher than Rangoon ginger yield. Although the predominant vegetative growth was indicated by the Rangoon accession of G34, the highest fresh yield was given by G28 accession. The reason for this type of situation may be the large amount of synthesized food was utilized for vegetative growth, and remaining only a small amount of synthesized food for the storage in rhizome.

IV. CONCLUSIONS

This research was carried out at Inter-cropping and Betel Research Station, Narammala. This area belongs to Kurunegala district. Kurunegala district is under the coconut triangle. Coconut plants are generally spaced in 26 ft x 26 ft. Due to this reason in 75% of area under the coconut plants are remaining unproductively. Underutilized area is high when the age of the coconut plants is below 5 years and over 20 years. Climatic conditions in Kurunegala district is more favourable for ginger cultivation. After the three years field experiment, the highest fresh yield of rhizome per clump for Chinese ginger accessions was given by the accession of G33 (949.2 g/clump) in Low Country Intermediate Zone under coconut cultivation. The highest fresh yield of rhizome per clump for Rangoon ginger accessions was given by the accession of G28 (754.2 g/clump) in low country Intermediate zone under coconut cultivation. The G28 and G33 accessions can be used to cultivate under coconut plantation as an intercrop to increase the productivity of coconut lands. Further research is required to identify the performances of this accession in other agro-ecological regions besides low country intermediate zone.

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Plant-derived Semiochemical Strategy for Sustainable Management of Coconut Whitefly (*Aleurodicus cocois*) using Trunk Injection Techniques

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Abstract

In Sri Lanka, the coconut industry, which is a major contributor to the national economy, is under severe threat from the recently introduced pest, the coconut whitefly (Aleurodicus cocois). This pest's resistance to conventional pesticides combined with the height of coconut trees has highlighted the need for sustainable management alternatives. The aim of this study is to develop and evaluate a plant semiochemical-based strategy for coconut whitefly control, using stem injection as a systemic alternative to chemical pesticides. The approach offers a sustainable solution by reducing pest populations without negatively impacting the ecosystem. Plant extracts of seeds and leaves of Strychnos nux-vomica (Goda kaduru), neem, mint and clove oil were formulated and tested. Four successful formulations were identified and initially tested by direct spraying. Building on these results, the formulations were combined with systemic recipients such as urea, NaCl, KCl and citric acid and evaluated by strain injection methods. Field trials showed significantly higher mortality rates (68%, 95.85%, 93.27% and 94.66%) for formulations 1 to 4 compared to the untreated control (p < 0.005). Stem-injected palms showed a gradual decline in whitefly populations, although adverse weather conditions prevented continuous monitoring. These findings suggest that repeated applications are necessary for long-term success.

Keywords: Alternative pesticides, Coconut whitefly, Plant semiochemicals, Trunk injection, Sustainable pest management.

I. INTRODUCTION

In Sri Lanka, the coconut palm, also known as *Cocos nucifera*, serves not only as a symbol of the country's thriving agricultural sector but also as a symbol of the country's cultural identity and its ability to recover economically. The sector, which spans around 410,000 hectares, serves as the foundation of rural economies, providing employment opportunities for thousands of small-scale farmers and making a substantial contribution to the economy of the country. Many aspects of everyday life are influenced by its products, including the gastronomic pleasures that are enjoyed all throughout the country, its function in traditional medicine, and the manufacture
of coir, which is a versatile material that is used in a broad variety of applications (Al-Ballaa, 2023). However, this essential sector is confronted with a severe challenge in the form of the coconut whitefly, also known as *Aleurodicus cocois*, a pest that puts the health of crops and their output at risk. The effect of this disease goes beyond the immediate harm it does to the coconut palms; it also affects the livelihoods of farmers, the supply of coconut-based goods, and the price of those items, and it upsets the ecological balance that is necessary for sustain\able agriculture. The current circumstance shows the urgent need for creative and effective ways for pest control, such as the semiochemical-based strategy that was developed in this study.

The current strategies employed to combat the coconut whitefly in Sri Lanka are riddled with limitations. Chemical pesticides, the most common method, pose significant environmental hazards, threatening non-target species and potentially leading to the development of pest resistance. These chemicals also pose health risks to the farmers and consumers. Manual removal of the pests, while non-toxic, is impractical and labor-intensive, especially considering the scale of infestations and the height of mature coconut palms. Yellow sticky traps, another method, provide limited control and are ineffective in large-scale infestations. (Abeysekera, 2019).

This prevailing situation underscores the urgent need for an innovative, sustainable, and practical solution to manage the coconut whitefly menace effectively. The limitations of existing pest control methods highlight the necessity for a strategy that is not only environmentally responsible but also economically viable and easy to implement on a large scale. (Maniania and Ekesi, 2016).

The purpose of this study is to establish a unique approach of pest management that is both successful and ecologically sustainable and develop a semiochemical-based strategy, utilizing trunk injections, to manage the coconut white-fly infestation. This approach promises to be a targeted, environmentally responsible, and potentially more effective method compared to the current practices.

II.MATERIALS AND METHODOLOGY

A.Extraction of Plant Compounds

The extraction of insect repellent compounds was carried out using a systematic distillation method. Selected plant materials were placed into a distillation flask, and the distillation apparatus was set up according to proper guidelines. Distilled water was added to the flask, ensuring it covered three-fourths of the plant material to prevent overflow during boiling.

Upon heating the distillation flask, the water began to boil, releasing steam that carried the insect repellent compounds from the plant materials. The steam was then passed through a condenser, where it was cooled and converted back into a liquid. The resulting liquid consisted of a mixture of water and the extracted insect repellent compounds (Irzhad et al., 2023).

B.Isolation and Purification of Extracted Plant Compounds

The isolated plant compounds underwent a systematic isolation and purification process in the well-equipped laboratories of the Microbiology and Crop Science Departments at the Faculty of Technology, South Eastern University of Sri Lanka. Firstly, the extracted plant compounds were transferred to a separation funnel, where petroleum ether was added and thoroughly mixed. The mixture in the separation funnel was allowed to settle, resulting in two distinct phases: an upper organic phase (containing the plant compounds) and a lower aqueous phase (water). Sodium sulfate was then added to remove any residual water. The petroleum ether was subsequently evaporated using a rotary vacuum evaporator at 40°C. Once refined, the compounds underwent rigorous testing to determine their purity and concentration, ensuring that the pesticide formulation contained only the most effective and consistent components. This meticulous purification process is essential for developing a pesticide solution that is both effective and safe for managing the coconut whitefly (Skoog et al., 2013).

C. Preparation of Semiochemical Pesticides

The selected plant materials were dried to reduce their moisture content and then cut into small pieces. These were ground into a fine powder using a blender and placed into flasks. Hexane and methanol were added to the flasks as solvents, and the mixtures were shaken overnight at 1600 rpm. The polar and nonpolar compounds in the plant materials were extracted by the respective solvents. The resulting mixtures were filtered using filter papers, and the filtrates were collected in separate flasks for further analysis.

The final stage of this process involved homogeneously mixing all the pesticide compounds. Strychnos nux-vomica was identified as a promising compound. Additionally, neem oil, clove oil, and mint oil were incorporated. An ultrasonic mixing machine was used to ensure thorough mixing. The ultrasonic mixer effectively disperses nano-sized particles into liquids, such as water, oil, and solvents. Four types of formulations were prepared for mortality testing (McMurry, 2016).

Table 2.1: The percentages of **Strychnos nux-vomica, clove oil, mint oil,** and **neem oil** in each formulation.

Formulation	Strychnos nux-vomica	Clove oil	Mint oil	Neem oil
1	5%	5%	5%	5%
2	10%	5%	5%	5%
3	15%	5%	5%	5%
4	20%	5%	5%	5%

A. Tested the Efficacy of the Prepared Formulation Against Whitefly Through Laboratory Bioassays.

The pesticide was tested for its efficacy in controlling whiteflies through direct spraying prior to trunk injection. High-pressure spraying and mist spraying techniques were used to minimize fly dispersal and ensure effective application. Before spraying, the whitefly population on each sample was roughly counted. After spraying, the number of dead whiteflies was recorded at various time intervals, such as 10, 20, 30, 60, and 120 minutes. The treated leaf area remained free of whitefly infestation for approximately seven days following pesticide application.

B. *Trunk injection solution compounds*

During direct spraying, mortality was recorded positive way. Formulation of the highest mortality recorded, further incorporated with systemic carrier materials and tested for trunk injection. The first step of this process was the preparation of trunk injection formulations. Mainly four types of formulations were used.

Figure 01: Prototype trunk injector

Table 2.2: Components of Trunk injection formulations

Formulation	Components	Water (ml)	Pesticide
1	Citric Acid	40	Yes
2	Urea, KCl, and NaCl	40	No
3	Pesticide, Water, Citric Acid, and Salt	40	Yes
4	Pesticide, Citric Acid, and Salt	40	Yes

Drilled 3 inches and made two holes in the coconut trunk, and set a 20ml needle for each hole. Then pesticide and translocation mixture were inserted into each needles. Four coconut trees were used for four mixtures. Then monitored the absorption condition of the mixtures. All the mixtures were absorbed within one day.

Leaf samples were methodically collected at 2, 4, and 7 days post-application marking key intervals for evaluation. As well these collected samples were subjected to GC-MS analysis as per the procedure with the goal of evaluating the translocation design and the effectiveness of the mixtures along the trunk to the leaves over the specified time intervals.

VIII. RESULTS & DISCUSSION

A. *Evaluating Mortality Rates Induced by Formulated Semiochemical Pesticides*

Table 3 1: Formulation 1 mortality rate results

Plant 01 Sample Nos	Alive (before spray)	Alive (after spray)	Number of dead whiteflies
2	98	27	71
5	63	29	34
1	38	11	21
3	250	80	170
3.1	140	30	110
Total	589	177	406
Morality rate			68.93%

The Table 01 illustrates that the number of coconut whiteflies that were alive before and after the application of formulation 1, along with the calculated mortality for each sample. The sum of white flies alive before the spray across all samples was 589, and the sum of those alive after the spray was 177. This resulted in a total of 406 dead. The mortality rate, presumably calculated as (Total dead / Total live before Spray) * 100, is approximately 68.93%. This indicates that, on average, about 68.93% of the coconut white flies were killed by formulation 1 across all the samples.

Table 3.2: Formulation 2 mortality rate results

Plant 02 Sample Nos	Live whiteflies (before spray)	Live whiteflies (after spray)	Number of dead whiteflies
18	338	19	319
10	178	7	171
12	244	0	244
10	156	12	144
Total	916	38	878
Morality rate			95.85%

Sample No 18: Initially had 338 white flies alive, and after spraying, 19 remained alive, resulting in 319 mortalities. Sample No 10: Started with 178 white flies alive, with 7 surviving post-spray,

leading to 171 mortalities. Sample No 12: Had 244 white flies before the spray, with none surviving afterward, thus 244 mortalities. Sample No 10: Had 156 were alive before the spray, and 12 remained after, resulting in 144 mortalities.
Summing up the figures, there were initially 916 white flies alive across all samples, and post-spray, 38 remained. This resulted in a total of 878 white flies being mortally affected by formulation 02.
The mortality rate for formulation 2 is calculated to be approximately 95.85%, as derived from the formula (Total dead/ Total Alive Before Spray) * 100. This suggests a very high efficacy of formulation 2 in causing mortality in the coconut whitefly population across the samples tested.

Table 3.3: Formulation 3 mortality rate results

Plant 03 Sample Nos	Alive (before spray)	Alive (after spray)	Number of dead whiteflies
7	38	4	34
8	89	3	86
16	106	13	93
18	208	14	194
Total	441	34	407
Morality rate			93.26%

The mortality rate for formulation 3 is calculated to be approximately 93.26%, as determined by the formula (Total dead/ Total Alive Before Spray) * 100. This rate suggests that Mixture 3 is highly effective, resulting in the death of a large majority of the coconut white-flies across the samples tested.

Table 3.4: Formulation 4 mortality results

Plant 04 Sample Nos	Live whiteflies (before spray)	Live whiteflies (after spray)	Number of dead whiteflies
2	197	4	193
6	141	8	133
3	69	13	56
10	268	11	257
Total	675	36	639
Morality rate			94.66%

The mortality rate for Formulation 4 is approximately 94.67%, calculated by the formula (Total dead / Total Alive Before Spray) * 100. This mortality rate is quite high, indicating that Formulation 4 is very effective in killing coconut white-flies across the tested samples.
Comparing formulations 4 to the previous formulations: Formulation 1 had a mortality rate of 68.93%, followed by Formulation 2 at 95.85% and Formulation 3 at 93.27%.Formulation 4's effectiveness is slightly less than that of Formulation 2 but is still considerably high and is more effective than Formulation 1 and slightly higher than Formulation 3. To determine the best mixture, one should consider not only the mortality rates but also factors such as environmental safety, cost-effectiveness, ease of application, and any non-target effects. Formulation 4 seems to be a strong candidate based on efficacy; however, a comprehensive evaluation including these additional factors is necessary for a conclusive decision.

IX. CONCLUSION

In conclusion, the experimental study on the effectiveness of different formulations for controlling coconut whiteflies in this preliminary study has shown promising results, especially with formulation 2 (10% Strychnos nux-vomica + 5% clove oil + 5% mint oil + 5% neem). oil) and formulation 4 (20% Strychnos nux-vomica + 5% clove oil + 5% mint oil + 5% neem oil). These formulations achieved high mortality rates of 95.85% and 94.67%, respectively, indicating their potential as effective pest control solutions. However, further research, including additional experiments and field trials, is essential to validate these results, ensure systemic properties of the coconut palm, and evaluate the effectiveness and sustainability in practice. The promising results of Formulations 2 and 4 highlight the need for further research to support their practical application in sustainable agricultural practices.

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The Foliar Application of Sea Lettuce (*Ulva lactuca*) Liquid Extract on Growth and Quality of Groundnut (*Arachis hypogaea* L.)

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Abstract

At present there is a significant demand for environmentally sustainable agriculture to produce high-quality, nutritious food for the growing global population. Research efforts are currently focused on sustainable crop production methods, utilizing organic fertilizers and botanical compounds derived from natural resources to enhance the yield of commercially valuable crops. A field study was conducted to investigate the effects of foliar application of seaweed (Ulva lactuca) liquid extracts (SLE) on the growth and yield of the 'Indi' cultivar. The foliar application of SLE was applied to the plant at one-week interval. As treatment, the seed extract was applied at different concentrations 10% SLE (T2), 20% SLE (T3), 50% SLE (T4), and 100% SLE (T5) (v/v). Control treatment consisted of foliar application of distilled water (T1). The results showed that there were significant differences(p<0.05) among the tested parameters of the 'Indi' cultivar.Foliar application of seaweed extract at concentrations of 20% (T3) increased the ground nut plant height (49.44 cm), number of nodules (144) and pods (27), air dry pod weight (36.38 g), air dry seed weight seed yield (24.28 g), biological yield (2898.12 kg/ha), and harvest index (41.96 %). Seaweed extract with 100% foliar application reduced the above-mentioned parameters significantly compared to the control. Therefore, it could be concluded that the seaweed extract at a 20% concentration level can be used to enhance the growth and yield of 'Indi' groundnut cultivar.

Keywords: Biostimulator, foliar application, Groundnut, Seaweed liquid extract

I. INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is an economically important crop in Sri Lankan region. It belongs to the Leguminosae family and requires applicable quantities of nutrients at appropriate times to achieve better yield and quality. There is a growing need to enhance the environmentally friendly cropping system and reduce the negative environmental impacts (Zuma *et al*.,2023). In Sri Lanka, growers use chemical fertilizers to meet the added demand for food and prefer to gain a quick return. Additionally, the inordinate operation of agrochemicals and synthetic fertilizers has led to numerous environmental problems. Due to the runoff of synthetic fertilizers from agrarian lands, nitrate and phosphate concentrations were set up to be significantly more advanced than the admissible limits of the World Health Organization norms (Divya and Balagali, 2012). Hence, the indispensable nutrient operation is essential for overcomes the constraints prevailing in the eastern part of Sri Lanka. Seaweed extracts contain a large proportion of growth hormones such as (IAA and IBA), cytokinin, trace elements (Fe, Cu, Zn, Co, Mo, Mn, and Ni), vitamins, and amino acids that promote the growth, yield, and productivity of numerous crops (Kumar and Sahoo, 2011). Seaweeds are biodegradable, non-toxic, non-polluting, and safe for humans, animals, and livestock (Dhargalkar and Pereira, 2005). Several regions of the world must be explored and exploited to understand the richness of marine plants and macroalgae. Algal resource use has not yet been optimized, and there is a great abundance of potentially important species, similar to sea lettuce. It is a macroalga belonging to the phylum Chlorophyta that can grow attached, sessile, or free-floating. Sea lettuce has proven to be a useful fertilizer because it not only provides macronutrients such as nitrogen, phosphorus, and potassium but also contains numerous micronutrients needed by crops (Eyras *et al.*, 1998). In Sri Lanka, the utilize of *Ulva lactuca* as a biofertilizer or bio stimulant has not yet been adequately investigated and has been reported as a beneficial application for the growth of plants (Metting *et al*., 1990). The specific objective of the current study was to estimate the effects of different concentrations of seaweed foliar spray on the growth and yield of groundnut.

II. MATERIALS AND METHOD

A. Experimental site.

The experiment was conducted at the agronomy farm of Eastern University of Sri Lanka. The soil of the experimental area is sandy regosol. The latitude is 43’ and the longitude is 81^{o} 42’. During the growing periods, the average temperatures ranged between 26-35°C. The minimum and maximum rainfalls during the experimental season were 7 mm and 60 mm respectively. Certified seeds ‘Indi’ was obtained from the seed sales Centre of Karadiyanaru, Batticaloa, Sri Lanka. The experiment was laid out in randomized complete block design (RCBD) with four replications. Polythene bags were used to establish the plants. The diameter and height of polythene bags were 42 cm and of 36 cm respectively. The foliar spraying was done five times during the experimental period at one-week intervals from three weeks after planting. The recommended plant management practices (watering, fertilizer applications) were carried out based on the guideline of the Department of Agriculture, Sri Lanka.

B. Seaweed collection and seed weed extract preparation.

Seaweed was collected by the hands along the coastal waters of Passikudaha, Batticaloa and the sediment, epiphytes, and organic matter on the surfaces of seaweed were cleaned immediately with seawater. The seaweed was packed in polythene bags and transported to the horticulture laboratory.Inorder to remove excess dirt and salt, the seaweed was once again cleaned with tap water in the laboratory. The seaweed was air dried in a dark room for three days. After drying, it was cut to a size of 0.5 cm to 1 cm. The samples were weighed (1 kg) and boiled in 1 litter distilled water for an hour. The mixture was allowed to cool to room temperature and was filtered through muslin cloth. The seaweed extract was treated at a 100% concentration and diluted with distilled water at a rate of 1:5 (Bhosle *et al*., 1975). During each application, 10 ml of extract was applied to each plant. The treatment structures are as follows,

Table 01. Details of treatments for conducting groundnut cultivar trials using seaweed liquid extract

Treatments	**Seaweed liquid extract (SLE)Concentrations**
T1	Distilled water (Control)
T2	10 %
T3	20 %
T4	50 %
T5	100 %

C. Samples Collection for analysis

Five plants have been arbitrarily chosen from each replicate of treatments. The control plants too were selected for the measurement.

D. Plant height

The plants were pulled out, and their roots were rinsed with tap water. A measuring tape was used to record the heights of each plant from the base of the stem (at the soil surface) to top of the highest part of the plant by a measuring tape.

E. Number of pods and number of nodules

The plants were uprooted from each treatment and the roots were washed with tap water. The plant’s pods and nodules were counted.

F. Air dry pod

The pods of each plant were removed and separated and sundried for five days and their dry weight was recorded using an electric balance.

G. Air dry seeds

Seeds were separated from the pods. Seeds were sundried for five days and their dry weight was recorded using an electric balance.

H. Seed yields

Seeds were collected from each pod and seed yield was calculated from each treatment

I. Biological yield

The biological yield was determined by weighing all pants harvested from each treatment.

J. *Harvest index*

The harvest index (HI) was calculated to determine the fraction of economically useful products of a plant in relation to its total productivity (grain-to-straw ratio) using the following formula:

$$HI = (EY/BY) \times 100$$

Where HI- Harvest index, EY- Economic yield, BY-Biological yield.

K. *Statistical analysis*

Data collected were subjected to analysis of variance (ANOVA) using Statistical Analysis System (SAS) software (SAS version 9.1, Institute INC., Cary, USA). Treatment means were compared according to Tukey's to find out the significance between the treatments at p<0.05.

III. RESULTS AND DISCUSSION

Foliar application of seaweeds affected the growth of groundnut plants and significantly (p<0.05) influenced plant height compared to the control treatment (Table2). The highest plant height was obtained from T3 (20% SLE) treatment, whereas the lowest average was observed in T5 (100 % SLE). The application of seaweed extracts may have contributed to the observed outcomes by tending to raise the total chlorophyll content of the leaves, which in turn affected the photosynthetic process's capacity and efficiency (Fan *et al.*, 2013) and enhancing nutrient availability and absorption (Mancuso *et al.,* 2006). These factors likely contributed positively to plant vegetative growth. This result is similar to the results of Sutharsan *et al.* (2017) who reported that a lower concentration of *Sargassum crassifolium* significantly increased the plant height of maize, while a higher concentration exhibited an inhibitory effect than control plants. Means followed by the same letter are not significantly different (P<0.05.) from each other according to Tukey's honestly significant difference test at 5% significant level. There was a noticeable difference (P<0.05) in the number of nodules between Seaweed Liquid Extract (SLE)-treated and untreated plants. The highest number of nodules (144.67) was recorded in 20% SLE (T3), which differed remarkably from T1, T2, T4, and T5. The lowest nodule number was observed at the highest SLE concentration (100 %). The results align with the findings of Sivashankari *et al.* (2006), who observed that higher concentrations of seaweed extracts hindered germination, while seeds of *V. sinensis* soaking in lower concentrations of the extracts showed higher rates of germination.. Additionally, they observed that certain growth-promoting compounds such IAA and IBA, Gibberellins, cytokinin, minerals (Fe, Cu, Zn, Co, Mo, Mn, and Ni), vitamins, and amino acids may be accountable for the higher germination percentage at low concentrations.

Table 02: Effect of foliar application of SLE on Plant height, pod and nodule numbers per groundnut cultivar.

Treatment	Plant height (cm)	Number of nodules/plants	Number of pods/ plants
T1	22.67± 0.12^{d}	99.53b±2.4 0^{d}	20.3±0.25 ^{d}
T2	36.65± 0.23^{b}	134.44±2.82 ^{b}	25.73 ± 0.88^{ab}
T3	49.44 ± 0.44^{a}	144.67± 0.43^{a}	27.00 ± 1.54^{a}
T4	31.97± 0.23b^{c}	131.54± 0.33^{bc}	22.27 ± 0.17^{ab}
T5	20.26± 0.15^{e}	91.14 ±2.73 ^{e}	14.34±0.38 ^{e}

Statistical analysis of data showed that application of a lower concentration (20%) of SLE (T3) significantly (P<0.05) increased the mean number of pods per plant (27) in treated plants compared to the control plants, whereas a higher concentration (100%) of SLE (T5) reduced the mean number of pods per plant (14). This could be because increased SLE concentrations have an inhibiting impact even if SLE contains higher concentrations of macro-and microelements. It was clearly indicated that foliar application of seaweed (*Sargassum crassifolium*) at lower concentrations favored tomato plant growth by increasing. photosynthesis through an increased leaf area, as reported by Rasheed *et al.* (2003). These results coincide with those of earlier studies on tomatoes, where the number of fruits of tomato remarkably increased at lower concentrations of *Kappaphycus alvarezii* sap of Zodape, since phytohormones, amino acids, and essential macro and micronutrients found in seaweed extracts enhance plant growth and development. Furthermore, he reported that fruit number per plant was significantly reduced at higher concentrations than in control plants. It was also in agreement with the findings of Vijayakumar *et al.* (2018) who stated that higher concentrations of seaweed liquid extracted from *Codium decorticatum* decreased chlorophyll content, which led to reduced plant growth as well as the number of pods in *Capsicum annum*. Means followed by the same letter are not significantly different (P<0.05.) from each other according to Tukey's honestly significant difference test at 5% significant level. The application of SLE treatments had a significant (P<0.05) effect on the air-dried weights of pods and seeds per plant compared to the control (Table 03). The highest air-dried pod weight (36.38 g) and seed weight (24.28 g) per plant were obtained in T3 (SLE 20 %), whereas 100% SLE exhibited an inhibitory effect on pods (13.12 g) and seeds (10.02 g) weight per plant.

Polyphenols, polysaccharides, alginates, polyamines, pigments, free amino acids, betaines, vitamins, micro- and macronutrients, and naturally occurring phytohormones are among the biologically active compounds found in seaweed extract. These different chemicals found in seaweed extract may have a stimulatory effect, potentially influencing the cellular metabolism processes of treated plants and producing the positive effects of seaweed extract that have been reported (Khan *et al.*, 2009).Additionally, the high magnesium and mineral content found in seaweed extracts may have contributed to the observed increases in total leaf chlorophyll and carotenoid concentrations, which in turn may have improved photosynthetic efficiency, nutrient availability, and absorption, ultimately leading to increased carbohydrate production (El-Din, 2015).

Table 03: Effect of foliar application of SLE on air-dried pod weight and air-dried seed weight of the groundnut cultivar.

Treatment	Air-dried pod weight per plant(g)	Air-dried seed weight per plant(g)
T1	16.24 ± 0.41^{d}	12.91 ± 0.35^{d}
T2	24.87 ± 0.47^{b}	17.38 ± 0.29^{b}
T3	36.38 ± 0.41^{a}	24.28 ± 0.55^{a}
T4	21.03 ± 1.14^{c}	15.72 ± 0.14^{c}
T5	13.12 ± 1.23^{e}	10.02 ± 0.45 ^{e}

Our results are in line with the findings of other researchers applying the SLE of *Sargassum crassifolium* with 20% concentration as the foliar application significantly increased the average polar diameter per fruit of tomato by 12.31% compared to control plants (Sutharsan *et al.*, 2014).

Means followed by the same letter are not significantly different (P<0.05.) from each other according to Tukey's honestly significant difference test at 5% significant level. Pod and seed yields were significantly (P<0.05) affected by the application of SLE (Table 04). It was noted that the addition of 20% SLE (T3) had a significant effect on economic yield than the other treatments. Maximum seed yield was obtained in T3 (2898.12 kg/ha) followed by T2 (2727.58 kg/ha) and T4 (2227.76 kg/ha) respectively. The harvest index is a consequence of the grain yield

Table 04: Effect of foliar application of SLE on pod yield, seed yield and harvest index of the ground nut plant during the harvesting stage.

Treatment	Pod yields (kg/ha)	seed yields (kg/ha)	Harvest index (%)
T1	2576.41 ± 106.40^{d}	2134.97± 232.66^{d}	30.89± 01.35^{d}
T2	3452.98 ± 105.53^{b}	2727.58 ± 111.40^{b}	36.12± 01.61^{b}
T3	4135.57 ± 123.14^{a}	2898.12 ± 134.01^{a}	41.96± 02.33^{a}
T4	3176.98 ± 117.21^{bc}	2227.76 ± 201.42^{c}	32.44± 02.33^{c}
T5	1796.23 ± 122.41^{e}	1978.55 ± 102.01^{e}	17.01± 01.31^{e}

and biological yield. There was also a significant difference ($P< 0.05$) in the harvest index of the ground nut plants after the foliar application of SLE (Table 03). Maximum harvest index (41.96 %) was noticed under the foliar application of T3 (20% SLE) which was followed by the foliar applications of T2 (10 % SLE) and T4 (50% SLE), whereas T5 (100 %) had the lowest value of 17.01 % in the present study. The increase in harvest index percentage may be due to an increase in seed yield. Major and minor minerals, vitamins, cytokinins, auxins, and compounds that promote growth akin to abscisic acid are all found in seaweed extracts. Studies have shown that these nutrients can enhance plant growth and yield as well as help plants become more resilient to environmental stress (Khan *et al*., 2009; Zhang *et al*., 2003). An increase in yield with SLE application is associated with improved chlorophyll biosynthesis (higher SPAD index) (Yusuf *et al*., 2018)

IV.CONCLUSION

The present study determined that the foliar application of Seaweed liquid extract **(***Ulva lactuca*) improved the growth and yield of 'Indi' groundnut cultivar. Among the four concentrations tested, 20% of SLE performed better in terms of groundnut plant growth and yield. Hence, foliar treatment with *Ulva lactuca* at 20% may thus be recommended for improving the characteristics of pods and nodules and yield and yield components of the groundnut.

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ABBREVIATIONS

SLE – Sea weed liquid extract