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Editorial Office:

Editor- in-Chief,
Applied Bio-Systems Technology,
Faculty of Agriculture & Plantation Management,
Wayamba University of Sri Lanka,
Makandura, Gonawila, 60170,
Sri Lanka.

Tel : +94-31 229 7075
E-mail : abse@wyb.ac.lk
Fax : +94-31 229 9248

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Research Article **Open Access**

Morphological and Physiological Responses of *Alysicarpus vaginalis* L. (*Aswenna*), A Native Ground Cover; Under Induced Water Deficit Conditions

Nirma Subashini[1], Nuwan Chathuranga[1], Kapila Yakandawala[1*] and Lahiru Udayanga[2]

Abstract

Background: Frequent occurrence of droughts has become a major challenge in agriculture and horticulture sectors, limiting the crop production. Therefore, screening for drought tolerance plants has become a key requirement in the landscape industry. The current study was conducted to investigate the drought tolerance ability of *Alysicarous vaginalis* L. (Fabaceae), to be used as a drought tolerant ground cover plant.

Methods: Tip cuttings of *A. vaginalis* were planted in pots and water stress conditions were imposed on plants through irrigating the plants up to the field capacity daily (T_1: control), every fifth (T_2), tenth (T_3), fifteenth (T_4) and twentieth (T_5) day. Each treatment consisted of 20 replicates arranged in Completely Randomized Design inside a plant house. Morphological characteristics were recorded up to 60 days along with the survival rate of plants. General Linear Model (GLM) was used for the statistical comparisons.

Results: All the plants survived in all treatments. All the growth parameters differed significantly among the treatments ($P<0.05$ at 5% level of significance), where the highest leaf area, number of leaves, leaf fresh weight, leaf moisture content, shoot moisture content and shoot fresh weight were observed in T_2, while, plants in T_5 showed the lowest morphometric parameters, except for leaf hair density and root Length. Therefore, the significant water stress resistant characteristics were observed at T_5.

Conclusions: *A. vaginalis* can be recommended as a water stress tolerant plant with a potential to be used in outdoor landscaping as a ground cover plant, with low maintenance requirements.

Keywords: *Alysicarpus vaginalis,* Drought Tolerance Plants, Ground Cover, Landscaping, Water Stress

[1]Department of Horticulture & Landscape Gardening, Faculty of Agriculture and Plantation Management, Wayamba University of Sri Lanka, Sri Lanka.

[2]Department of Biosystems Engineering, Faculty of Agriculture and Plantation Management, Wayamba University of Sri Lanka, Sri Lanka.

* Correspondence: kapilay@wyb.ac.lk

https://orcid.org/0000-0002-1985-348X

INTRODUCTION

Global climate change, which is referred to the long-term changes in the average weather patterns, is currently viewed as one of the most devastating threats to the environment and socio-economic sectors [1]. This has caused numerous adverse impacts on the environment, humans and prevailing climatic patterns, leading to continuous rising of temperature, changes in precipitation patterns and elevated frequency of natural disasters.

Water is a vital commodity for the survival and sustainable existence of all living beings. Undesirable impacts of droughts on societal, and environmental activities take place primarily as a water stress and then as a scarcity. This significantly influence the survival and productivity of plants [2-3]. The water consumption in the agricultural context, is a major component of overall water demand in the world. Thus, droughts or water deficit conditions are one of the most important environmental constrains faced by the agriculture sector [4-5].

Plant water stress has been defined as a state of insufficient level of water prevalence, which affects the normal functioning of a plant [6]. Plants experience water stress conditions as a result of limited absorption and high evapotranspiration demand or as a combined effect of both [7]. Water stress is multidimensional in nature and affects plants at various levels of their organization by changing plant anatomy and ultrastructure, resulting decrease in leaf size, reduction of stomata count, thickening of cell walls and early senescence. In fact, under long periods of drought, many plants will dehydrate and die. This hinders the possibility of the plants in reaching potential growth and yield [2, 5, 8].

Since landscaping is a segment that majorly deals with plants, water scarcity has become a major issue especially in outdoor landscaping, as it needs more water than indoor landscaping. Therefore, outdoor landscaping is more liable to adverse climatic conditions. Especially ground covers, and turfs are adversely affected by water crisis, which possess higher water requirements for maintenance. With the increasing shortages in rainfall, water restrictions for landscaped areas have become a common issue in many tropical countries around the world [9-10].

Water stress tend to influence landscape plants by decreasing the aesthetic and functional quality of the plants. Various symptoms including, stunted growth, wilting, curling, or browning of leaves, leaf firing, no flowering and increased insect or disease attacks would appear as consequences of water stress, reducing the overall ornamental plant quality, during a water deficit period of a plant [11]. Consequently, landscape managers are struggling to address the foresaid challenges, while sustaining the landscape quality with less water consumption. As a response, landscaping practices are being evolved based on the emerging variations in climate.

Drought tolerant landscaping remains as an innovative concept, which has recently gain popularity among plant scientists and landscape professionals. Growing native plants, using effective irrigation systems, use of wastewater for watering and practicing xeriscaping are some of the approaches used in this concept to enhance the sustainability of landscaping plants in the face of climate change [12-13]. Therefore, screening of plants for water stress resistance is a widely used strategy in drought tolerant landscaping.

Drought tolerant/ water stress resistance plants use less water, but still provide beauty and functionality in the landscape designs. They are capable of surviving long periods of water deficient conditions through development of various morphological, anatomical and metabolic adaptations. Ability of storing water internally, development of extensive root systems, decreasing the leaf area, optimizing the stomatal closure, reduced plant growth, osmotic adjustments, development of a thick waxy cuticle layer and leaf hairs on the leaf surface could be recognized as some of such adaptations [14]. Most drought tolerant plants use several of these features to survive on low amounts of irrigation [1]. Understanding the minimal irrigation requirements and extent of water stress that a particular plant species can tolerate while exhibiting acceptable quality, is of immense importance in landscape designing [9]. This would enable the landscape designers to establish a pleasing landscape with a certain degree of water stress tolerance, using selected plants.

Alysicarpus vaginalis, commonly known as "Aswenna" (Sinhala; *local language*) or "Alyce Clover" (English) is a widely distributed plant in South Asia. It belongs to the family Fabaceae and is recognized to possess a potential drought tolerance. Based on general observations, *A. vaginalis* shows a notable survival ability under water deficit conditions, making it an appealing choice for outdoor landscaping. In case of morphology, *A. vaginalis* is a semi woody herbaceous annual plant with a creep growing nature. Thin cylindrical stem often grows up to 60 to 120 cm in length, while ascending is branched wiry, glabrous, and often rooting at base. Leaves can grow up to 1.2 to 5 cm in length with alternate arrangements, where shape may vary from liner lanceolate to broadly oval, cordate at base and glabrous surface.

Flowers of *A. vaginalis* are bisexual, pinkish violet in colour with five sepals and five petals [15]. This plant has been traditionally used in herbalism for diuretics, leprosy, pulmonary troubles, back pain, treat stones in the bladder and renal calculi [15-16]. Furthermore, *A. vaginalis* is a native plant in Sri Lanka, which is naturally distributed within all three climatic zones of the country, making it a better choice for landscaping [17].

Despite its wide distribution and native nature, *A. vaginalis* is being limitedly used in landscaping within Sri Lanka. Furthermore, the water stress resistance of *A. vaginalis* has not been assessed to evaluate its potential to be used in drought tolerant landscaping. Therefore, the current study was conducted to evaluate the resistance of *A. vaginalis* for water deficit stress conditions, with the view of introducing it in sustainable landscaping context as a drought tolerant ground cover with low maintenance.

METHODOLOGY

Location

This experiment was conducted at the Faculty of Agriculture and Plantation Management, Wayamba University of Sri Lanka, Makandura, situated in the Low Country Intermediate zone (IL_{1a}), under plant house condition to prevent any interference from rainfall on experimental pots.

Collection of Planting Materials and Propagation

The planting material (stem cuttings) of *A. vaginalis* were collected from Makadura area. The most successful plant part to propagate *A. vaginalis* is tip cuttings of the stem. Five-centimeter length tip cuttings of *A. vaginalis* were obtained and planted in black polythene pots (6 cm x 15 cm in size; gauge 150) using a mixture of topsoil and compost (1:1 ratio) as the media. Plants were allowed to establish in a propagator, which was prepared using transparent polythene with a gauge of 500 to facilitate better propagation. Plants were kept inside the propagator for six weeks for rooting, followed by another week for hardening outside the propagator. Plants were irrigated according to the requirements.

Screening for Drought Tolerance

Healthy vigorously grown 100 similar sized plant pots were randomly selected, maintaining a density of 2 plants per pot. According to Fu *et al*. [18], water stress conditions can be replicated by extending the frequency of irrigation. Hence, *A. vaginalis* plants in the current study were subjected to five water stress conditions by varying the addition of a constant amount of water with five different applying frequencies as, daily

(T_1- control), every fifth (T_2), tenth (T_3), fifteenth (T_4) and twentieth (T_5) day as indicated in Table 1. The field capacity of the soil medium in pots was considered as the constant irrigation amount for all the treatments. Pots were arranged in a Completely Randomized Design (CRD) and maintained under an average sunlight of 2.36 Klux inside a plant house. The environmental parameters including temperature (T), relative humidity (RH) and light intensity inside the plant house were recorded three times per day. The water stress conditions were maintained for 60 days, and the entire experiment was replicated for 20 times.

Table 1: Treatments used in the Experiment

Treatment	Water Application/ Irrigation Intervals
T1 (control)	Everyday
T2	Once in 5 days
T3	Once in 10 days
T4	Once in 15 days
T5	Once in 20 days

Growth Parameters

During the study period several growth parameters, namely plant height (from the base of the plant to the tip in cm), number of leaves, number of shoots per plant and the number of surviving plants were recorded at one-week intervals. At the end of 60 days survival rate of the plants were recorded. Then the plants were uprooted and the total leaf area (cm^2, Bench top leaf area meter model Li-3100C), fresh weight of leaves, shoots and roots (g), length of the longest root (cm), dry weight of leaf, shoots and roots (g, oven dried at 80 ^{0}C for 72 hours) were measured. Leaf, root and shoot moisture content were calculated. Further, the leaf hair density was measured using dissecting microscope (model Euromex Holland).

Statistical Analysis

All the recorded data were entered into Excel sheets adhering to quality control procedures. General Linear Model followed by Tukey's pair-wise comparison was used to identify the significance in temporal variations of studied growth and morphological parameters of *A. vaginalis* under different water stress conditions. IBM SPSS (version 23) was used for the statistical analysis.

RESULTS AND DISCUSSION

Effect of Water Stress on Leaf Parameters

The studied morphological and physiological parameters unveiled pronounced responses under the imposed stress conditions, which revealed restraining effects of *A. vaginalis* under the water deficit conditions. Significant alternations in the leaf area, leaf count, leaf hair density, leaf fresh weight and leaf moisture content were found in *A. vaginalis* ($P<0.05$) grown under different water stress conditions as indicated in Table 2. The highest leaf area was indicated by T_2 (113.5±13.8 cm^2), while T_5 (66.0±5.0 cm^2) reported the lowest value for the leaf area. The leaf area of *A. vaginalis* denoted a significant decreasing trend along with the water stress, except for T_2 treatment. A similar trend was observed in leaf count also, where, the highest leaf count was observed at T_2 (50.80±5.59), whereas T_5 (30.65±2.59) denoted the lowest value.

A vaginalis comprise of single type leaf hair (trichome) as shown in Figure 1. Leaf hair density showed a significant variation ($P<0.05$ at 95 % level of confidence) among the treatments, where the highest leaf hair density was observed from T_5 (648.14±15.96 cm^2). On the other hand, T_1 and T_2 recorded the lowest values as 241.40±12.71 cm^2 and 278.10±13.27 cm^2, respectively (Table 2). In case of leaf fresh weight, T_2 (1.25±0.16 g) recorded the highest leaf fresh weight, while T_5 (0.61±0.02 g) had the lowest. Even though, the leaf fresh wight denoted a significantly ($P<0.05$) decreasing trend under increasing water deficit conditions (except for T_2), leaf dry weight didn't denote any significance. However, the highest mean value for leaf dry weight was observed from the T_2 treatment (1.25±0.16 g), while plants reared under T_5 (0.61±0.02 g) denoted the lowest mean value (Table 3). A similar significantly decreasing trend in leaf moisture content was noted from *A. vaginalis* grown under gradually increasing water deficit conditions, except for T_2

treatment, which reported the highest moisture content as 1.00±0.13 g.

Effect of Water Stress on Root Characteristics

Root growth is an important parameter of plant performance. In the present study, the lowest root length (12.74±0.74 cm) was denoted by T_2, while the T_5 treatment reported the lowest root fresh weight (0.112±0.013 g) and the moisture content (0.065±0.012 g). Meanwhile, *A. vaginalis* plants maintained under T_5 denoted the highest root length as 19.18±0.63 cm. Further, the highest root fresh weight (0.144±0.025 g) and the moisture content (0.101±0.019 g) values were observed from the *A. vaginalis* reared under T_2 treatment as shown in Table 3.

Table 2: Leaf Parameters of *Alysicarpus vaginalis* subjected to Different Treatments

Treatment	Leaf Area (cm^2)	Leaf Count	Leaf Hair Density (cm^2)	Leaf Fresh Weight (g)	Leaf Dry Weight (g)	Leaf Moisture Content (g)
T_1	90.08±13.54^{a,b}	48.6±5.8^{a,b}	241.40±12.71^{d}	0.94±0.13^{b}	0.04±0.006^{a}	0.76±0.11^{b}
T_2	113.52±13.84^{a}	50.8±5.^{a}	278.10±13.27^{d}	1.25±0.16^{a}	0.04±0.007^{a}	1.00±0.13^{a}
T_3	85.91±10.11^{b}	42.7±4.0^{b}	453.00±23.61^{c}	0.89±0.12^{b}	0.04±0.003^{a}	0.71±0.09^{b}
T_4	80.08±7.65^{b}	41.9±4.9^{b}	537.29±22.58^{b}	0.87±0.08^{b}	0.04±0.005^{a}	0.69±0.07^{b}
T_5	66.05±5.03^{c}	30.7±2.1^{c}	648.14±15.96^{a}	0.61±0.02^{c}	0.03±0.004^{a}	0.45±0.05^{c}

Note: *Mean ± SE of each value is included. Means with different superscript letters within a column show significant differences among the means as indicated by Tukey's pair-wise comparison followed by One-way ANOVA (P<0.05). T_1: Control, T_2: Once in 5 days, T_3: Once in 10 days, T_4: Once in 15 days and T_5: Once in 20 days.*

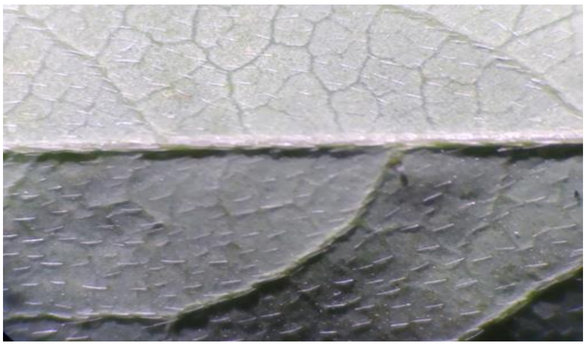

Figure 1: Leaf Trichome of *A. vaginalis*

Even though, the root length of *A. vaginalis* indicated significant variations among the treatments (P<0.05), the post-hoc analysis evidenced that there are no significant differences (P>0.05 at 95 % level of confidence), between T_1, T_3, T_4 and T_5 in case of root fresh weight and moisture content (Table 3). Meanwhile, the variations in root fresh weight and root moisture content remained non-significant (Table 3), suggesting that the studied water stress conditions have no notable effect on the above parameters of *A. vaginalis*.

Among the studied shoot parameters, number of branches, shoot fresh weight and shoot moisture showed significant variations (P<0.05) among different water stress conditions (Table 4). The highest number of branches (3.2±0.5), shoot fresh weight (1.29±0.7 g) and shoot moisture content (1.01±0.13 g) were reported from the T_2 treatment, while *A. vaginalis* reared under the T_5 treatment had the lowest values as 1.7±0.4, 0.62±0.05 g and 0.44±0.03 g, respectively. A similar trend was apparent in shoot length also, where plants maintained under T_2 had the highest shoot length as 39.8±1.3 cm, while the lowest was observed in T_5 (36.1±1.1 cm). However, this trend was not statistically significant (P>0.05) as shown in Table 4. In general, all the shoot parameters of *A. vaginalis* denoted a decreasing trend with the

Table 3: Root and Shoot Parameters of *Alysicarpus vaginalis* subjected to Different Treatments

Treatment	Root Length (cm)	Root Fresh Weight (g)	Root Moisture Content (g)
T_1	18.91±0.95^{a}	0.117±0.021^{a}	0.075±0.017^{a}
T_2	12.74±0.74^{b}	0.144±0.025^{a}	0.101±0.019^{a}
T_3	17.98±1.27^{a}	0.113±0.018^{a}	0.076±0.014^{a}
T_4	18.03±1.18^{a}	0.120±0.018^{a}	0.078±0.014^{a}
T_5	19.18±0.63^{a}	0.112±0.013^{a}	0.065±0.012^{a}

Note: *Mean ± SE of each value is included. Means with different superscript letters within a column show significant differences among the means as indicated by Tukey's pair-wise comparison followed by One-way ANOVA (P<0.05). T_1: Control; T_2: Once in 5 days; T_3: Once in 10 days; T_4: Once in 15 days and T_5: Once in 20 days*

Table 4: Shoot Parameters of *Alysicarpus vaginalis* subjected to Different Water Stress Levels

Treatment	Shoot Length (cm)	Number of Branches	Shoot Fresh Weight (g)	Shoot Moisture (g)
T_1	38.1±1.8^{a}	3.1±0.6^{a}	0.99±0.14^{a,b}	0.75±0.12^{a,b}
T_2	39.8±1.3^{a}	3.2±0.5^{a}	1.29±0.17^{a}	1.01±0.13^{a}
T_3	36.6±1.1^{a}	3.0±0.5^{a}	0.99±0.11^{a,b}	0.80±0.09^{a,b}
T_4	36.5±1.5^{a}	2.5±0.4^{a}	0.91±0.09^{a,b}	0.71±0.07^{a,b}
T_5	36.1±1.1^{a}	1.7±0.4^{b}	0.62±0.05^{b}	0.44±0.03^{b}

Note: *Mean ± SE of each value is included. Means with different superscript letters within a column show significant differences among the means as indicated by Tukey's pair-wise comparison followed by One-way ANOVA (P<0.05). T_1: Control; T_2: Once in 5 days; T_3: Once in 10 days; T_4: Once in 15 days and T_5: Once in 20 days.*

increasing water deficit conditions (except in T2). Most interestingly, a 100 % survival rate was observed (within 60 days) from plants reared under the five water stress treatments, reflecting a higher water stress tolerance ability.

Water stress can be defined as a situation in which plant water relationship alter the interface for normal functioning, by influencing the plant performances at various levels leading to anatomical, physiological, biochemical and molecular responses [19]. Environmental stresses could trigger a wide variety of plant responses, ranging from altered gene expression and cellular metabolism to changes in growth rate and plant productivity. Landscaping is a special segment in horticulture, which is highly affected due to water deficit conditions. In landscaping, ground covers are widely used to cover the spaces in gardens, public open spaces and playing areas providing aesthetic beauty and enhancing the conservation of soil [20].

Generally, the water requirement of ground covers is high in maintaining the visual quality, signifying the importance of utilizing plants with drought tolerance and low irrigation requirements [21]. Hence, screening of drought tolerance ground covers is of great importance in sustaining landscaping [22]. The present study was designed with the context on investigating the effects of induced water deficit conditions on a selected plant species, *A. vaginalis*.

Findings of the study denoted a range of water stress adaptations in *A. vaginalis* plants exposed to varying levels of water stress. Leaf characteristics such as, leaf area and leaf count of *A. vaginalis* plants denoted significant variations among the imposed stress conditions. Water stress conditions has been recognized to often modify the leaf growth and in turn the leaf count, individual leaf size/leaf area and biomass of plants [23]. As per the results of the current study, *A. vaginalis* plants grown under T_2 treatment (113.52±13.84 cm^2) recorded the highest leaf area, while the lowest value was observed from T_5 (66.05±5.03 cm^2). The leaf area has been reduced significantly with the induced stress conditions. Conversely the highest leaf count was denoted by T_2 (48.6±5.8 leaves), while the lowest value was by T_5 (30.7±2.1 leaves). Expansion of the leaf area of a plant is influenced by temperature conditions, leaf turgor and plant growth requirements. Under stress conditions, cell elongation is influenced leading to reduction in cell size and thereby reduction in leaf size [24]. The reduction in the leaf area is a modification to avoid evapotranspiration losses by lowering the stomatal activity and to increase water use efficiency in plants, which aids the survival under water deficit conditions [25-26].

A study conducted by Chaves *et al.* [27] emphasized that leaves become spindle shaped and leaf area tends to get reduced in grass cultivars under water deficit conditions. A similar variation in wheat genotypes has been reported by Foulkes *et al.* [28]. Further, a study on *Arachis hypogeae*, a plant in the same family of *A. vaginalis*, has also reported a similar trend of leaf area reduction under water deficit conditions [29]. Therefore, significant reduction in total number of leaves, total leaf area, and total leaf biomass could be recognized as a critical response of plants to survive under water deficit conditions [30]. Thus, with the significant reduction in leaf area and leaf count under water deficit conditions, *A. vaginalis* evidence its potential as a drought tolerant ground cover.

Leaf trichome is another parameter, which confers the ability of plants to withstand the stress conditions. The leaves of *A. vaginalis* typically bares single trichome leaf hairs. The findings of the current experiment denoted a significantly increasing trend in leaf hair density along with the elevating water deficit condition. Low leaf hair densities were observed from the *A. vaginalis* plants maintained under high irrigation frequencies in T_1 and T_2 (241.4±12.7 cm^2 and 278.1±13.2 cm^2, respectively). Leaf hairs are a protective mechanism in plants, where higher leaf trichome density is induced by drought or defoliation to protect plants from drought by reducing absorption of solar radiation. This in turn reduces the heat load gained by the leaves and minimizes the need for transpirational cooling [31]. A recent field experiment on *Solanum lycopersicum* by Armero *et al.* [32] has reported an increasing trend in thricome density with the water deficit conditions, while a similar observation has been experienced in olive cultivar by Ennajeh [33].

Root growth is another important parameter for plants, where a prolific root system contributes for the tolerance of water stress conditions. Despite being significant, the highest mean values for root fresh weight (0.144±0.025 g) and root moisture content (0.101±0.019 g) were recorded in T_2 , while T_5 with the lowest irrigation frequency reported the lowest mean values for these parameters as 0.112±0.013 g and 0.065±0.012 g, respectively. On the contrary, the highest mean value for the root length was recorded from T_5, while the lowest was observed at T_2, denoting an increasing trend in the root length with the decreasing frequency in irrigation. This implies that *A. vaginalis* plants tend to allocate more energy towards the elongation of roots, under water stress conditions.

Further, increased root growth reflects the ability of plants to withstand water stress, making it to be widely applied to screen plant cultivars for drought tolerance [25, 34-35]. Roots play an important role in catering for the water requirements of plants, while being the main engine of meeting the transpiration demand [36]. A study by Kemp and Culvenor [37], conveyed that deeper rooting improves drought tolerance of perennial temperate C_4 grasses. In addition, a study conducted by Riaz *et al* [26], has evidenced that the root length of grass cultivars tends to significantly reduce under water stress conditions, while studies on *Albizzia* seedlings [38] and *Erythrina* seedlings [39] also have expressed a similar trend.

Shoot length, which determines the rate of ground coverage in ground covers, also remain as a critical determinant of drought tolerance. Even though, no significant difference was denoted ($P>0.05$) in the shoot length with the imposed stress conditions, the highest mean height was observed in T_2, while the lowest mean shoot length was reported from *A. vaginalis* plants maintained under T_5. Water stress is an important limiting factor at the initial phase of plant growth and establishment, where the shoot height is correlated with the declining of cell enlargement [2]. A similar decreasing trend in shoot height under increasing water deficit conditions have been reported for a variety of plants such as *Albizzia* [40], *Erythrina* [41] and *Populus cathayana* [42]. This further verifies the drought tolerance potential of *A. vaginalis*.

Growth parameters like fresh and dry weight have a profound effect in water-limited conditions. Water stress influence the dry matter accumulation, which results in reduced plant biomass. In the present study, no significant differences were observed in the leaf dry weight, root and shoot fresh weights. Yet the results indicated that the degree of water deficit conditions leads to a gradual decrement in the shoot and root dry weights, where the highest mean root (0.144±0.025 g) and shoot (1.29±0.17 g) fresh weights were recorded in T_2. A parallel configuration was also observed with the leaf fresh and leaf dry weight, agreeing with the fact that water stress leads to growth reduction, which is reflected in dry weight [25]. This fact is further supported by several recent studies conducted as field or pot experiments. According to Shao *et al.* [19], low levels of fresh and dry weight of shoot is a result of a reduction in plant growth, photosynthesis and plant structure during the water stress conditions [43]. A similar reduction in biomass has been reported in Avacado cultivars [44] and pearl millets [45].

The relative moisture content is considered as one of the easiest parameters that can be used to screen plants for drought tolerance. Drought tolerant plant species tend to keep high relative moisture contents with compared to drought-sensitive species [46]. A significant variation was observed in the moisture content of leaves and shoots, where the plants in treatment T_2 showed the highest mean value, while plants in T_5 recorded the lowest. Tambussi *et al.* [47] has also reported a similar trend in wheat cultivars under water stress conditions, further emphasizing the drought tolerance capacity of *A. vaginalis*.

In the current study, *A. vaginalis* plants responded differently to varying conditions of water availability, where plants in T_2 treatment that were irrigated once in 5 days recorded the best growth performances, except for root length and leaf hair density. However, the growth performance of *A. vaginalis* plants in T_1 treatment, which were irrigated daily, remained significantly lower than in T_2, suggesting that more water availability would also impose negative impacts on the growth of *A. vaginalis*. Water logging conditions may induce the production of numerous metabolic chemicals in plants that could alter the plant architecture, anatomy, metabolism, growth patterns and survival strategies of plants [48].

A study by Mass *et al*. [49] on the growth responses of nine tropical grasses under flooding conditions, has revealed a significant reduction in forage dry matter and shoot growth, while a moderate negative impact has been reported in tomato plants under flooding conditions [50]. This suggests that *A. vaginalis* may impose a negative growth pattern under water logging conditions as well. Nevertheless, plants in treatment T_5 showed the best drought tolerance characteristics, suggesting that *A. vaginalis* is capable of altering the morphological features and plant growth parameters to thrive well under water stress conditions. Therefore, *A. vaginalis* could be recommended as an ideal candidate for sustainable landscaping as a drought tolerant ground cover with low maintenance.

CONCLUSIONS

Landscaping of outdoor places using low water use ground cover plants is a promising alternative to conventional lawn grass-based landscapes due to the potential in reducing the overall water usage in maintenance. As depicted by the findings, the leaf area, leaf hair density, number of leaves, leaf fresh weight, leaf moisture content, shoot moisture content, shoot fresh weight, and root length of *A. vaginalis* maintained under different water stress conditions varied significantly among treatments.

The T_5 (irrigated once in 20 days) recorded the highest leaf hair density (648.14±15.96 hairs/cm^2) and root length (19.18±0.63 cm), while denoting the lowest values for leaf area (66.05±5.03) and leaf count (30.65±2.59), demonstrating the best drought tolerance characters. Furthermore, a 100% survival rate was observed from *A. vaginalis* under all treatment conditions.

In the view of findings of the present study, it can be concluded that *A. vaginalis* positively responded to water deficit conditions, where it can be recommended as a water stress tolerant plant. Therefore, *A. vaginalis* can be used as a low maintenance ground cover plant in climate smart landscaping. However, detailed studies are needed to elucidate the underlying anatomical parameters and biochemical processes, which are responsible for differential responses to water deficit conditions. Further, supplementary studies with prolonged water stress conditions are recommended to identify the maximum recovering ability of *A. vaginalis.*

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

AUTHORS' CONTRIBUTIONS

NS: Designed the study, supervised the experiments and wrote the initial draft of the manuscript; NC: Carried out the investigations and collected data; KY: Supervised the study and reviewed the manuscript; LU: Supported the designing of the research, conducted the statistical analysis and wrote the manuscript. All authors read and approved the manuscript.

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REFERENCES

1 Bandara RMAL, Yakandawala K. and Abeynayake NR. Drought tolerance of a native plant *Helicteres isora* L. In Proceedings of 16th Agricultural Research Symposium. Wayamba University of Sri Lanka. 2017; 339-343.

2 Saidi A, Ookawa T, Hirasawa T. Responses of root growth to moderate soil water deficit in wheat seedlings. Plant production science. 2010; 13(3):261-268.

3 Jaleel CA, Manivannan PA, Wahid A, Farooq M, Al-Juburi HJ, Somasundaram RA, Panneerselvam R. Drought stress in plants: a review on morphological characteristics and pigments composition. Int. J. Agric. Biol. 2009; 11(1):100-105.

4 Sen, 2015 - Dasgupta P, Das BS, Sen SK. Soil water potential and recoverable water stress in drought tolerant and susceptible rice varieties. Agricultural Water Management. 2015; 152:110.

5 Sarkar B, Savita SK, Varalaxmi Y, Vanaja M, Kumar NR, Sathish P, Lakshmi NJ, Prabhakar M, Shanker AK, Yadav SK, Maheswari M. Stress Reactions of Maize Genotypes to Drought Stress at Different Phenophases and Recovery. Russian Journal of Plant Physiology. 2022;69(3):54.

6 Boutraa T, Akhkha A, Al-Shoaibi AA, Alhejeli AM. Effect of water stress on

growth and water use efficiency (WUE) of some wheat cultivars (*Triticum durum*) grown in Saudi Arabia. Journal of Taibah University for science. 2010; 3(1):39-48.
7 Staniak M, Kocoń A. Forage grasses under drought stress in conditions of Poland. Acta Physiologiae Plantarum. 2015; 37:1-16.
8 Atkinson NJ, Urwin PE. The interaction of plant biotic and abiotic stresses: from genes to the field. Journal of experimental botany. 2012; 13;63(10):3523-3543.
9 Wherley B, Labedzki L. Turfgrass growth, quality, and reflective heat load in response to deficit irrigation practices. Evapotranspiration. Labedzki, L.(Ed.). 2011; 419-430.
10 Fernando MS, Yakandawala K. Performance of selected native ground cover species under induced drought conditions. Journal of Environmental Professionals Sri Lanka. 2015; 4(2).
11 Caser M, Lovisolo C, Scariot V. The influence of water stress on growth, ecophysiology and ornamental quality of potted Primula vulgaris 'Heidy'plants. New insights to increase water use efficiency in plant production. Plant Growth Regulation. 2017 Dec;83: 361-373.
12 Hilaire RS, Arnold MA, Wilkerson DC, Devitt DA, Hurd BH, Lesikar BJ, Lohr VI, Martin CA, McDonald GV, Morris RL, Pittenger DR. Efficient water use in residential urban landscapes. HortScience. 2008; 43(7):2081-2092.
13 Özyavuz A, Özyavuz M. Xeriscape in landscape design. Landscape planning. 2012; 353-360.
14 Basu S, Ramegowda V, Kumar A, Pereira A. Plant adaptation to drought stress. F1000Research. 2016; 5: 1-10.
15 Jayaweera MA. Medicinal Plants (Indigenous and Exotic) Used in Ceylon. The National Science Council of Sri Lanka. 1981: 3:148-149.
16 Rathi MA, Meenakshi P, Gopalakrishnan VK. Hepatoprotective activity of ethanolic extract of *Alysicarpus vaginalis* against nitrobenzene-induced hepatic damage in rats. South Indian Journal of Biological Sciences. 2015; 1(2):60-65.
17 Dassanayake MD. (1996). Fabaceae. In: MD Dassanayake, and WD Clayton (Eds.), A Revised Handbook to the Flora of Ceylon X. Oxford & IBH Publishing Co. Pvt., Ltd. New Delhi. 1996; 152-153.
18 Fu D, Huang B, Xiao Y, Muthukrishnan S, Liang GH. Overexpression of barley hva1 gene in creeping bentgrass for improving drought tolerance. Plant cell reports. 2007; 467-477.
19 Shao HB, Chu LY, Jaleel CA, Zhao CX. Water-deficit stress-induced anatomical changes in higher plants. Comptes rendus biologies. 2008; 331(3):215-225.
20 Meerow AW. Native Ground Covers for South Florida. University of Florida-IFAS Publication EES-60, Gainesville. 1999; 1-10
21 Fan Y, McCann L, Qin H. Households' adoption of drought tolerant plants: an adaptation to climate change?. Journal of Agricultural and Resource Economics. 2017; 236-254.
22 Heflebower R, Cerny-Koenig T, Waters M, Ward R. (350) A Water-wise Plant Recognition Program for Utah. HortScience. 2005; 40(4):1061B.
23 Gómez-del-Campo M, Ruiz C, Lissarrague JR. Effect of water stress on leaf area development, photosynthesis, and productivity in Chardonnay and Airén grapevines. American Journal of Enology and Viticulture. 2002; 53(2):138-143.
24 Reddy AR, Chaitanya KV and Vivekanandan M. Drought-induced responses of photosynthesis and antioxidant metabolism in higher plants. Journal of plant physiology, 2004; 161(11); 1189-1202.
25 Boutraa T, Akhkha A, Al-Shoaibi AA, Alhejeli AM. Effect of water stress on growth and water use efficiency (WUE) of some wheat cultivars (*Triticum durum*) grown in Saudi Arabia. Journal of Taibah University for science. 2010; 1;3(1):39-48.
26 Riaz A, Younis A, Hameed M and Kiran S. Morphological and biochemical responses of turf grasses to water deficit conditions. Pakistan Journal of Botany, 2010; 42: 3441–

3448.
27 Chaves MM, Maroco JP, Pereira JS. Understanding plant responses to drought—from genes to the whole plant. Functional plant biology. 2003; 30(3):239-264.
28 Foulkes MJ, Sylvester-Bradley R, Weightman R, Snape JW. Identifying physiological traits associated with improved drought resistance in winter wheat. Field crops research. 2007; 103(1):11-24.
29 Suthar DM and Patel MS. Yield and nutrient absorption by groundnut and iron availability in soil as influenced by lime and soil water. Journal of the Indian Society of Soil Science. 1992; 40(3):594-596.
30 Singh TN, Paleg IG and Aspinall D. Stress metabolism I. Nitrogen metabolism and growth in the barley plant during water stress. Australian journal of biological sciences. 1973; 26(1); 45-56.
31 Huttunen, P., Kärkkäinen, K., Løe, G., Rautio, P. & Ågren, J. 2010, Leaf trichome production and responses to defoliation and drought in *Arabidopsis lyrata* (Brassicaceae), Ann. Bot. Fennici, (47), 199–207.
32 Galdon-Armero J, Fullana-Pericas M, Mulet PA, Conesa MA, Martin C, Galmes J. The ratio of trichomes to stomata is associated with water use efficiency in *Solanum lycopersicum* (tomato). The Plant Journal. 2018; 96(3):607-619.
33 Ennajeh M, Vadel AM, Cochard H, Khemira H. Comparative impacts of water stress on the leaf anatomy of a drought-resistant and a drought-sensitive olive cultivar. The Journal of Horticultural Science and Biotechnology. 2010; 85(4):289-294
34 Boutraa T, Akhkha A, Al-Shoaibi AA, Alhejeli AM. Effect of water stress on growth and water use efficiency (WUE) of some wheat cultivars (*Triticum durum*) grown in Saudi Arabia. Journal of Taibah University for science. 2010; 3(1):39-48.
35 Hurd EA. Phenotype and drought tolerance in wheat. Agricultural Meteorology. 1974; 14(1-2):39-55.
36 Huang B, Gao H. Physiological responses of diverse tall fescue cultivars to drought stress. HortScience. 1999; 34(5):897-901
37 Kemp DR, Culvenor RA. Improving the grazing and drought tolerance of temperate perennial grasses. New Zealand journal of agricultural research. 1994; 37(3):365-378.
38 Nanjo T, Kobayashi M, Yoshiba Y, Sanada Y, Wada K, Tsukaya H, Kakubari Y, Yamaguchi-Shinozaki K, Shinozaki K. Biological functions of proline in morphogenesis and osmotolerance revealed in antisense transgenic Arabidopsis thaliana. The Plant Journal. 1999; 18(2):185-193.
39 Nativ R, Ephrath JE, Berliner PR, Saranga Y. Drought resistance and water use efficiency in *Acacia saligna*. Australian Journal of Botany. 1999;47(4):577-586.
40 Patel MS and Golakia BA. Effect of water stress on yield attributes and yield of groundnut (*Arachis hypogaea* L.), Indian Journal of Agriculture Sciences. 1988; 58: 701–703.
41 Pita P and Pardes JA. Growth, leaf morphology, water use and tissue water relation of *Eucalyptus globules* clones in response to water deficit, Tree Physiol. 2001; 21: 599–607.
42 Nautiyal PC, Ravindra V, Joshi YC. Dry matter partitioning and water use efficiency under water deficit during various crowth stages in groundnut. Indian Journal of Plant Physiology (India). 2002; 7, 135–139.
43 Bahreininejad B, Razmjou J, Mirza M. Influence of water stress on morpho-physiological and phytochemical traits in *Thymus daenensis*.2013; 151-166
44 Chartzoulakis K, Patakas A, Kofidis G, Bosabalidis A, Nastou A. Water stress affects leaf anatomy, gas exchange, water relations and growth of two avocado cultivars. Scientia horticulturae. 2002; 95(1-2):39-50.
45 Manivannan P, Jaleel, CA, Kishorekumar A, Sankar B, Somasundaram R. Sridharan R. and Panneerselvam R. Drought stress induced changes in the biochemical

parameters and photosynthetic pigments of cotton (*Gossypium hirsutum* L.). Indian J. Appl. Pure Biol, 2007: 52:369-372.

46 Chaves MM, Pereira JS, Maroco J, Rodrigues ML, Ricardo CP, Osório ML, Carvalho I, Faria T, Pinheiro C. How plants cope with water stress in the field? Photosynthesis and growth. Annals of botany. 2002; 89(7):907-916.

47 Tambussi EA, Bort J, Araus JL. Water use efficiency in C3 cereals under Mediterranean conditions: a review of physiological aspects. Annals of Applied Biology. 2007 Jun;150(3):307-321.

48 Bailey-Serres J, Voesenek LA. Flooding stress: acclimations and genetic diversity. Annu. Rev. Plant Biol. 2008; 59:313-339.

49 Junior RM, Domiciano LF, Ribeiro LF, Pedreira BC. Growth responses of nine tropical grasses under flooding conditions. Tropical Grasslands-Forrajes Tropicales. 2016; 22;4(1).

50 Jannah R, Natalia JD, Kurniadinata OF. Development of Tomato (*Lycopersicum esculentum* Mill.) Roots in Every Growth Stage in Flooding Conditions. Journal of Tropical Horticulture. 2019; 2(1):11-15.

APPLIED BIO-SYSTEMS TECHNOLOGY

Research Article Open Access

The Influence of Labour Competencies on the Efficiency of Road Construction Operations in Sri Lanka

Kesavan Manoharan[1,2*], Pujitha Dissanayake[2], Chintha Pathirana[2], Dharsana Deegahawature[3] and Renuka Silva[4]

Abstract

Background: The successful completion of a construction project is largely dependent on the efficiency of labour. But, low efficiency of labour operations is the biggest problem faced by the construction sector in emerging nations like Sri Lanka. Many previous studies highlight that competencies of labour have a significant impact on how well construction operations are executed. However, studies that focus on efficiency improvement in road construction project operations are lacking in the Sri Lankan construction industry, even though both the public and private sectors invest more in road construction as a part of the development process of the nation's infrastructure. Accordingly, this study intended to pinpoint the crucial competencies of labourers that have a significant impact on how well road construction projects in Sri Lanka operate.

Methods: The significant knowledge and skill elements were qualitatively identified through literature surveys and interviews. A total of 40 scholarly articles were included in the literature survey. The collected data was analysed using the qualitative thematic analysis. A questionnaire survey was conducted among 39 road construction contractors who were identified using the snowball sampling method. The relative importance index (RII) method was used to determine the influence level of those elements on the efficiency of road construction projects.

Results: A total of 27 causes were found to be critical, where the top five ranking labour-related criteria were found to be the lack of thinking abilities, lack of knowledge in construction works, communication issues, lack of labour morale/commitment and labour discipline. Through statistical testing, the validity and reliability of the study findings were confirmed.

Conclusions: It is strongly advised to take the crucial labour competencies found in this study into consideration, to improve and enhance the construction labour force in the industry. The study findings are anticipated to be extremely helpful in similar circumstances for the Sri Lankan construction sector as well as other growing construction industries.

Keywords: Construction Industry, Labour Skills, Road Projects, Sri Lanka

[1]Department of Construction Technology, Wayamba University of Sri Lanka, Sri Lanka.
[2]Department of Civil Engineering, Faculty of Engineering, University of Peradeniya, Sri Lanka.
[3]Department of Industrial Management, Wayamba University of Sri Lanka, Sri Lanka.
[4]Centre for Quality Assurance, Wayamba University of Sri Lanka, Sri Lanka.

* Correspondence: kesavan@wyb.ac.lk
https://orcid.org/0000-0002-1985-348X

INTRODUCTION

Various studies highlight that a nation's economy heavily depends on the construction sector [1-4]. Due to the potential of the human population, the economy is growing more productive, inventive and competitive. The use of the labour force is the key element for effective completion of any construction project. One of the most challenging issues with human resources in the construction sectors, particularly in developing nations, is the poor efficiency of labour [1].

Most construction workers in developing nations typically originate from low-income families with little formal education [2-3]. Their work processes and outputs are influenced by a variety of factors [1-3]. Their levels of competencies need to cover a wide range of work processes. Therefore, the development of labourers' competencies might enhance their efficiency [3]. The competencies of labourers can be improved by enhancing practices in the areas of education and training, working conditions, health care facilities, motivating elements, tool and material use, job quality and other aspects that are relevant to the construction work [1, 4].

Fernando *et al.* [2] has emphasised the skill shortage of labourers as one of the significant issues in construction projects from a Sri Lankan perspective. According to the Tertiary and Vocational Education Commission of Sri Lanka's Construction Industry Sector Training Plan 2018-2020 [3], cognitive, soft and job-specific technical skills have been identified to be limited among construction labourers. This has also been confirmed by the Construction Industry Sector Council (CISC) and Industry Sector Skills Councils (ISSC) of Sri Lanka.

Numerous studies reveal that the Sri Lankan labourers' competencies have not been at an adequate level for enhancing the efficiency of construction project operations [2-3]. The construction sector can greatly benefit from identifying the essential competencies of workers affecting efficiency with severity measurements in order to take the appropriate actions for improvement. Notably, consultations with representatives of the Sri Lankan Construction Industry Development Authority (CIDA) have revealed that both the public and private sectors invest more in road construction as a part of the nation's infrastructure development and that there is a lack of studies focused on the labour-related skills influencing road project operations in Sri Lanka. Accordingly, this study aims to investigate how the competencies of labourers are affecting the efficiency of road construction project operations in Sri Lanka. This may help the construction sector of a developing nation like Sri Lanka in tackling the efficiency and productivity-related challenges linked to the modernisation of construction site practices.

Many studies have investigated the knowledge bases, skills and performance of construction labourers around the world [1-7]. Patel *et al.* [4] has examined the factors influencing labour performance in the construction industry using a systematic analysis of recently released research articles. The primary element that affects labour efficiency in the construction industry has been identified as the inadequate cognitive skills of labourers in applying construction methods and techniques [4]. Regarding the construction projects in India, Iran and New Zealand, respectively, Soham and Rajiv [5], Parviz and Mohammed [6] and Serdar and Jasper [7] have brought attention to the same issue.

From the project manager's perspective, it has been discovered that the workers need to pay greater attention to their health and safety procedures in the State of Queensland, Australia [19]. Regarding the construction projects in Nigeria, Peter *et al.* [20] and Oseghale *et al.* [21] have brought attention to the same issue. Soham and Rajiv [5], Shahab and Audrius [22], and Abdulaziz *et al.* [23] have reported that the labourers' cognitive skills in health science and their physical ability are quite inadequate in many construction projects in India, Lithuania, and Qatar, respectively.

Oseghale *et al.* [21] has assessed the skilled labour supply in the Nigerian construction industry and indicated that their labourers' technical skills need to be enhanced. Meanwhile, the need to increase the Sri Lankan labourers' technical drawing comprehension and material handling skills has been highlighted by Praveen *et al.* [24]. However, a limited number of studies have examined the competencies of labourers in the Sri Lankan construction industry. This study sought to better the efficiency of road construction projects by identifying the major competencies of Sri Lankan labourers using qualitative and quantitative methodologies.

MATERIALS AND METHODS

Preliminary Survey

In order to qualitatively identify the critical competencies of labourers affecting the efficiency of road construction operations in Sri Lanka, a preliminary survey was carried out using a comprehensive literature review and a series of structured interviews.

Literature Survey

A comprehensive literature review was conducted by considering 40 scholarly studies from 18 different nations, as indicated in Table 1. Out of them, eight studies in total were based on the Sri Lankan viewpoint. Table 2 displays the number of research publications reviewed based on the published period. Notably, it shows that more than 80% of these articles were published in the last decade, whereas around half of them were released within the latter half of the last decade.

According to their reputation, impact rankings and subject contents, the majority of these research publications were initially chosen by well-known online search engines such as 'Google Scholar', 'ResearchGate', 'ScienceDirect' and 'Scopus'. Some of the articles were located on the basis of the suggestions made by the subject matter experts. The article titles, abstracts and keywords were carefully scrutinised. Following a thorough review process, a table was created to compile the information gathered from the literature study.

Table 1: Number of Studies Reviewed based on the Country

Country	Number of Studies
India	10
Sri Lanka	8
Nigeria	3
South Africa	3
Indonesia	2
Egypt	2
Australia	1
Iran	1
Lithuania	1
New Zealand	1
Palestine	1
Qatar	1
Singapore	1
Spain	1
Trinidad & Tobacco	1
Turkey	1
UK	1
Vietnam	1

Table 2: Number of Studies Reviewed based on the Published Period

Study Period	Number of Studies
2016 - 2020	16
2011 - 2015	17
2006 - 2010	4
2001 - 2005	1
Up to 2000	2

Preliminary Survey

Construction specialists from the Sri Lankan construction sector participated in structured interviews to identify the most recent practices in the sector. These interviews included 42 construction industry professionals in total, representing different fields, as shown in Table 3. Participants in these interview sessions included directors, project managers, engineers, quantity surveyors and institutional specialists from training providers, supervisors and technical officers. Notably, 15 interviewers in total had experience working with foreign labourers.

Table 3: Number of Interviewed Construction Experts based on their Years of Experience

Years of Experience in the Construction Field	Number of Interviewed Construction Experts
Less than 5 Years	-
5 – 10 Years	16
11 – 15 Years	04
16 – 20 Years	07
21 – 25 Years	03
More than 25 Years	12

Thematic Analysis

On the competencies of labourers that were identified from the preliminary survey, a thematic analysis was conducted as recommended by Caulfield [25]. It is a technique for qualitative analysis where the data is studied to find recurring themes like topics, ideas and patterns. The competencies identified from the preliminary survey were examined for specific characters, and the codes were issued as necessary.

The associated codes were then established between the groupings of competencies discovered through literature reviews and interviews based on the themes developed. According to the identified associated codes, the repetition of competencies was eliminated. The final collection of competencies was derived from this qualitative analysis after a second assessment of the themes and codes.

Questionnaire Survey

To assess the severity of the selected competencies of labourers influencing the efficiency of labour in road construction projects, a questionnaire survey was conducted among Sri Lankan road construction contractors. A total of 39 road construction contractors were chosen using the snowball sampling technique due to the challenges in finding the genuine sample size with the required attributes [26]. Only the construction contractors who work on projects having a minimum Construction Industry Development Authority (CIDA) registration grade of 'C4' were taken into account in this survey.

The CIDA in Sri Lanka grants the essential grades for a contractor's registration based on the contractor's financial availability, technical proficiency and work experience. Between 50 million and 150 million Sri Lankan Rupees are the permitted financial limits for the 'C4' grade [27]. The Table 4 illustrate the number of replies received based on the contractor's level of CIDA registration.

Table 4: Number of Responses based on the Contractor's Grade of CIDA Registration

CIDA Grade	Financial Limit of the Projects (X: LKR in Million)	Number of Responses
CS2 / CS1	X > 1500	04
C1	1500 >= X > 600	03
C2	600 >= X > 300	07
C3	300 >= X > 150	04
C4	150 >= X > 50	21

The respondents were classified into two working categories based on their employment titles, which are Director/ Managerial/ Engineer (DME) level and Assistant Engineer/ Supervisor/ Technical Officer (AST) level. Accordingly, 54% of the respondents were working in the DME level, whereas 46% of them were from the AST category. Table 5 shows their profile based on their work experience in the construction field.

Table 5: Number of Responses based on the Respondents' Work Experience

Experience in the Construction Field	Number of Responses
Less than 5 Years	01
5 – 10 Years	16
11 – 15 Years	10
16 – 20 Years	8
21 – 25 Years	4
More than 25 Years	0

The prepared questionnaire contained the competencies that were determined from the preliminary survey of this study. A Likert scale with five ordinal measurements ranging from 1 to 5, was used to base the questions (1 represents the very low effect and 5 represents the very high effect). Before the commencement of the survey, cognitive interviews were conducted with five construction experts for their feedback on the prepared questionnaire to validate the questionnaire design.

Relative Importance Index (RII)

The influence level of each detected competency on the efficiency of road construction operations was determined using the Relative Importance Index (RII) technique. According to Dinh and Nguyen [28], this can be determined for each element using the Equation 1.

$$RII = \Sigma W/(A * N) \qquad (1)$$

Where, W: Weight assigned by response ranges (1 – Very Low, 2 - Low, 3 - Moderate, 4 - High, 5 - Very High); A: Maximum weight given; N: total number of responses. To determine the extent of the effects of competencies, the following RII value ranges were taken into account. The competencies were deemed critical, if their RII values were 0.7 or above.

RII >= 0.9 : Very High (VH)
0.9 > RII >= 0.8 : High (H)
0.8 > RII >= 0.7 : High – Moderate (HM)
0.7 > RII >= 0.6 : Moderate (M)
0.6 > RII >= 0.5 : Moderate – Low (ML)
0.5 > RII >= 0.3 : Low (L)
0.3 > RII : Very Low (VL)

To assess the accuracy of the findings, standard deviation, coefficient of variation and margin of error values were also computed for each competency element. The lower standard deviation suggests that the respondents' values are close to the mean [29]. The error margin values of competencies were computed for a 95% confidence interval.

Statistical Analysis

The degree of agreement between DME level and AST level working categories on the competencies of labourers in Sri Lankan road construction projects was determined using Spearman's coefficient of rank correlation. As per the recommendations of recent studies [30-31], this can be determined using the Equation 2.

$$\rho = 1 - [6\,\Sigma D^2/n(n^2 - 1)] \qquad (2)$$

Where, ρ: Spearman's coefficient of rank correlation; D: Difference between the ranks of two variables; n: Number of observations. To determine the effects of the degree of agreement, the values of Spearman's coefficient of rank correlation were investigated in the following ranges.

ρ > 0 : Positive degree of agreement (Positive relationship)
ρ = 0 : Neutral (No correlation)
0 > ρ : Negative degree of agreement (Negative relationship)

RESULTS AND DISCUSSION

In the preliminary survey, more than 85% of the respondents concurred that the cognitive components of Sri Lankan labourers are currently insufficient. Meanwhile, 90% of the interviewees stated that the manual skills of Sri Lankan labourers are currently insufficient for enhancing the efficiency of construction operations. Most importantly, the majority of interviewees claimed that inadequate training facilities are not being offered by construction organisations to develop the competencies of labourers. Based on the RII values of each competency element, which are displayed in Table 6 and Table 7, the level of effect for each competency element of labourers was calculated. The findings indicate the degree to which each competency element of labourers has an impact on the performance level of the road construction projects in Sri Lanka.

Overall, the critical competencies of labourers influencing the efficiency of road construction project operations in Sri Lanka included 18 knowledge domains and 30 skills/abilities. The labourer's cognitive abilities in numeracy, understanding basic structures, performing simple measurements, applying construction methods, procedures and technology and material handling were found to be in the top five ranked components in the knowledge category, while their attitude, punctuality and their communication, measuring and problem-solving skills were at the top five in the category of skills/abilities (Table 8).

Table 6: Ranking of Cognitive Components of Labourers Working in the Sri Lankan Road Construction Projects

Knowledge Areas	Statistical Values					
	RII	**SD**	**CV**	**ME**	**#**	**LE**
Numeracy	0.80	0.16	0.20	0.03	1	H
Basic structures	0.79	0.15	0.19	0.03	2	HM
Simple measurements	0.78	0.15	0.19	0.03	3	HM
Construction procedures and technology	0.78	0.16	0.21	0.02	3	HM
Construction materials	0.76	0.12	0.16	0.03	5	HM
Material handling	0.76	0.15	0.20	0.02	5	HM
Equipment handling	0.76	0.12	0.16	0.02	5	HM
Quality assurance and control	0.75	0.14	0.19	0.02	8	HM
New technologies in construction	0.75	0.16	0.21	0.03	8	HM
Health & Safety in construction	0.75	0.15	0.20	0.03	8	HM
English / Languages other than mother tongue	0.73	0.12	0.16	0.02	11	HM
Financial knowledge	0.72	0.14	0.19	0.02	12	HM
Basic labour laws and regulation	0.72	0.14	0.19	0.02	12	HM
Simple architecture	0.71	0.15	0.21	0.02	14	HM
Estimation	0.71	0.12	0.17	0.02	14	HM
Health science	0.70	0.14	0.20	0.03	16	HM
Psychology	0.70	0.14	0.20	0.02	16	HM
Information and communication technology	0.70	0.12	0.17	0.02	16	HM
Environmental sustainability	0.69	0.13	0.19	0.02	19	M
Drawing	0.69	0.16	0.23	0.03	19	M
Waste management	0.66	0.13	0.20	0.02	21	M
Environment & Society	0.66	0.17	0.26	0.03	21	M
Basic electricity	0.65	0.16	0.25	0.03	23	M
Water management	0.63	0.16	0.25	0.03	24	M

Note: *RII: Relative Importance Index; SD: Standard Deviation; CV: Coefficient of Variation; ME: Margin of Error; #: Rank; LE: Level of Effects; VH: Very High; H: High; HM: High – Moderate; M: Moderate; ML: Moderate to Low; L: Low; VL: Very Low*

Table 7: Ranking of Skills and Abilities of Labourers Working in the Sri Lankan Road Construction Projects

Skills/Abilities	Overall					
	RII	**SD**	**CV**	**ME**	**#**	**LE**
Attitude	0.87	0.16	0.18	0.03	1	H
Measuring	0.85	0.16	0.19	0.03	2	H
Problem solving	0.84	0.17	0.20	0.03	3	H
Punctuality	0.84	0.15	0.18	0.03	3	H
Communication	0.84	0.17	0.20	0.02	3	H
Decision making	0.83	0.17	0.20	0.03	6	H
Leadership	0.83	0.18	0.22	0.03	6	H
Reading, writing and listening	0.83	0.14	0.17	0.03	6	H
Commitment	0.83	0.13	0.16	0.02	6	H
Attendance	0.83	0.15	0.18	0.03	6	H
Learning	0.82	0.19	0.23	0.03	11	H
Memorization	0.82	0.16	0.20	0.03	11	H
Planning	0.81	0.12	0.15	0.02	13	H
Reduction of alcohol and drugs usage	0.81	0.11	0.14	0.02	13	H
Math and language literacy	0.80	0.17	0.21	0.02	15	H
Estimating	0.80	0.15	0.19	0.03	15	H
Analytical skills/abilities	0.79	0.13	0.16	0.02	17	HM
Critical reasoning	0.78	0.12	0.15	0.03	18	HM
Ability to understand drawings	0.78	0.16	0.21	0.03	18	HM
Understanding with other workers	0.77	0.15	0.19	0.02	20	HM
Multiple work coordination	0.77	0.14	0.18	0.02	20	HM
Skills in team work	0.76	0.18	0.24	0.03	22	HM
Equipment / Tool handling	0.76	0.12	0.16	0.02	22	HM
Material handling	0.75	0.13	0.17	0.02	24	HM
Physical ability	0.74	0.12	0.16	0.02	25	HM
Psychology	0.72	0.13	0.18	0.03	26	HM
Management & Organisational skills	0.71	0.11	0.15	0.02	27	HM
Innovative	0.71	0.12	0.17	0.03	27	HM
Concreting	0.71	0.18	0.25	0.03	27	HM
Ability to adapt to changes and new environments	0.70	0.15	0.21	0.02	30	HM

Note: *RII: Relative Importance Index; SD: Standard Deviation; CV: Coefficient of Variation; ME: Margin of Error;* ***#****: Rank; LE: Level of Effects; VH: Very High; H: High; HM: High – Moderate; M: Moderate; ML: Moderate to Low; L: Low; VL: Very Low*

Table 8: Ranking of Skills and Abilities of Labourers Working in the Sri Lankan Road Construction Projects

	Rank	Competency Elements	Past Studies
Knowledge	1	Numeracy	Tertiary and Vocational Education Commission [3]; Praveen *et al.* [24]
	2	Basic structures	Tertiary and Vocational Education Commission [3]
	3	Simple measurements	Soham and Rajiv [5]; Praveen *et al.* [24]; Dolage *et al.* [32]
	4	Construction methods, procedures and technology	Patel *et al.* [4]; Soham and Rajiv [5]; Parviz and Hosseini [6]; Serdar and Jasper [7]
	5	Material handling	Praveen *et al.* [24]; Dolage *et al.* [32]
Skills / Abilities	1	Attitude	Soekiman *et al.* [33]; Dharani [17]; Fernando *et al.* [2]; Orando and Isabirye [14]; Dinh and Nguyen [28]
	2	Measuring	Soham and Rajiv [5]; Praveen *et al.* [24]; Dolage *et al.* [32]
	3	Problem solving	Tertiary and Vocational Education Commission [3]; Lim and Jahidul [11]
	4	Punctuality	Fernando *et al.* [2]; Brent and Leighton [12]; Orando and Isabirye [14]; Dharani [17]; Shashank *et al.* [34]
	5	Communication	Robles *et al.* [13]; Rami and David [19]

Degree of Agreement between the Levels of Workers

The findings of the Spearman's rank coefficient of correlation showed that in the cognitive domains of labourers, DME level and AST level personnel had a degree of agreement (positive association) of 78.0%. They agreed (have a favourable relationship) to an extent of 91.1% with respect to labourers' skills and abilities. The findings showed that there are not many conceptual distinctions between DME level workers and AST level workers on the identified critical competencies for labourers.

Validity/Reliability of the Findings

The reliability and accuracy of the results were guaranteed by the standard deviation (SD) and coefficient of variation (CV) values of competencies, as shown in Table 6 and Table 7. For all categories of competencies, the CV values were below 0.3. These CV values ensured that the validity and reliability of the findings were at a suitable level for the purpose of this study, according to the Labour Force Survey Guide-2020 of Canada [36]. The degree of agreement found between the two working categories' observations on the KSAs further supports the trustworthiness of these results.

CONCLUSIONS

Current study pinpointed the key areas of labourers' competencies that should be taken into account in improving the efficiency of construction operations in Sri Lankan road projects. Overall, the findings indicated that a wide range of cognitive and self-management abilities of labourers need to be improved more than their transferable and technical skills. The study also emphasised the urgent need to enhance the training programmes for the construction labourers employed in the Sri Lankan road projects. Based on the crucial competencies discovered from this study, essential workplace training activities and experimental exercises should be established to apply improved practices to labour operations.

These findings will be useful for developing new training programmes based on industry needs, particularly for establishing learning outcomes, learning materials and training delivery strategies. This study suggests creating a suitable mechanism to assess labour capabilities on the job sites of Sri Lankan construction firms. The labourers in Sri Lanka should receive more attention from construction organisations in terms of performance evaluation techniques and practices for their skill enhancement. The results of this study are anticipated to be extremely helpful to Sri Lankan construction firms, skill development agencies and training organisations in order to take the essential activities for improvement. Other emerging construction organisations could test some of these findings in comparable circumstances. This study recommends to conduct more studies on enhancement of procedures based on the crucial competencies of labourers depicted in this article.

CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

AUTHORS' CONTRIBUTIONS

KM: Conceptualized, designed the research, carried out the investigation, performed data curation and analysis, and wrote the manuscript. PD: Supervised the study and reviewed the manuscript. CP: Supervised the study and reviewed the manuscript. DD: Supervised the study and reviewed the manuscript. RS: Supervised the study and reviewed the manuscript.

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REFERENCES

1 Mistri A, Patel CG, Pitroda JR. Analysis of causes, effects and impacts of skills shortage for sustainable construction through analytic hierarchy process, Int J Tech Innov Mod Eng Sci. 2019; 5(5): 168-176.

2 Fernando PGD, Fernando NG, Gunarathna MACL. Skills developments of labourers to achieve the successful project delivery in the Sri Lankan construction industry. Civ Env Res. 2016; 8(5): 86-99.

3 Tertiary and Vocational Education Commission. Construction industry sector training plan 2018 – 2020. Sri Lanka. 2018.

4 Patel B, Bhavsar JJ, Pitroda J. A critical literature review of labour productivity in building construction. Int J Construct Res Civ Eng. 2017; 3(4): 76-80.

5 Soham M, Rajiv B. Critical factors affecting labour productivity in construction projects: case study of South Gujarat Region of India. Int J Eng Adv Tech. 2013; 2(4): 583-591.

6 Parviz G, Mohammad RH. A survey of the factors affecting the productivity of construction projects in Iran. Tech Econ Dev Economy. 2012; 18(1): 99-116.

7 Serdar D, Jasper M. On-site labour

productivity of New Zealand construction industry: key constraints and improvement measures. Australasian J Constr Econ Build. 2011; 11(3): 18-33.
8 Dixit S, Amit KP, Satya NM, Sanjeev B. A study of enabling factors affecting construction productivity: Indian scenario, Int J Civ Eng Technol. 2017; 8(6): 741-758.
9 Mostafa ES, Khaled MEG. Towards improving construction labor productivity and projects' performance. Alex Eng J. 2011; 50: 321-330.
10 Peter FK, Paul OO, Gary DH, Frank CH. Factors influencing craftsmen's productivity in Indonesia. Int J Proj Manage. 1997; 15(1): 21-30.
11 Lim EC, Jahidul A, Construction productivity: issues encountered by contractors in Singapore. Int J Proj Manage. 1995; 13(1): 51-58.
12 Hickson BG, Ellis L. Factors affecting construction labour productivity in Trinidad and Tobago. J Assoc Prof. Eng. Trinidad and Tobago. 2013; 42(1): 4-11.
13 Robles G, Stifi A, Jose LP, Gentes S. Labor productivity in the construction industry - factors influencing the Spanish construction labor productivity. Int J Civ Env Eng. 2014; 8(10): 1061-1070.
14 Orando M, Isabirye AK. Construction workers' skill development: a strategy for improving capacity and productivity in South Africa. Int J Econ Fin Stud. 2018; 10(1): 66-80.
15 Rasool F, Botha CJ, The nature, extent and effect of skills shortages on skills migration in South Africa. SA J Hum Res Manage. 2011; 9(1): 1-12.
16 Silva GASK, Warnakulasuriya BNF, Arachchige BJH. A review of the skill shortage challenge in construction industry in Sri Lanka. Int J Econ Bus Manage Res. 2018; 2(1): 75-89.
17 Dharani K. Study on labours productivity management in construction industry. Int J Latest Trends Eng Tech. 2015; 6(1): 278-284.
18 Aynur K, Ekrem M, Serdar U. Effect of basic motivational factors on construction workforce productivity in Turkey. J Civ Eng Manage. 2008; 14(2): 95-106.
19 Hughes R, Thorpe D. A review of enabling factors in construction industry productivity in an Australian environment, Constr Innov. 2014; 14(2): 210-228. doi:10.1108/CI-03-2013-0016.
20 Okoye PU, Ezeokonkwo JU, Ezeokoli FO. Building construction workers' health and safety knowledge and compliance on site. J Saf Eng. 2016; 5(1): 17-26. https://doi:10.5923/j.safety.20160501.03.
21 Oseghale BO, Abiola-Falemu JO, Oseghale GE. An evaluation of skilled labour shortage in selected construction firms in Edo State, Nigeria. Am J Eng Res. 2015; 4(1): 156-167.
22 Shahab S, Audrius B. Application of fuzzy fault tree analysis to identify factors influencing construction labor productivity: a high-rise building case study. J Civ Eng Manage. 2018; 25(1): 41-52. doi:10.3846/jcem.2019.7785.
23 Jarkas AM, Kadri CY, Younes JH. A survey of factors influencing the productivity of construction operatives in the State of Qatar. Int J Constr Manage. 2012; 12(3): 1-23. doi:10.1080/15623599.2012.10773192.
24 Praveen R, Niththiyananthan T, Kanarajan S, Dissanayake PBG. Shortage of skilled labour and professionals in the construction industry of Sri Lanka, Transac Instit Eng Sri Lanka. 2011; I(B): 239-247.
25 Caulfield J. How to do thematic analysis? 2019. https://www.scribbr.com/methodology/thematic-analysis/
26 Showkat N, Parveen H. Non Probability and Probability Sampling. e-PG Pathshala Publishers. 2017.
27 Construction Industry Development Authority. National Registration and Grading Scheme for Construction Contractors. Sri Lanka. 2018. http://www.cida.gov.lk/sub_pgs/con_registration.html
28 Dinh TH, Nguyen VT. Analysis of affected factors on construction

productivity in Vietnam. Int J Civ Eng Tech. 2019; 10(2): 854-864.
29 Solly MS, Gezani RM, Construction and application of a statistical test for coefficient of variation on normal distributions. Am J Appl Sci. 2017; 14(11): 1024–1030.
30 Kesavan M, Gobidan NN, Gobishanker R, Dissanayake PBG. Proper project planning in avoiding construction project delays. Proceedings of the special sessions on sustainable design and construction, 5th international conference on sustainable built environment. Kandy, Sri Lanka. 2014; 77-84.
31 Manoharan K, Navanesan G, Dissanayake PBG. Analysis of factors contributing civil engineering construction project delays in Sri Lankan building construction industries. J Ind Eng Res. 2015; 1(7): 5-11.
32 Dolage DAR, Wijesundara WRGA, Nandasiri DG, Analysis of user problems in construction machinery hiring, engineer. J Inst Eng Sri Lanka. 2010; 43(1): 32-41.
33 Soekiman A, Pribadi KS, Soemardi, BW, Wirahadikusumah RD. Factors relating to labor productivity affecting the project schedule performance in Indonesia, Procedia Eng. 2011; 14: 865-873. doi:10.1016/j.proeng.2011.07.110.
34 Shashank K, Hazra S, Pal NK. Analysis of key factors affecting the variation of labour productivity in construction projects. Int J Emerg Tech Adv Eng. 2014; 4(5): 152-160.
35 Onyekachi VN. Impact of low labour characteristics on construction sites productivity in EBONYI state, Int J Adv Res Sci Eng Tech. 2018; 5(10): 7072-7087.
36 Statistics Canada. Guide to the labour force survey 2020. Canada. 2020.

APPLIED BIO-SYSTEMS TECHNOLOGY

Research Article Open Access

Evaluation of the Efficacy of Bio Rational Pesticides for Eco Friendly Management of Leaf Curl Complex in Chili (*Capsicum annum*)

Anuruddhika Rajapaksha[1], Bandula Ranaweera[1*], Indika Karunarathna[2] and Susantha Somasiri[1]

Abstract

Background: Leaf curl complex can be identified as a major disease found in most of the Solanaceous vegetable crops, including green chili. Thrips (*Scirtothrips dorsalis* H.) and white flies (*Bemisia tabaci*) are the major vectors responsible for the spread of Leaf curl complex. Farmers tend to use synthetic chemicals as the main control method of this disease. Continuous use of synthetic insecticides results in serious health and environmental hazards. Therefore, application of bio rational pesticides is one of the best alternatives for it. This experiment was conducted to evaluate the efficiency of six bio rational pesticides for the control of leaf curl complex in chili.

Methods: A combination of natural plant extract (T_2), Neem (Azadiractin) based product (T_3), *Beauveria bassiana* based product (T_4), *Metarhizium anisopliae* based product (T_5), *Saccharopolyspora spinosa* based product (Spinosad) (T_6) and a combination of *Beauveria bassiana* and *Metarhizium anisopliae* based product (T_7) were applied to chili plants, starting from three weeks after transplanting, while control (T_1) remained without any pesticide application. The Disease Incidence (DI) and Disease Severity Index (DSI) were calculated for each treatment.

Results: Mean DSI and DI values reported significant differences among the treatments ($P<0.05$). The control treatment recorded the highest DSI value (44.3±2%), while the treatment 6 (Spinosad) recorded the lowest DSI value (31.1±4%). Similarly, the control plot recorded the highest DI (73.6±1%) value, while T_6 (Spinosad) plot recorded the lowest DI value (58.8±3%). Spinosad bio rational pesticide (T_6) showed a significantly lower disease severity and disease incidence.

Conclusions: Based on the overall findings, Spinosad bio rational pesticide (T_6) was identified as the bio rational with a high potential to control leaf curl complex in chili. Further studies are suggested to optimize the effect and minimize the hazard to pollinators.

Keywords: Bio Rational, Green Chili, Leaf Curl Complex, *Saccharopolyspora spinosa*

[1]Department of Horticulture and Landscape Gardening, Faculty of Agriculture and Plantation Management, Wayamba University of Sri Lanka, Sri Lanka.

[2]Department of Plantation Management, Faculty of Agriculture and Plantation Management, Wayamba University of Sri Lanka, Sri Lanka.

* Correspondence: branaweera@gmail.com

https://orcid.org/0009-0008-8809-2785

INTRODUCTION

Chili (*Capsicum annum*), which is considered as a popular cash crop in Sri Lanka belongs to the family *Solanaceae.* Chili has several species in the genus Capsicum that are widely consumed throughout the world as a condiment or a vegetable. Central and South America is considered as the center of origin of chili. The pod is consumed as the edible portion of chili plant, which helps to prevent cancers, heart problems, treat infections, and combat mood swings. Further, chili is also a good source of dietary fiber, Vitamins B6 and C, Sodium and Potassium. India is the major country that produces dried chilis and green chilis in the world. In Sri Lanka, chili is considered as one of the important condiments due to high demand, export potential and nutritional value. Chili is widely cultivated in Anuradhapura, Monaragala, Ampara, Puttalam, Kurunegala, Hambantota districts and Mahaweli System H [1].

The crop is infested by more than 21 insects and non- insect pest. Leaf curl virus is one of the major limiting factors in the cultivation of the crop [2]. Thrips (*Scirtothrips dorsalis* H.), mites (*Hemitarsonormus latus*), aphids, white flies (*Bemisia tabaci*), nematodes and pod borers are the major pests of chili, while fusarium wilt, collar rot, bacterial spot, seedling rot, anthracnose, bacterial wilt, narrow leaf disorder and leaf curl are the major diseases associated with chili cultivation. Leaf curl complex is a major biotic stress for chili cultivation in Sri Lanka caused by begomoviruses [1]. This disease is identified as a complex because it is a combination of thrips attack, mites attack and leaf curl virus. Thrips and mite attacks and involvement of viruses transmitted by whitefly are the major reasons for chili leaf curl disease complex [3]. Initial symptoms of leaf curl disease appear from the leaves of the plant. After infection of leaf curl complex reduction of leaf area, upward curling in the leaves, crinkling appearance and vein banding can be observed. The diseased plants show bushy appearance, stunting in plant, bunchy leaves, shortening of petioles and internodes and finally leads to bearing few flowers and fruits [4].

Since, Leaf Curl Complex (LCC) is not a seed borne disease, the responsible virus can remain in the cultivated lands through alternative host crops such as tobacco and other solanaceous crops like tomato, capsicum and weeds. In nurseries, chili plants are frequently prone to infection of LCC during the seedling and vegetative stages [5]. Once the chili plants are affected by this disease, those plants should be removed from the field as soon as identifying the symptoms by bagging and discarding to prevent the spread of white flies on them that may carry the virus. Other methods that can be used to control LCC are removal of weeds, avoiding growing of other host crops near to chili, cultivation of resistant or moderately resistant varieties, Integrated Pest Management (IPM) approach and chemical control [1].

Therefore, farmers are facing the necessity to protect this high value crop from diseases, leading to application of large amounts of pesticides, that has caused the development of pest resistance, phytotoxicity on fruits, human health hazards, destruction of beneficial microbes and environmental pollution. Therefore, the recent trend is going on the improvement of non-chemical or ecofriendly methods for the management of this disease, which has provided impacts to more extensive exploration of natural resources and to identify effective plant extracts or botanical bio rational pesticides for the management of leaf curl virus by reducing vector population in the field [6].

Bio rational pesticides can be defined as certain types of pesticides that are derived from natural materials including animals, plants, microbes and certain minerals. They can be considered as a viable alternative to synthetic pesticides, which are known for their qualities of bio rationality, bio deterioration and low impacts on the environment [1]. Neem (*Azadirachta Indica*) is an evergreen plant that belongs to the family Meliaceae. Different parts of the neem tree, like seed kernel, leaves, roots and stem parts are used to extract bio rationals. The effect of neem can be used to control more than 200 insect species and some nematodes, fungi, bacteria and viruses. Azadirachtin is the widely used active ingredient extracted from neem. Neem based products are popular and available because of their easy preparation, environmentally safe nature and not being harmful to humans and animals [1].

Beauveria bassiana and *Metarhizium anisopliae* are two entomopathogenic fungi, which are used as bio rational pesticides because of their ecofriendly behaviour. *Metarhizium anisopliae* is used to control of pests like termites, thrips etc., while *Beauveria bassiana* is used to control pests like aphids, thrips and whitefly [2]. Both *Beauveria bassiana* and *Metarhizium anisopliae* spores when in contact with the outer surface of the insect, start germination and begin to grow from outside of the skeleton to inside causing the insect to die [7]. Spinosad was the first commercialized active ingredient in the unique class of insect control products, the spinosyns that have a natural origin and are produced from the metabolites of the naturally occurring soil bacterium *Saccharopolyspora spinosa.* Spinosyns are highly active on insect pests including the orders Lepidoptera, Diptera, Hymenoptera, Thysanoptera and some Coleoptera [8].

However, limited studies have attempted to evaluate the effectiveness of using biorationals in controlling pests in chili cultivation in Sri Lanka. Identifying such bio rational could significantly elevate the sustainability of the chili cultivation, while ensuring minimum negative impacts on the environment. Therefore, this study was conducted to identify a suitable biorational pesticide for effective control of LCC in chili.

MATERIALS AND METHODS

Experimental Site

The experiment was carried out at the farm field of the Faculty of Agriculture and Plantation Management, Wayamba University of Sri Lanka, Makandura, Gonawila (NWP), which is located in the Low Country Intermediate Zone (IL_{1a}), at an elevation of 30 m from the mean sea level. The experiment was carried out from November to April 2022. During the period of the experiment, the average day temperature and Relative Humidity levels were 33.1^{0}C and 80%, respectively.

Field Layout

Land was deep ploughed up to 15-20 cm in depth. A total of 21 raised beds were prepared at the size of 2.5 × 2.5 m with each bed having 12 planting holes. Between row and within row spacing were 90 cm and 60 cm, respectively. In addition, 50 cm width drains were prepared to ensure the drainage between beds. Seven treatments were arranged in a Randomized Complete Block Design (RCBD) with three replicates.

Crop Establishment and Maintenance

Chili seedlings of the variety MI 2 were transplanted in the field after three weeks of seed sowing. Compost was incorporated as a basal dressing to each planting hole and top dressing was applied one month after field establishment, according to the recommendation of the Department of Agriculture (DOA), Sri Lanka. Irrigation, weeding and other cultural practices were practiced according to the recommendation of DOA [9].

Types of Bio Rational Pesticides Tested

Six bio rational pesticides (Table 1) were applied by spraying onto the plant canopy. Treatment application started after three weeks of transplanting. Preparations of bio rational pesticides, Natural plant extracts [1 L/1 ac] (T_2), neem preparation [3200ml/ 1 ha] (T_3), *Beauveria bassiana* [spores 1.15% w/w] (T_4), *Metarhizium anisopliae* [spores 1.15% w/w] (T_5), Spinosad [200-240 ml/1 ac] (T_6) and *Beauveria bassiana* + *Metarhizium anisopliae* [spores 1.15% w/w] (T_7), were applied according to the concentrations given in the product label.

Table 1: Bio Rational Pesticides Tested in Experiment

Trt	Bio Rational Pesticide	Application Dosage (g/ml/6.25m²)
T_1	No pesticide (Control)	-
T_2	Natural plant extract SARUSARA	1.5ml/250ml
T_3	Neem (Azadirachtin) LAKGRO NEEM	75ml/150ml
T_4	*Beauveria bassiana*	1.56g/312ml
T_5	*Metarhizium anisopliae*	1.56g/312ml
T_6	Spinosad SUCCESS	0.25ml/250ml
T_7	*Beauveria bassiana* + *Metarhizium anisopliae*	1.56g/312ml

Note: *Trt; Treatment*

Data Collection

As the growth and reproductive parameters, the plant height of the chili plants was recorded by measuring from the base of the plant to the highest point of the plant at the age of 60 days and 75 days, separately in a sample of ten randomly selected plants from each treatment in each block. In addition, the number of branches and number of flowers were counted. At the age of 75 days, number of pods per plant was recorded in a sample of ten randomly selected plants from each treatment in each block. Each plot was visited by a trained field assistant from 7.00 a.m. to 9.00 a.m., 24 hours before and 72 hours after bio rational application and the number of pest species available in each plot and the average number of pests available on plants were recorded. Based on the recorded data, the Disease Incidence (DI) and Disease Severity Index (DSI) were calculated using the equations 1 and 2.

An eight-point based scoring scale was prepared based on the development extent of leaf curl symptoms in affected leaves to determine the DSI level of affected plants, as shown in Table 2 [10], the scores were given in the Table 2.

Table 2: Disease Severity Index Score Scale

Score	Symptoms	Disease Severity (%)
1	Partially curled	0-25
2	Fully curled	0-25
3	Partially curled	26-50
4	Fully curled	26-50
5	Partially curled	51-75
6	Fully curled	51-75
7	Partially curled	76-100
8	Fully curled	76-100

Statistical Analysis

The obtained data of the study was analyzed using Statistical Analytical System (SAS) software (version 9.4). Mean separation was done by Analysis of Variance (One-Way ANOVA), followed by the Tukey's pair-wise comparison at a significance level of 5%.

RESULTS AND DISCUSSION

Disease Severity Index (DSI) and Disease Incidence

Significant differences were observed in mean DSI values among the treatments (Table 3). The control treatment recorded the highest DSI value (44.3±2%), while the plot maintained under T_6 treatment (Spinosad) recorded the lowest DSI value (31.1±4%). When the total number of infected leaves per plant increased, the DSI values also increased. Due to the infection by LCC, plant leaves become small and curled, which results in the decrease of photosynthetic area of the plant causing a reduction of the yield. Therefore, treatments should be done in the nursery period as well as on the growth period [10].

$$Disease\ Incidence\ (DI) = \frac{Number\ of\ infected\ plants\ in\ a\ plot}{Number\ of\ plants\ in\ a\ plot} \times 100 \quad (1)$$

$$Disease\ Sevirity\ Index\ (DSI) = \frac{Total\ number\ of\ infected\ leaves}{Total\ number\ of\ leaves} \times 100 \quad (2)$$

Significant differences were observed in the mean DI values among the treatments (Table 3). Similar to DSI, the control plot recorded the highest DI (73.6±1%) value, while T_6 (Spinosad) plot recorded the lowest DI value (58.8±3%). Increased DI value indicated a higher number of infected plants, thereby suggesting a higher population of pests. Spinosad demonstrated its effect on the spread of LCC by controlling the disease vectors of LCC. According to the results, Spinosad bio rational pesticide could be effectively used to maintain a lower disease severity and low number of infected plants.

Table 3: Effect of Treatments on Disease Severity Index (DSI) and Disease Incidence (DI)

Treatment	DSI ± SE	DI± SE
T_1	$44.3±2^{a}$	$73.6±1^{a}$
T_2	$38.9±2^{ab}$	$66.7±2^{ab}$
T_3	$39.6±2^{ab}$	$67.8±1^{a}$
T_4	$37.2±1^{ab}$	$67.8±2^{a}$
T_5	$40.5±2^{ab}$	$67.8±1^{a}$
T_6	$31.1±4^{b}$	$58.8±3^{b}$
T_7	$38.8±2^{ab}$	$65.7±1^{ab}$

Note: *Values are mean ± standard error. Different superscript letters within a column indicate significantly different means at a 0.05 significance level, resulted by One-Way ANOVA, followed by the Tukey's pair-wise comparison. T_1: Control; T_2: Sarusara; T_3: Neem; T_4: Beauveria bassiana; T_5: Metarhizium anisopliae; T_6: Spinosad; T_7: Beauveria bassiana + Metarhizium anisopliae*

Growth and Reproductive Parameters

There were no significant differences observed in height, number of branches, number of flowers and number of pods among the treatments (Table 4). Chilis are generally self-pollinating but cross pollination is also common [11]. The control treatment recorded the highest number of pods. The control plot was not treated with any bio rational pesticides and that could have resulted the enhanced pollination by pollinators like bees, ants etc. Despite the lowest DSI and DI values, the plot treated with Spinosad (T_6) recorded the lowest number of pods. This can be attributed to the effect of Spinosad on pollinators like honeybees and other flower habituating insects of order Thysanoptera [9].

Sarusara (T_2) and *Beauveria bassiana*+ *Metarhizium anisopliae* (T_7) recorded the second highest number of pods, though it had lesser number of flowers. This observation could be due to the safer effect of those preparations for the pollinators and the possible content of plant growth hormones in the products based on plant extracts [12]. In this experiment, all treatment applications were done in the morning to avoid the negative effect of prevailed higher temperature on the efficiency of bio rational, due to quick evaporation of the applied bio preparations. Concurrently, morning is the time period at which insects including pests and pollinators like honeybees are active [13]. Therefore, bio rational pesticides like Spinosad that are with a high toxicity against pollinators should be applied at a time of the day when the pollinators are less active and the relevant pests are active.

Number of Pests Available on a Plant

Pest amount denoted significant differences among the treatments, ranging from 0 to 4.0 (Table 5). All other treatments recorded no pests, except the control treatment that recorded the highest number of pests (4.0). When the number of pests and pest species increase, the possibility of spreading LCC can also increase, since vectors are the mechanism of the spread of LCC in chili. Hence, vector control is an essential practice in order to control the LCC in chili. This proves the effect of bio rational treatments on controlling pest incidence. Also, based on the LCC incidence recorded in all treatments, there was a lower quantity of food source for the pests in the affected leaves. Therefore, with time the

Table 4: Effect of Treatment on the Growth and Reproduction of Chili

Treatment	Growth Parameters						
	At the Age of 60 Days			At the Age of 75 Days			
	Height	Branches	Flowers	Height	Branches	Flowers	Pods
T_1	24.3±2[a]	20.7±1[a]	15.0±2[a]	33.3±3[a]	30.0±4[a]	17.0±4[a]	6.6±3[a]
T_2	24.2±1[a]	16.7±4[a]	14.7±3[a]	31.5±1[a]	22.7±4[a]	15.0±2[a]	4.0±3[a]
T_3	24.9±1[a]	17.7±1[a]	13.0±1[a]	33.5±2[a]	29.0±2[a]	19.0±3[a]	3.7±1[a]
T_4	24.3±1[a]	17.3±2[a]	16.0±4[a]	32.4±1[a]	26.0±2[a]	14.3±1[a]	33±0[a]
T_5	21.8±1[a]	11.0±1[a]	11.3±1[a]	29.4±1[a]	20.7±3[a]	16.0±1[a]	1.7±2[a]
T_6	24..9±1[a]	16.0±2[a]	15.3±1[a]	34.0±1[a]	27.7±2[a]	21.3±4[a]	2.0±1[a]
T_7	25.0±1[a]	14.6±2[a]	16.3±2[a]	33.4±1[a]	28.3±1[a]	18.0±1[a]	4.0±2[a]

Note: *Values are mean ± standard error. Different superscript letters within a column indicate significantly different means at a 0.05 significance level, resulted by One-Way ANOVA, followed by the Tukey's pair-wise comparison. T_1: Control; T_2: Sarusara; T_3: Neem; T_4: Beauveria bassiana; T_5: Metarhizium anisopliae; T_6: Spinosad; T_7: Beauveria bassiana + Metarhizium anisopliae.*

number of pests has reduced, since thrips and whitefly much prefer to feed on younger leaves [14]. Furthermore, there may be repellant effects by the applied pesticides, especially by the odour of the pesticides. Therefore, as a result, pest population has become reduced.

Table 5: Effect of Treatments on Pest Population Available on Plants

Treatment	Average Number of Pests	Number of Pest Species
T_1	4	2
T_2	Not Detected	Not Detected
T_3	Not Detected	Not Detected
T_4	Not Detected	Not Detected
T_5	Not Detected	Not Detected
T_6	Not Detected	Not Detected
T_7	Not Detected	Not Detected

CONCLUSIONS

The findings of the current study suggests that all six bio rational pesticides have a significant effect on the disease severity and disease incidence of the Leaf Curl Complex in chili, with compared to the control treatment (T_1). The best result for the control of LCC in chili was observed from the treatment applied with Spinosad (T_6). Hence, this treatment can provide the best yield performance as well, since a reduced number of affected leaves in plants represents lower DSI and DI values. The increased photosynthesis can result in an increased yield as well. Therefore, Spinosad bio rational pesticide could be suggested as the best option to control LCC in chili.

However, this experiment should be again conducted under different climatic conditions and protected environments, while starting the application of the treatment at the nursery period. Plants should be continued until the economic lifespan of the crop as well. Furthermore, attention should be given to studying the optimum time and other methods of bio rational pesticide application to avoid negative effects on the pollinators and to improve efficiency of applications.

CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

AUTHORS' CONTRIBUTIONS

AR: Conducted the field experiments and wrote the manuscript. BR: Conceptualized and designed the research, supervised the field experiments and reviewed the manuscript. IK: Performed data analysis. SS: Assisted field experiments. All authors read and approved the manuscript.

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REFERENCES

1 Perera DH, Ranaweera B. Field evaluation of selected bio pesticides for the control of leaf curl virus disease in capsicum (*Capsicum annuum* L.). 2016; 274-278.
2 Mondal B, Mondal P. Ecofriendly pest management practices for leaf curl complex of chilli (*Capsicum annuum* L.). Journal of Biopesticides. 2012;5:115-118.
3 Senanayake DM, Dhammika WA, Dassanayake PJ, Naveditha AM, Kumari KA. Detection of chilli leaf curl Sri Lanka virus in chilli plants showing different virus like symptoms and in alternative weed hosts. Annals of Sri Lanka Department of Agriculture. 2015;17:76-79.
4 Shingote PR, Wasule DL, Parma VS, Holkar SK, Karkute SG, Parlawar ND, Senanayake DM. An overview of chili leaf curl disease: Molecular mechanisms, impact, challenges, and disease management strategies in Indian subcontinent. Frontiers in Microbiology. 2022 Jun 29;13:512-516.
5 Thakur H, Jindal SK, Sharma A, Dhaliwal MS. Chilli leaf curl virus disease: A serious threat for chilli cultivation. Journal of Plant Diseases and Protection. 2018 Jun;125:239-49.
6 Chaubey AN, Mishra RS, Virendra Singh VS. Ecofriendly management of leaf curl disease of chilli through botanical bio-pesticides. Plant Archives. Corteva Agriscience. 2021;17:285-291.
7 Goettel MS, Eilenberg J, Glare T. Entomopathogenic fungi and their role in regulation of insect populations. Comprehensive Molecular Insect Science.2005;361-405.
8 Bunch TR, Bond C, Buhl K, Stone D. Spinosad General Fact Sheet. National Pesticides Information Center: Oregon State University Extension Services; 2014.
9 Department of Agriculture Sri Lanka. Chilli (*Capsicum annuum* L); 2021. [Accessed 15th April, 2023]. Available at https://doa.gov.lk/field-crops-chilli-si/
10 Jayasinghe JTC and Ranaweera B. Field evaluation of selected bio pesticides for the control of leaf curl virus disease in tomato (*Solanum esculentum* Mill.). In *Proceedings of the 14th Agricultural Research Symposium-2015*, Wayamba University of Sri Lanka; 2015.p. 83-86.
11 Ritonga AW, Syukur M, Yunianti R, Sobir. Assessment of natural cross pollination levels in chili pepper (*Capsicum annuum L.*). IOP Conference Series. Earth and Environment Science.2008;196.012008.
12 Amobonye A, Bhagwat P, Pandey A, Singh S, Pillai S. Biotechnological potential of *Beauveria bassiana* as a source of novel biocatalysts and metabolites. Critical Reviews in Biotechnology. 2020 Oct 2;40(7):1019-1034.
13 Landaverde-González P, Quezada-Euán JJ, Theodorou P, Murray TE, Husemann M, Ayala R, Moo-Valle H, Vandame R, Paxton RJ. Sweat bees on hot chillies: Provision of pollination services by native bees in traditional slash-and-burn agriculture in the Yucatán Peninsula of tropical Mexico. Journal of Applied Ecology. 2017 Dec;54(6):1814-1824.
14 Varghese TS, Mathew TB. Bioefficacy and safety evaluation of newer insecticides and acaricides against chilli thrips and mites. Journal of Tropical Agriculture. 2013 Dec 24;51(1):111-5.