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Investigation on the Suitability of Limestone Quarry Dust as an Alternative to Crystalline Rock Quarry Dust as a Filler Material in Hot Mix Asphalt Production in Sri Lanka

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Abstract – *With the recent boom in infrastructure development, especially in the road construction industry, the demand for hot-mix asphalt concrete has increased in Sri Lanka. This has created a rise in demand for hot mix asphalt concrete and thus an increase in the price of quarry dust, which is used as the filler material in hot mix asphalt concretes. As a solution to this problem, this work investigates the appropriateness of using limestone quarry dust as the filler material in place of conventionally used crystalline rock quarry dust in the production of hot mix asphalt concrete. Results are found to be very encouraging from the inception as the physical properties of limestone quarry dust comply with the local standard specifications as a filler material for hot mix asphalt concrete. Moreover, a Marshall Test programme was carried out to evaluate the performance of hot mix asphalt concrete blended with limestone quarry dust as a filler material, which encompassed tests such as stability, flow, voids in the mix, and percentage voids filled with bitumen of hot-mix asphalt concrete. Limestone quarry dust was replaced with crystalline rock quarry dust in percentages of 10%, 40%, 70%, and 100% by weight in the blended samples and each sample set was further tested under different bitumen contents of 5.0%, 5.3%, 5.6% and 6.0% by weight of the filler. Results reveal that all the blended samples satisfy the compliance levels for all the tested parameters specified by Standard Specifications for Construction and Maintenance of Roads and Bridges in Sri Lanka and thus can be concluded that limestone quarry dust can be used as a filler material in place of conventionally used crystalline rock quarry dust. It has also been revealed that an optimum bitumen content of 5.43% needs to be adopted if only limestone quarry dust to be used as the filler material.*

Keywords: *Limestone quarry dust, Asphalt Concrete, Filler material, Marshall Test*

Nomenclature

CQD – Crystalline Quarry Dust
HMAC – Hot Mix Asphalt Concrete
PSD - Particle Size Distribution
MT-Marshall Test
OBC – Optimum Bitumen Content
VFB – Voids Filled with Bitumen
VMA – Voids in Mineral Aggregates
LQD -Limestone Quarry Dust

1 INTRODUCTION

Hot Mix Asphalt Concrete (HMAC) is widely preferred in the road construction sector as the primary surfacing layer, due to its distinctive attributes, including cost-effectiveness, easy maintenance, durability and excellent resistance to cracking and rutting. Moreover, HMAC can be recycled and can be customized to meet specific engineering requirements. These qualities render it a reliable option for creating enduring road surfaces.

Typically, HMAC consists of a carefully blended combination of a coarse aggregate made from crushed rock or gravel (with a size greater than 2.36 mm), fine aggregate (either natural sand or crushed rock fines with a size less than 2.36 mm), filler, and asphalt cement, serving as the binding agent for the asphalt (Pandit and Roy, 2019). This combination helps to enhance the performance of asphalt pavements. Filler plays a crucial role in filling voids in the aggregate mix, thereby enhancing the density, stability, and toughness of the asphalt concrete mix. However, the inclusion of an excess amount of filler is likely to enhance the brittleness of the mixture which will induce cracking. Conversely, a shortage of filler tends to elevate the void content, resulting in the development of a softer mixture characterized by reduced stability. Therefore, it is prudent to use the ideal proportions of filler in HMACs, in considering the durability of the surfacing layer, which reduces the cost of pavement rehabilitation and maintenance (Csanyi, 1994).

The commonly used filler materials are cement, hydrated lime, and quarry dust (Rahman et al., 2012). Crystalline quarry dust (CQD), which forms in quarries of crystalline rock, typically of metamorphic origin in the Sri Lankan context, is widely employed as a filler material in Sri Lanka. This is primarily attributed to its more economical cost compared to alternative filler materials (Diyes et al., 2014). Nevertheless, the previously perceived low-cost nature of quarry dust is no longer accurate, as the material's price is currently on the rise. This increase can be attributed to its widespread utilization in concrete, mortar mixtures, and the production of bricks and blocks.

About 10 % of Sri Lanka's geological rock terrain composition consists of limestone, which belongs to the Miocene aged sedimentary category. Therefore, it is commonly used as a raw material in the construction industry (Jayawardene, 2017). A considerable amount of Limestone dust generates as waste material in the comminution process during aggregate production, which causes a huge negative impact on the ecosystem.

In contrast, the lower demand for quarry dust produced in limestone quarries in Sri Lanka makes it more economical compared to its crystalline counterpart. Therefore, this study aimed to assess the suitability of utilizing limestone quarry dust (LQD) as a filler material in the production of HMAC.

2 PREVIOUS STUDIES

Numerous studies have been carried out to evaluate the efficacy of utilizing waste materials as fillers in asphalt concrete. In this context, Diyes et al. (2014) conducted a study to assess the suitability of employing fly ash (FA) as the filler material in Hot Mix Asphalt. By employing the Marshall test (MT), which assesses the load and flow rate of asphalt specimens, the researchers determined the optimal ratios for the components of the asphalt concrete mix in a testing regime involving replacements of 100%, 58%, and 42% (corresponding to 12%, 7%, and 5% of the total weight of aggregates), mineral filler substituted with fly ash. According to their findings, FA obtained from the waste generated in the Norochcholai Coal Power Plant is found to resemble the particle size distribution of a conventional mineral filler, with a slightly lower specific gravity and a slightly higher fineness compared to quarry dust. They have been able to successfully replace 42% (equivalent to 5% of the total weight of the aggregates) of the mineral filler by FA to yield a mixture that surpasses the minimum stability requirement (8 kN) and with an optimum bitumen content (OBC) of 5.5% (by weight of the aggregates) criteria meeting the specified guidelines in the Construction Industry Development Authority (CIDA, 2009).

Mistry and Roy (2016) conducted a similar type of study on FA as the filler material for HMAC with the waste FA from a thermal power plant. By carrying out a MT programme of different bitumen contents (3.5−6.5% at 0.5% increments) with 2% hydrated lime and varying FA replacement of 2% to 8% with the mineral filler, they were able to successfully replace with a 4% (of the total weight of aggregates) FA to obtain a HMAC of higher stability with lower OBC, satisfying their local regulatory specifications.

Saw dust ash (SDA) as a filler material is found to produce promising results when it is replaced with the original basaltic stone dust filler (Fayissa et al., 2021). In a test programme of 3% to 12% replacement in 3% increments of SDA in place of basaltic dust, the best results were produced at a 12% replacement level. The OBC obtained at this replacement level met the local regulatory standards, and optimal outcomes are observed for both tensile strength and fatigue performance at this replacement level as well. The addition of SDA has improved the fatigue life of HMAC, and an increased concentration of calcium carbonate in SDA has reduced the potential for moisture damage. Nevertheless, basaltic stone dust was still found to perform well compared to SDA with respect to most of the MT parameters, including stability and OBC.

Jony et al., (2011), have investigated three types of filler materials, viz., limestone dust (LD), Ordinary Portland Cement (OPC), and glass powder (GP) in their study. They found that the optimal replacement level for GP is 7% of the total aggregate weight when used with conventional mineral filler. Out of the three filler material options they have investigated, a notable increase of stability up to 13% and a decrease in flow and density to 39% and 10% respectively is reported in HMACs with GP, when compared to LD and OPC. These results have been produced in a test programme of filler replacement in 4%, 7%, and 10% by weight of total aggregate.

Tire-derived fuel fly ash (TDFFA), which mainly constitutes CaO and SiO_2 is also can be effectively replaced in place of mineral fillers in HMACs (Choi et al., 2020). Choi et al., (2020) carried out a study to investigate the filler suitability of TDFFA, cement, stone dust (SD) and hydrated lime (HL) in HMACs. Choi et al., (2020) further reports that the addition of TDFFA has caused to increase in the stripping resistance, and the degree of coating and hence causes an increase in the peeling resistance by exertion of a uniform bonding force between the asphalt and the aggregate by the spherical particles of the TDFFA. Moreover, the tensile strength ratio (which is used as a parameter to measure the moisture resistance of a mineral filler) of TDFFA is found to be greater compared to cement and SD, thus implying that TDFFA effectively improves the moisture resistance. In addition to the compliance with the basic Korean specifications, the HMACs which use TDFFA were also found to satisfy the local criteria on dynamic stability.

According to research conducted by Choudhary et al. (2020), it was found that Limestone sludge (LS) generated in the dimensional limestone industry exhibits outstanding performance as a filler in HMAC. Particularly noteworthy are its superior qualities in essential parameters such as rutting resistance, fatigue resistance, indirect tensile strength, and resilient modulus when compared to HMACs containing conventional fillers. This was revealed during a testing programme of MT and OBC, where LS was substituted at varying percentages of 4%, 5.5%, 7%, and 8.5% by weight of aggregates. The results indicated that the optimal filler percentage for LS was determined to be 6.45%.

3 METHODOLOGY

As the initial step, the conformity of the conventional filler material, CQD, and the alternative material, LQD, with standard specifications was examined. For this, particle size distribution (PSD), specific gravity, and water absorption tests were carried out to evaluate their adherence to established standards.

Secondly, Marshall Tests (MT) were conducted on both a control sample (solely comprised of CQD) and blended samples (mixed with varying proportions of LQD). This aimed to acquire Marshall parameters, including stability, Marshall flow, air voids in the mix, voids in mineral aggregate (VMA), and voids filled with bitumen (VFB). Subsequently, the attained Marshall parameters were compared with the prescribed levels outlined in accordance with the CIDA guidelines.

3.1 Materials

To facilitate the preparation of HMAC in this study, metamorphic aggregates of two specified sizes were employed: Coarse aggregates, denoted as Type 1 (20mm), and medium-sized aggregates, denoted as Type 2 (5mm). Additionally, Type 3 aggregates with a finer granularity of 2mm were also utilized. These were employed as the conventional filler material (CQD). The asphalt binder used was 60/70 pen-grade bitumen. To prepare the blended samples, LQD was obtained from the Aluvihare limestone quarry in Matale. As the binder in preparation for HMA, grade 60 penetration bitumen was used.

3.2 Tests and Standards

The PSD for CQD aggregates Type 1, Type 2, Type 3, and LQD was conducted using a sieve analysis test as per BS 812-103.1:1985, while the specific gravity test and water absorption tests were conducted according to BS 812:1995: Part 2 standards. For the control sample as well as for the blended HMACs, conventional MTs were carried out according to the specifications stipulated in the standard AASHTO T245- 97, (2001).

Initially, coarse aggregate, fine aggregate, and filler were proportioned according to the specified standards. A quantity of around 1250g of the mix was selected to make the compacted bituminous specimens with an approximate thickness of around 65-70mm. Aggregates were heated to a temperature range of 175°C to 190°C, while simultaneously, the compaction mould assembly and rammer were cleaned and preheated to temperatures between 100°C and 145°C. The bitumen was also heated to a temperature in the range of 121°C to 138°C. In the initial bitumen trial, the required amount was added to the heated aggregates and thoroughly mixed to achieve uniformity. The resulting mix was placed in a mould and compacted with 75 blows for each side from the rammer. Following compaction, the sample was swiftly extracted from the mould using a sample extractor within a very short period.

3.3 Sample Preparation

HMAC samples were made as per Marshall Mix Design procedure and the blended samples were prepared by replacing the CQD with LQD for filler content as per table 1 given below.

LQD percentages for filler were selected based on previously conducted research to assess the possibility of completely replacing CQD with LQD.

Table 1 Different blends of HMA with LQD as filler

% of Bitumen by weight	Experimental Programme			
5	100% LQD	30% CQD, 70% LQD	60% CQD,40% LQD	90% CQD,10% LQD
5.3	100% LQD	30% CQD, 70% LQD	60% CQD,40% LQD	90% CQD,10% LQD
5.6	100% LQD	30% CQD, 70% LQD	60% CQD,40% LQD	90% CQD,10% LQD
6	100% LQD	30% CQD, 70% LQD	60% CQD,40% LQD	90% CQD,10% LQD

Bitumen percentages were obtained according to CIDA (2009) specifications and by considering the workability during the HMAC sample preparation.

The physical properties of aggregates and fillers are shown in Table 2. The performance criteria (stability, flow, voids in the mix, voids in the aggregate, percentage voids filled with bitumen) of different blends (mixtures) of hot mix asphalt made with LQD are assessed and compared with that of Sri Lankan local authority's conventional asphalt concrete standards.

4 RESULTS AND DISCUSSION

Results of PSD, specific gravity, and water absorption for CQD and LQD are given in Table 2 and Figure 1.

Table 2 Specific gravity and water absorption test results of CQD and LQD

Materials	Specific gravity	Water absorption (%)
Type 1 (CQD)	2.86	0.45
Type 2 (CQD)	2.80	0.20
Type 3 (CQD)	2.82	0.20
LQD	2.76	0.76

Utilizing the PSD results, a control HMAC sample was made in triplicate (Sample 1, Sample 2, and Sample 3) using the conventional CQD material, maintaining the same mixing ratios to investigate their mixing uniformity. The uniformity of mixing was assessed in accordance with ICTAD specifications for PSD in Table 2 and Fig. 2. Consequently, all three samples were found to meet the ICTAD specifications.

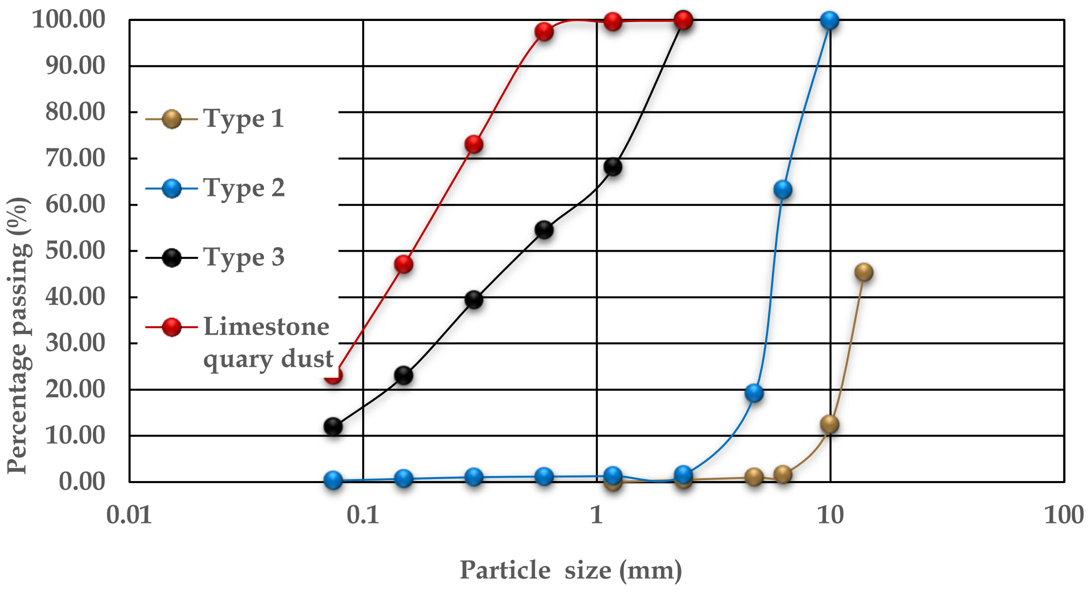


Figure 1. PSD curves of conventional aggregate materials (CQD) and LQD

Table 3 PSD results for aggregate sample mixtures

Sieve size (mm)	% passing			Grading Requirement as per CIDA Specifications (%)
	Sample 01	*Sample 02*	*Sample 03*	
10	75.87	74.30	74.24	56 - 82
5	57.89	55.61	55.39	36 - 58
2.36	42.87	40.98	39.73	21 - 38
1.18	35.13	33.28	32.58	15 - 32
0.6	27.58	25.36	24.76	10 - 26
0.3	19.71	17.94	17.51	6 - 20
0.15	11.66	11.07	11.01	3 - 13
0.075	4.98	4.51	5.08	1 -7

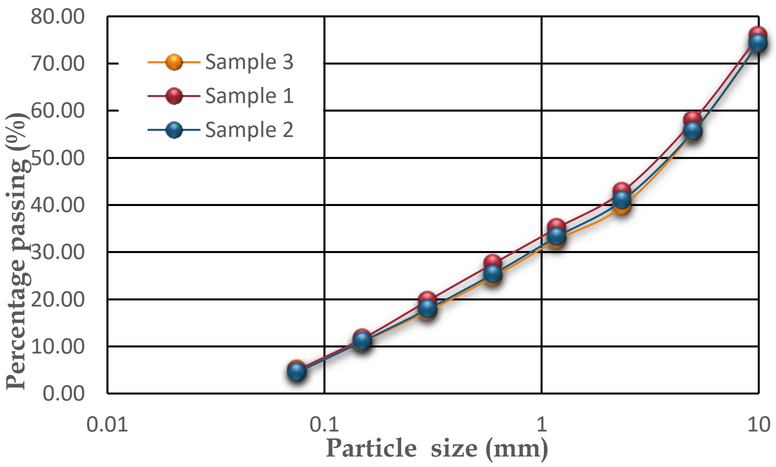


Figure 2. PSD curves for aggregate sample mixtures

As the next step, material passing from the 0.15 mm size sieve corresponding to Sample 01 was replaced with LQD as described in section 3.2 and proceeded with the MTs to check the CIDA compliance criteria. MT results are given in Table 3 with relevant CIDA compliance levels and Fig.3 to Fig.7 depict the variation of different Marshall parameters against different binder contents at different LQD replacement levels.

According to the graphical behaviour reported in Fig. 3, the stability of HMAC increases with increasing asphalt binder content and produces a post-peak decline, thus creating an optimum binder (bitumen) content to adopt in HMAC mix designs.

Flow is defined as the vertical deformation during the test. The curves in Fig. 4 indicate a general increase in flow as bitumen content rises. Notably, the results consistently met the compliance levels. It is crucial to emphasize that, under these conditions, the minimum value must stay within the specified limit to prevent the mixture from becoming excessively stiff. Concurrently, the maximum value should remain within the limits to prevent the mixture from being too soft and ensure its ability to withstand expected traffic loads. Adhering to these prescribed limits will ensure the optimal performance and durability of the asphalt mixture under various traffic conditions.

Table 4 Marshall stability test results for blended asphalt concrete with LQD

Replacement level of LQD as the filler in place of CQD	Stability (kN)	Flow (0.25mm)	Air voids (%)	VMA (%)	VFB (%)
100%	8.79	10.32	4.43	16.75	73.54
	10.56	12.04	3.98	17.00	76.61
	10.50	13.4	3.83	17.51	78.13
	8.33	14.96	3.73	18.28	79.58
70%	9.09	9.76	4.11	16.30	74.80
	11.24	11	3.83	16.70	77.07
	11.14	12.6	3.73	17.27	78.42
	8.75	14.44	3.54	17.96	80.31
40%	10.34	8.96	3.66	15.92	77.00
	12.71	9.92	3.51	16.43	78.62
	12.11	11.36	3.38	16.94	80.03
	10.41	13.52	3.19	17.65	81.90
10%	11.91	8.2	3.40	15.80	78.51
	14.00	9.2	3.26	16.33	80.05
	12.74	10.28	3.21	16.91	81.02
	10.74	13.56	3.18	17.77	82.11
CIDA Specifications for High Traffic CNSA > 10^6	Not less than 8	8 to 16	3 to 7	>14	-

The air void content decreases against increasing bitumen content, which matches the expected theoretical behaviour of these parameters as depicted in Fig. 5.

As depicted in Fig. 6, VMA levels gradually increase with increasing bitumen content. When VMA values are high, it implies that more space is available for the binder. As Table 3 reveals, VMA levels surpass the compliance limits, affirming the sufficient durability of the specific HMACs.

VFB increases with increasing bitumen content while decreases with the addition of LQD in Fig.7. Hence, this suggests that an excessive amount of LQD diminishes the effective thickness of bitumen, leading to the formation of a less durable HMAC.

The optimum binder contents, which produce maximum stability levels corresponding to the respective replacement levels of LQD are obtained using the stability curve presented in Fig.3, as the other parameters are within the limits of CIDA specifications. Table 4 presents the optimum bitumen contents to be adopted under different LQD replacement levels as filler material in HMACs.

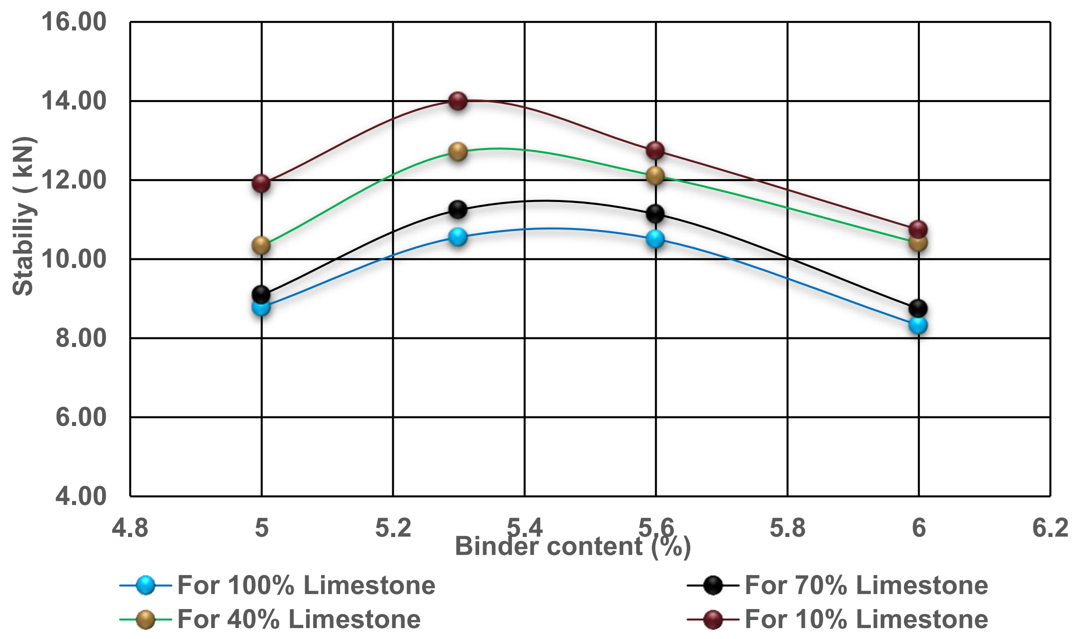


Figure 3. Stability variation in HMAs with binder content under different filler replacement levels of LQD

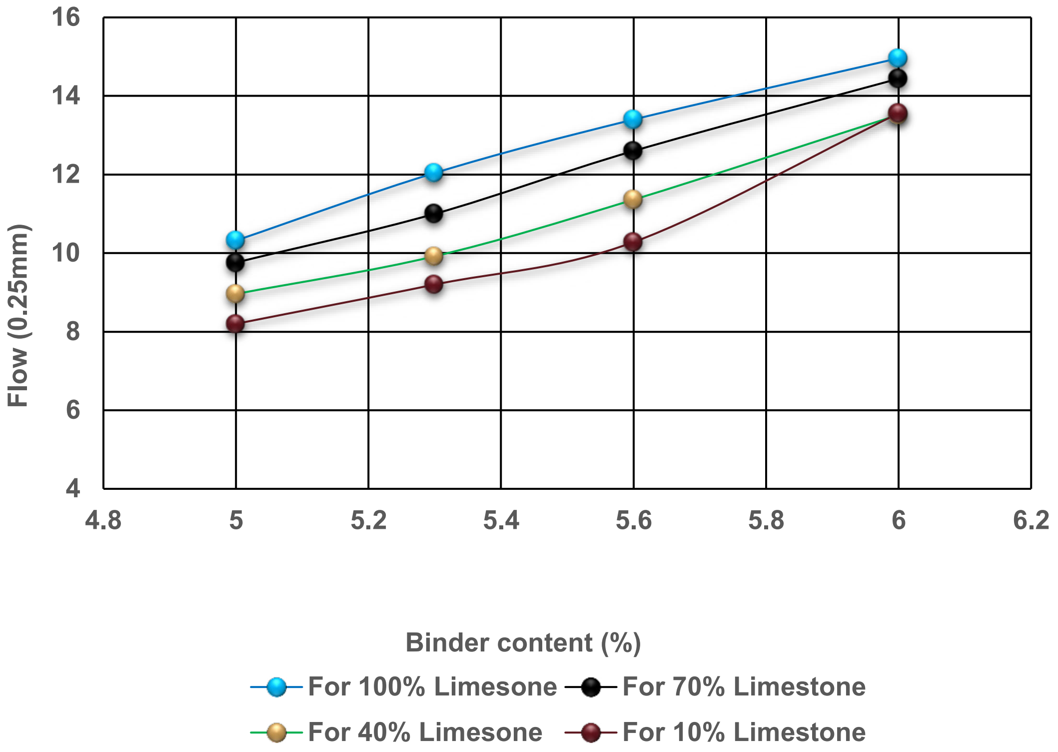
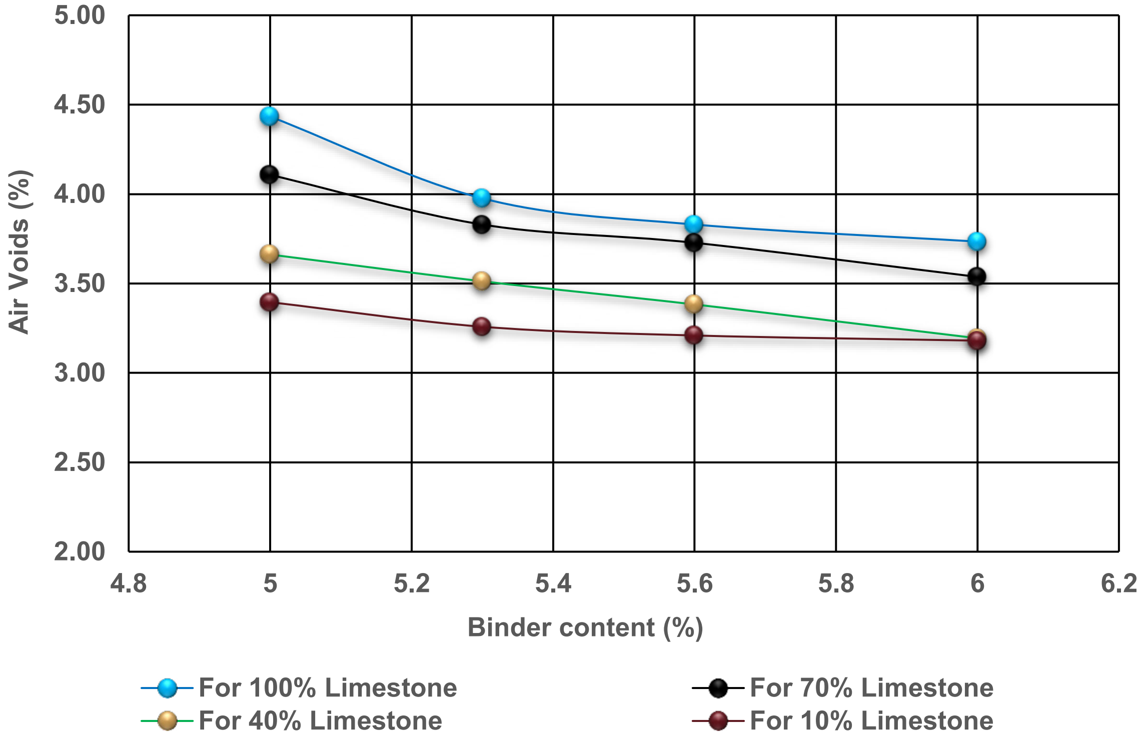


Figure 4. Flow variation in HMAs with binder content under different filler



replacement levels of LQD

Figure 5. Air void variation in HMAs with binder content under different filler replacement levels of LQD

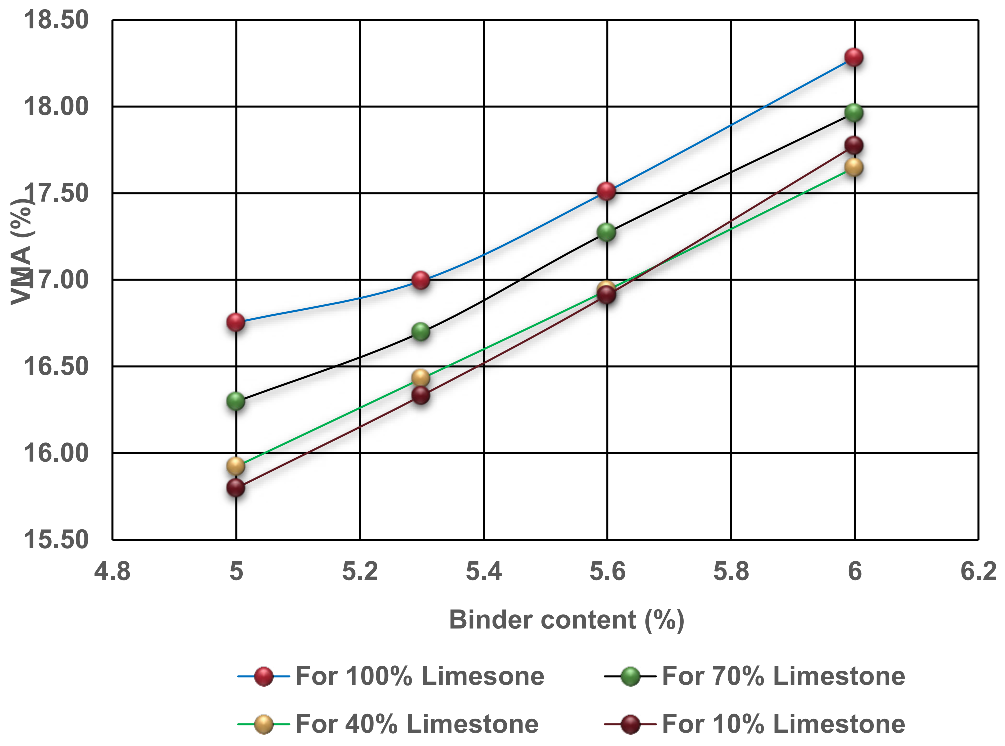


Figure 6. Voids in mineral aggregate variation in HMAs with binder content under different filler replacement levels of LQD

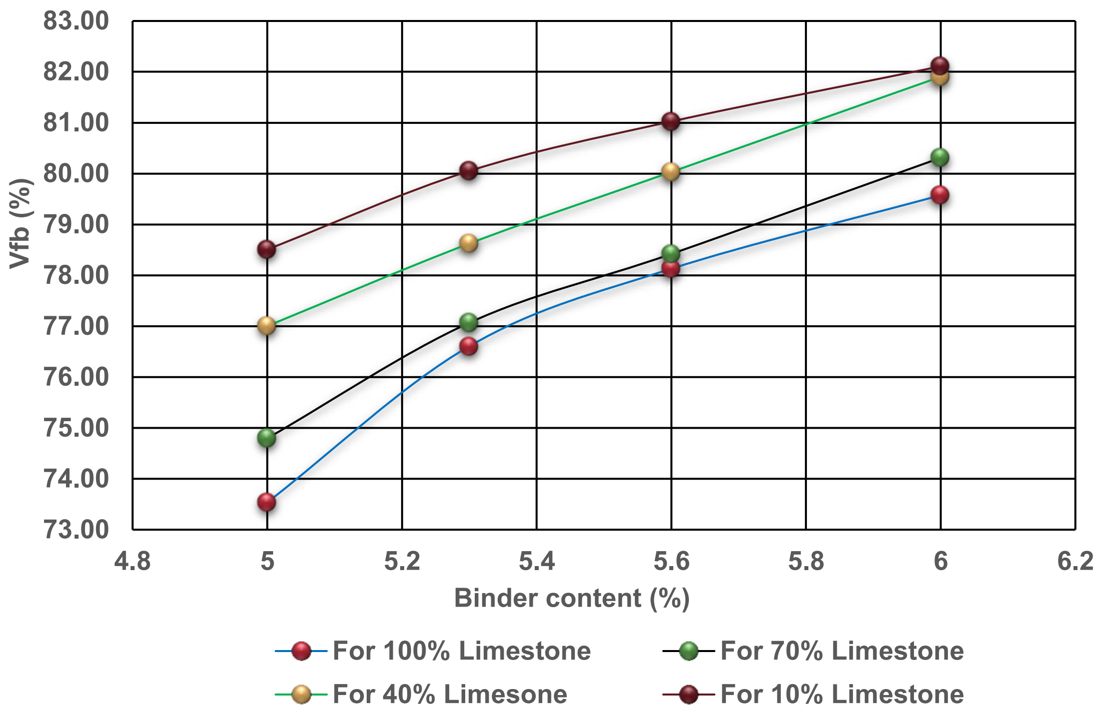


Figure 7. Voids filled with bitumen variation in HMAs with binder content under different filler replacement levels of LQD

Table 4 Optimum bitumen content for different mixes

Mix proportion of LQD as filler	Optimum bitumen content (%)
100%	5.43
70%	5.42
40%	5.36
10%	5.32

Table 5 (a) Summary of Material Properties

Name of the Test	Type 1 crushed stones	Type 2 crushed stones	Type 3 crushed stones	LQD	CIDA specification
Sieve Analysis Test	As per Table 3, all the aggregate types as well as blended samples were within the specified grain size standards.				
Specific gravity(g/cm^3)	2.86	2.8	2.82	2.76	>2.75
Water absorption	0.45	0.2	0.2	0.76	<2

Table 5 (b) Summary of Martial Parameters

Marshall parameters	Average values for blended samples with LQD as filler				CIDA Compliance levels
Percent of LQD filler	100%	70%	40%	10%	
Stability (kN)	9.55	10.06	11.39	12.35	>8
Flow (mm)	12.68	11.95	10.94	10.31	8-16
Air voids (%)	3.99	3.80	3.44	3.26	3-7
VMA (%)	17.39	17.06	16.74	16.7	>14
VFB (%)	76.97	77.65	79.39	80.42	

5 CONCLUSIONS AND RECOMMENDATIONS

Following conclusion can be made based on the summary of results presented in Table 5(a) and Table 5(a).

The PSD, specific gravity, and water absorption results fall within the stipulated compliance limits set by the CIDA specifications. Marshall test results for both the control sample and blended samples affirm the viability of substituting LQD as a suitable alternative to conventionally employed CQD as the filler material in HMAs. All Marshall Test parameters consistently fall within the CIDA compliance levels designated for asphalt concrete.

The main progressive finding made in this study is the recognition that locally available LQD not only can be used as a partial replacement of CQD but also as an alternative material that can even completely replace CQD in using as a filler material in HMAs.

In the case of using LQD as a complete alternative filler material in HMA, a bitumen content of around 5.43% can be recommended.

In practical HMAC production, it is typical to encounter situations which create a common shortfall of 1% to 2% in filler material, particularly when employing CQD as the filler material. Based on the aforementioned findings, it can be inferred that the relatively lower specific gravity of LQD requires a correspondingly larger volume of LQD. Therefore, if HMACs can be manufactured solely using LQD, such a shortfall filler material may not arise, as there would be an abundance of fine material in the HMAC compared to an HMAC produced with CQD. This, in turn, could contribute to a reduction in production costs.

This study has been carried out to assess the suitability of incorporating LQD as a filler material in the production of HMACs. Based on the findings, it is suggested to conduct additional investigations to explore the viability of substituting coarser grades of limestone quarry aggregates for the larger size ranges of crystalline rock aggregates in HMAC production.

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Comparative Study Between an Organic Liquid Fertilizer Developed by Fish Waste and Department of Agriculture Recommended Inorganic Fertilizer on Growth and Yield of Chilli (*Capsicum frutescens* L.) in Sri Lanka

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Abstract – *The increased and long-term use of chemical fertilizers has led to numerous environmental, economic, and social issues in Sri Lanka. To ensure the long-term sustainability of agriculture, the application of liquid organic fertilizers produced from agricultural and industrial wastes is becoming much more popular. At the same time, the Sri Lankan fish processing industry is looking for ways to utilize the inedible fish wastes from their plants. Therefore, the present study was carried out to examine the effect of novel organic liquid fertilizer (NOLF) produced from fish wastes on the growth and yield of green chilli. Five different formulas of NOLFs i.e. 1% NOLF (T_1), 2% NOLF(T_2), 3% NOLF (T_3), 4% NOLF (T_4), 5% NOLF (T_5), and the recommended chemical fertilizer for Chilli by the Department of Agriculture (DOARF) were used as the treatments of this experiment. The plant height, number of branches/plant, number of leaves/plant, leaf area at the time of flowering and number of fruits/plant were recorded as growth and yield parameters of Chilli, respectively. Analysis of variance (ANOVA) was performed to analyze the data by using the SPSS software package. The significance of means was analyzed with the least significant differences (LSD) between treatment means at $P < 0.05$. The results revealed that the growth and yield parameters of Chilli plants added with DOARF are significantly better than the plants added with different formulas of NOLFs (T_1 to T_5).*

Key words: *Chilli, fish waste, novel organic liquid fertilizer, Sri Lanka*

1 INTRODUCTION

The application of any fertilizer improves the amount of plant nutrients in the soil, making it more fertile and conducive to crop growth and development, ultimately increasing the final yield of crops. The sources of fertilizer vary from natural to industrial products (Sherer *et al*., 2009). Therefore, the sources of fertilizer can be classified into two broad categories; organic fertilizer and inorganic or chemical fertilizer. As the name suggests, organic fertilizer comes from organic sources such as animal and plant materials, which are natural. Chemical fertilizer comes from inorganic sources, which are synthetic in nature.

Major plant nutrients or the primary nutrients are Nitrogen (N), Phosphorus (P) and Potassium (K) which are consumed by crop plants in relatively large quantities. Crop plants also need minor nutrients or secondary nutrients such as Calcium, Magnesium, Sulfur, Boron, Copper, Chlorine, Iron, Manganese, Molybdenum, and Zinc which are consumed by crop plants in relatively smaller quantities. The response to the fertilizer application of high yielding crop varieties developed during and after the Green Revelation is very high. Therefore, the Application of chemical fertilizers becomes more important in present developing intensive agriculture (Adesemoye *et al*., 2009 and da Costa *et al*., 2013). With the Green Revolution usage of nitrogen fertilizer in the world increased by 800% (from 1961 to 2019) which also increased the productivity of conventional food systems by more than 30% per capita (Mbow *et al*., 2019).

However, increased and long-term use of chemical fertilizer has led to lots of environmental, economic and social issues. Air pollution, water pollution, soil pollution, increase in production cost and human health issues due to food safety problems, and deterioration of quality of agricultural products are some of them. To overcome the problems in the use of chemical fertilizer and to ensure the long-term sustainability of agriculture organic farming has become acceptable. Though organic farming is always associated with lower yields, it has experienced fast growth globally.

Organic farming systems involve the natural management of soil with the help of organic fertilizer such as compost, animal manure and application of soil organic matter. Organic fertilizer improves the physical, chemical, and biological properties of soil and thus improves soil fertility. Various research carried out by various researchers revealed that the use of organic fertilizer as an alternative to chemical fertilizer minimizes food safety and quality issues and associated other negative impacts (Caris-Veyrat *et al*., 2004, Luthria *et al*., 2010, Vallverdú-Queralt *et al*., 2012 and Oliveira, A. B. *et al*. 2013). Furthermore, the application of organic fertilizer improves the nutritional quality of certain vegetable crops such as tomatoes. For example, organic tomatoes had significant amount of vitamin C, carotenoids and polyphenols when compared to the tomatoes harvested from a conventional system of cultivation (Caris-Veyrat *et al*., 2004).

Liquid organic fertilizers produced from agricultural residues and industrial wastes are becoming much more popular among farmers nowadays. The above wastes can be used as a carbon substrate and a simple fermentation process carried out with the help of microorganisms is the principle behind the production of liquid organic fertilizers. Fish waste is one such carbon substrate that can be easily converted into liquid organic fertilizer. The fish processing industry produces large amounts of fish waste (Jung, H.Y. and Kim, J.K. 2016) which causes marine and land pollution due to inappropriate disposal in the sea or on land (FAO, 2018). Therefore, the conversion of fish waste into liquid organic fertilizer has the added advantage of reducing soil and water pollution. However, the application of fish waste as an organic fertilizer can attract mice and flies due to its bad smell (Bhagwat *et al.,* 2018). Biodegradation of fish waste through proper fermentation solves this problem. Therefore, the production of liquid organic fertilizer by using fish waste provides a solution to the problem of waste disposal and the resultant liquid organic fertilizer can be used as an effective plant growth promoter (Jung *et al.,* 2016, Dao *et al,*. 2011). The liquid organic fertilizer acts faster than solid organic ones and is short-acting compared to the dry organic once which are longer acting.

Further, in Sri Lanka, the fish processing industry is looking for the ways to dispose of inedible fish wastes from their plants. Therefore, the present study was carried out with the intention of introducing a new liquid organic fertilizer developed from fish wastes and assessing its performance by comparing it with inorganic fertilizer recommended by the Department of Agriculture in Sri Lanka for the growth and yield of green chilli (*Capsicum frutescens* L.).

2 METHODOLOGY

2.1 Experimental Site

The study was carried out in a field belonging to Ceylon Agro Chain (Pvt) Ltd, Anamaduwa in Sri Lanka during the period from March to July 2023. Anamaduwa is situated in the Puttalum administrative district in the North Western Province of the country. Green Chilli (*Capsicum frutescens* L.) belonging to the family Solanaceae and the Genus Capcicum, one of the important spice crops widely grown in Sri Lanka has been selected as the test crop for the experiment. This is a short term crop with a life spans of three and half months.

2.2 Production of Novel Organic Liquid Fertilizer (NOLF)

The novel liquid organic fertilizer was produced using fish waste remains after processing fish for the export market by Ceylon Agro Chain (Pvt) Ltd. Ten Kilograms (10kg) of fish waste and 7kg of crushed Jaggery (local name - Sakkara) were mixed and added into an airtight container, allowing for anaerobic digestion (fermentation) for a period of 15 days at ambient temperature. At the end of 15^{th} day another 3kg of crushed Jaggery was added to the container, stirred thoroughly and allowed for another 15 days for to complete the fermentation under the same anaerobic condition. On the 30^{th} day the mixture was filtered using 1mm mesh. The fermented filtrate was used as the novel organic liquid fertilizer. The newly produced organic liquid fertilizer was analyzed for its color through visual inspection, odor through sniffing, pH with the help of pH meter, N % using Kjeldhal method, P % by using Olsen method and K % with the help of Flame Photometer.

2.3 Treatments

Before use, the NOLF was diluted with distilled water to produce five different formulas of NOLF; 1% NOLF - 10ml NOLF + 1leter of distilled water, treatment one (T_1), 2% NOLF – 20ml of NOLF + 1leter of distilled water, treatment two (T_2), 3% NOLF - 30ml of NOLF + 1leter of distilled water, treatment three (T_3), 4% NOLF – 40ml of NOLF + 1leter of distilled water, treatment four (T_4) and 5% NOLF - 50ml of NOLF + 1leter of distilled water, treatment five (T_5). The Sri Lankan Department of Agriculture recommended inorganic fertilizer (DOARF) for Chilli used as the control treatment in this experiment. Accordingly there were 6 treatments in this experiment.

2.4 Experimental Design and Allocation of Treatments

The experimental design was the completely randomized design (CRD). All 6 treatments were replicated 5 times. Poly bags filled with a medium of top soil : compost : paddy husk charcoal, 3:2:1 were used to transplant the Chilli plants. Each poly bag was planted with two Chilli plants, properly selected from a Chilli nursery managed as recommended by the Department of Agriculture (DOA) Sri Lanka. All treatments were allocated among the experimental units (polybags) randomly. The different formulas of NOLFs (i.e., 1%, 2%, 3%, 4% and 5%) were added to the relevant polybags once in four (04) days until the fruiting stage of Chilli plants. DOARF was added to the relevant poly bags with Chilli plant as recommended by the DOA of Sri Lanka. All other cultural practices were performed as recommended by the DOA of Sri Lanka.

2.5 Growth and Yield Parameters Recorded

Plant height, the number of branches/plants, number of leaves/plant, and leaf area were recorded at the time of flowering as growth parameters. Number of fruits/plants was recorded as yield parameter.

2.6 Data Analysis

Analysis of variance (ANOVA) was performed to analyze the data by using SPSS software package. The significance of means was analyzed with the least significant differences (LSD) between treatment means at $P < 0.05$.

3. RESULTS AND DISCUSSION

Color, odor, pH, N%, P%, and K% of the NOLF were measured and the results are shown in Table 1.

Table 1 Characteristics of NOLF

Characteristic	Feature or value
Color	Vine red in color
Odor	Ripen wood apple odor
pH	4.4
N%	0.06
P%	1.1
K%	0.67

The color and odor of the NOLF were acceptable. The pH of the NOLF is acidic. pH of most liquid organic fertilizers ranges from 3 to 5 which is considered as a suitable pH for crop production (Saelee, 2004). The pH value of the NOLF was 4.4 which is within the range of above finding, pH = 3 – 5. According to the standards given for any liquid organic fertilizer by the Sri Lanka Standards Institute (SLSI), good quality liquid organic fertilizers should normally have a pH range from 6.0 - 8.5 (SLSI 2021). The pH value of NOLF is slightly acidic when compared with the SLSI standards. After 30 days of fermentation the NOLF had 0.06% total N, 1.1% total P and 0.67% total K. According to the standards given by the SLSI 2021, any liquid organic fertilizer should be consisted of 1.0 N (as N, percent by mass), 0.5 P (as P_2O_5 percent by mass), and 0.5 K (as K_2O_2 percent by mass). According to the present finding the amount of N present in the NOLF was relatively low (0.06%). The total amount of P was higher (1.1%) than standard amount given by the SLSI. The total K content was slightly higher than the recommended value of SLSI. According to Sureshkumar *et al.*, 2013, the presence of large population of phosphate dissolving microorganisms, results more mineralizing P. Denitrification can be the reason for low amount of N in the NOLF.

The effect of all six (06) treatments on the plant height (cm) of Chilli at the time of fruiting showed that the plants cultured under the treatment DOARF had the tallest mean plant height of 32.05cm which was significantly different ($P < 0.05$) from all other five treatments i.e. from T_1 to T_5. The chilli plants under the application of different formulas of NOLFs i.e. from T_1 to T_5 had the mean plant height of around 28cm. However, there was no significant difference between the mean plant heights among the treatments T_1 to T_5 (Table 2).

Table 2 Mean plant height (cm) of the Chilli plants under different treatment

Treatments	Mean Plant Height (cm)	SD	Std. Error
DOARF	32.05[a]	0.69	0.31
T_1 (1% NOLF)	28.42[c]	0.38	0.17
T_2 (2% NOLF)	28.29[c]	0.39	0.18
T_3 (3% NOLF)	28.95[c]	0.13	0.05
T_4 (4% NOLF)	28.43[c]	0.45	0.19
T_5 (5% NOLF)	28.31[c]	0.16	0.16

Note: Means in a column with the same letter/s are not significantly different at p = 0.05

When it comes to the mean number of branches/plant at the time of fruiting, the plants cultured under the treatment DOARF had the highest mean number of branches/plant, i.e. around 8 and significantly different ($P < 0.05$) from all other treatments from T_1 to T_5.

The chilli plants under the application of different formulas of NOLF had a mean number of 6 – 8 branches/plant which was closer to the mean number of branches/plant produced by the treatment DOARF. Treatment T_3 produced a mean number of 8 branches/plant which was significantly different from the mean number of branches/plant under the treatments T_1, T_2, T_4 and T_5 (Table 3).

Table 3 Mean number of branches/Chilli plant under different treatments.

Treatments	Mean number of branches/plant	SD	Std. Error
DOARF	8.20[a]	0.837	0.374
T_1 (1% NOLF)	7.10[b]	0.418	0.187
T_2 (2% NOLF)	6.80[b]	0.837	0.374
T_3 (3%NOLF)	8.40[a]	0.548	0.245
T_4 (4% NOLF)	6.90[b]	0.652	0.291
T_5 (5% NOLF)	7.10[b]	0.652	0.291

Note: Means in a column with the same letter/s are not significantly different at p = 0.05

At the time of the fruiting stage, the number of leaves/plants was counted manually. No significant difference of number of leaves/plant among the treatments DOARF, T_3, T_4 and T_5. However, the highest number of leaves/plant was recorded in treatment DOARF (40 leaves). The number of leaves/plants in treatment T_1 and T_2 were significantly different from all other treatments. However, the number of leaves/plants in each treatment was less (Table 4). The number of leaves in a plant is important for the photosynthesis of the plant. Increased number of leaves increases the leaf area of a plant which can contribute to a high yield.

Table 4 Mean number of leaves/plant under different treatments

Treatments	Mean number of leaves/plant	SD	Std. Error
DOARF	40.90[a]	3.5249	1.5764
T_1 (1% NOLF)	32.20[b]	1.9875	0.8888
T_2 (2% NOLF)	30.30[bc]	2.2528	1.0075
T_3 (3% NOLF)	38.30[a]	1.9875	0.8888
T_4 (4% NOLF)	36.90[a]	2.8592	1.2787
T_5 (5% NOLF)	33.40[a]	1.3874	0.6205

Note: Means in a column with the same letter/s are not significantly different at p = 0.05

The leaf area is also considered one of the growth parameters of this experiment. At the time of fruiting the length and width of randomly selected leaves were measured in cm using ruler to calculate the leaf area. The leaf area (cm^2) was determined by multiplying both length and width of the leaf. The mean leaf area of the plants cultured under different treatments showed significant differences ($P < 0.05$) except for the treatments T_1 and T_5. The highest mean leaf area was recorded in the plants treated with the DOARF (15.38 cm^2). Leaf area of a plant is important its photosynthesis rate and net assimilation and thus influencing the final yield. No significant difference on mean leaf areas of the plants cultured under T_1 and T_5 (Table 5).

Table 5 Mean leaf area of Chilli plant under different treatments

Treatments	Mean leaf area (cm^2)	SD	Std. Error
DOARF	15.38[a]	0.4302	0.1924
T_1 (1% NOLF)	10.30[e]	0.1914	0.0856
T_2 (2% NOLF)	11.99[cd]	0.2931	0.1311
T_3 (3% NOLF)	14.22[b]	0.1412	0.0631
T_4 (4% NOLF)	12.92[bc]	0.5589	0.2499
T_5 (5% NOLF)	10.76[e]	0.2728	0.1220

Note: Means in a column with the same letter/s are not significantly different at p = 0.05

Seventy (70) days after transplanting, the harvesting performed. The number of chilli fruits per plant was counted manually. The number of fruits per plant is the most important yield component of chilli. The mean number of fruits in the plants under different treatments were significantly ($P < 0.05$) different except the two treatments DOARF and T_3. The highest mean number of fruits per plant (19) was counted in chilli plants cultured under DOARF (table 6).

Table 6 Mean number of chilli fruits per plants under different treatments

Treatments	Mean number of fruits/plant	SD	Std. Error
DOARF	19.10[a]	1.4318	0.6403
T_1 (1% NOLF)	14.90[bc]	0.8216	0.3674
T_2 (2% NOLF)	12.70[cd]	1.5248	0.6819
T_3 (3% NOLF)	16.70[a]	1.2042	0.5385
T_4 (4% NOLF)	13.50[bd]	1.7321	0.7746
T_5 (5% NOLF)	11.60[d]	0.8216	0.3674

Note: Means in a column with the same letter/s are not significantly different at p = 0.05

4. CONCLUSIONS AND RECOMMENDATIONS

This research revealed that the Department of Agriculture recommended inorganic fertilizer is effective for the growth and yield of Chilli compared to the newly produced organic liquid fertilizer. The colour, odor, and the pH value of the newly produced organic liquid fertilizer are acceptable. The P% of newly produced organic liquid fertilizer is higher than the expected value of SLSI and the K% is similar to the expected value of SLSI. The N % of the newly produced organic liquid fertilizer is lower than the expected value of SLSI. This could be the reason for less effectiveness of newly produced organic liquid fertilizer.

Further research is recommended to improve the N% of the newly produced organic liquid fertilizer and adjust the pH value to achieve similar performance as inorganic fertilizer.

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Strength Improvement of Cement – stabilized Soil using Natural Rubber Latex for pavement base applications

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Abstract *Cement-stabilized soil, especially those with high fine contents, often exhibits brittle behavior under both flexural and compressive stress, which leads to macrocracks and microcracks in road structure and pavement. Moreover, the properties also may not be sufficient to meet the local authority specifications. Hence, in this work, Natural Rubber Latex is used in conjunction with cement to improve the properties of lateritic soil to be used in road subgrade. The samples were prepared by varying percentages of cement (5%, 10%, 15%, and 20%) by weight of soil and NRL replacement ratios (5%, 10%, 15%, and 20%) by weight of the soil. The test programme included sieve analysis, California bearing ratio (CBR) (soaked), Proctor compaction test (modified), and Atterberg Limits tests to assess the suitability of the virgin gravelly soil and the blended samples. The results showed that increase in the cement and NRL percentages up to 15% improved the CBR value (after four days of soaking) but decreased thereafter. The optimum moisture content (OMC) decreased continuously until 15% replacement of NRL and thereafter a very slight increase was observable. A similar trend was observable in the maximum dry density (MDD) as well, where it increased up to 15% and then decreased thereafter. Blended soil samples achieved CBR values of 14%, 28%, 38%, and 31%, with 5%, 10%, 15%, and 20%of cement and NRL replacements respectively, meeting the CIDA requirements. Findings suggest using an optimum proportion of 15% cement and 15% NRL mixture for optimal results in compliance with the CIDA specifications for roads in Sri Lanka.*

Keywords: *Natural rubber latex (NRL), California bearing ratio (CBR) test (Soaked), optimum moisture content (OMC), maximum dry density (MDD), Proctor compaction test (Modified), subgrade*

2 INTRODUCTION

A pavement structure is generally composed of base and subbase layers, which play an important role in the bearing capacity and serviceability of a road. This pavement structure requires high-quality soil as a construction material. Nevertheless, natural soils typically demonstrate undesirable physical and engineering characteristics, that frequently make them undesirable for road construction (Buritatun et al., 2020).

Lateritic soil is a common pavement material in the tropical region, especially in Southeast Asia. However, the virgin lateritic soil in its original state, might not meet the necessary pavement specifications to be used as a subgrade due to it's poor bearing capacity (Emmanuel et al., 2021). Hence soil stabilization technique is usually employed to enhance the properties of the natural soil, encompassing both its physical attributes and strength. This approach yields significant engineering and economic advantages. Soil stabilization is mainly used in road construction to avoid the need to remove the existing soil and replace it with new soil possessing the required properties (Firat, et al., 2020). Therefore, the objective of soil stabilization is to enhance existing soil resilience, durability, and strength (Glossop, 1968; Sabat 2012).

Conventional additives include lime, fly ash, and cement. Broadly, substantial research has been conducted on the efficacy and reliable performance of these conventional materials, as well as waste materials (palm oil fuel ash, quarry dust, waste crumb tyre, cement kiln dust, etc.,) often exploring their interaction behaviors (Arinzie et al., 2018, Firat et al., 2017, Mahmood et al., 2020, Tingle et al., 2007, Mahdi et al., 2018). The utilization of Portland cement as a stabilizer is preferred to other additives in Southeast Asia due to its cost-effectiveness and the rapid enhancement of mechanical properties, including the bearing capacity, stiffness, and strength of the soil. This approach has been extensively applied in various countries as a solution to address the scarcity of high-quality materials (Horpilbulsuk et al., 2006, Zhang and Tao, 2008). Nevertheless, the cement-stabilized soil, especially with high fine contents, exhibits brittle behavior and extremely low flexibility, which causes macro and micro-cracks when subjected to static and repeated loads (Jamsawang et al., 2015). Therefore, several studies have been conducted, with the addition of different admixtures on soil stabilized with cement and as such there has been research conducted to appraise the improvement of compacted soil cement using different rubber alternatives. The listed below are the most novel and innovative studies of rubber alternatives to enhance the properties of cement-stabilized soil.

Meghana and Veerendra (2022) investigated the potential of using styrene butadiene rubber (SBR), a synthetic rubber, as a stabilizer to enhance the characteristics of expansive clay subgrade. Researchers conducted the Standard Proctor Compaction Test and California Bearing Ratio Test on soil samples mixed with different percentages of SBR. The findings indicated that the addition of SBR up to 12% resulted in favourable outcomes. The Optimum Moisture Content (OMC) of soil decreased while the Maximum Dry Density (MDD) increased, suggesting improved stability. Compared to untreated soil, the use of SBR significantly enhanced the California Bearing Ratio (CBR) values. At 2.5mm penetration, the CBR values increased by 6.5 times, 7.2 times, 8.0 times, and 9.18 times for soil stabilized with 3%, 6%, 9%, and 12% SBR, respectively. These findings indicate that SBR can effectively serve as a stabilizer for enhancing the properties of expansive clay subgrade.

Juliana, et al., (2020) evaluated the effectiveness of using crumb rubber for stabilizing subgrade soil. Crumb rubber, known for its lightweight and strong shear strength, was investigated as a solution for reducing pollution and improper tyre disposal. The study involved altering subgrade soil with varying percentages (2%, 4%, 6%, and 8%) of crumb rubber. CBR tests were conducted on unsoaked and soaked soil mixtures from a landslide area in Malaysia. All mixtures met the subgrade requirements set by the Public Construction Department Malaysia (JKR) for road construction, with the 4% crumb rubber mixture showing the highest CBR values. The presence of crumb rubber improved the subgrade soil's CBR values, with the 4% mixture proving the most effective. Thus, the study recommends using 4% crumb rubber for subgrade soil stabilization.

Kererat, et al., (2022) investigated the potential use of a novel road base material composed of bottom ash blended with Portland cement and para-rubber latex. Various mixtures were tested, and the findings revealed that the optimal ratios of bottom ash to Ordinary Portland Cement were 95:5% and 93:7%, each with 6% para rubber latex content. These mixtures exhibited excellent performance in terms of unconfined compressive strength, skid resistance, and wet/dry durability. Compaction tests highlighted that 6% and 8% para rubber latex content yielded the best maximum dry density results. The study also indicated that fine bottom ash outperformed its coarse counterpart in terms of strength. Moisture presence decreased the unconfined specimen strength as anticipated. Most importantly, these mixtures satisfied the requirements for both light and heavy traffic scenarios, showcasing the potential for substituting traditional road-based materials with this innovative combination.

A study carried out by Buritatun, et al., (2020) to enhance the mechanical strength of cement-stabilized soil using NRL for pavement base by replacing varying percentages of cement with NRL. The optimum NRL replacement ratios providing the optimum unconfined compressive strength (UCS) and Flexural strength (FS) were found at 20%, 15%, and 10% for 3%, 5%, and 7% cement contents, respectively. At the optimum NRL replacement ratio, the UCS was improved up to 30%, 21%, and 18% for 3%, 5%, and 7% cement contents while, FS was improved up to 78%, 40%, and 29% for 3%, 5%, and 7% cement contents. However, excessive NRL replacement hindered compactability and delayed cement hydration, leading to diminished strength. This research suggests that NRL could serve as a sustainable alternative to synthetic latexes for boosting the mechanical strength of soil-cement mixes, particularly for pavement-based applications. They also reported that NRL as an additive could improve the compressive and flexural strengths, cracking problems, and premature pavement distress, due to the cyclic wet and dry seasons of cement-stabilized pavement base material.

As can be seen from the results of previous research findings, NRL is a viable substitute for cement-stabilized soils for improving its properties. Hence, it is worthwhile to investigate the applicability of NRL to cement-stabilized lateritic soil subbases. NRL is a biopolymer from the Hevea brasiliensis tree. The raw state of NRL consists of polymer content (cis-1,4- polyisoprene) and water. The solid polymer content consists of approximately 94% rubber hydrocarbon and 6% non-rubber substances, such as phospholipids, and protein (Buritatum, 2020). Natural rubber is obtained by tapping the tree's bark; the rubber latex is found inside cells that are created by plant metabolic processes. The milky-looking, viscous liquid that drips from the tree is actually a colloidal dispersion of polyisoprene molecules in water.

To the best of the authors' knowledge, there has been no research undertaken to date on the usage of NRL in pavement geotechnics to assess the NRL enhancement applicability to the laterite soil of Sri Lanka and the compliance of the local authority guidelines (CIDA, 2007). The outcome of this research will result in the promotion of NRL utilization as a sustainable additive in cement-stabilized pavement base/subbase courses for Sri Lankan lateritic soils. In this study, lateritic soil was mixed with NRL and cement to assess whether the properties of the subgrade soil could be improved. It is also to note that NRL utilization in soil stabilization does not cause negative environmental impacts because NRL is a plant-based product, devoid of chemical hazards and petroleum components. A series of laboratory tests were carried out on gravelly soils blended with cement and NRL to evaluate the MDD, OMC (NRL and water), Atterberg limits, and CBR to assess whether NRL in conjunction with cement stabilization for lateritic soils of Sri Lanka would comply with the Institute for Construction Industry Development Authority (CIDA, 2007) guidelines.

2 CIDA (2007) SPECIFICATIONS

The following road construction specifications have been outlined by the CIDA. These specifications ensure the quality and performance of the constructed road.

Table 1 CIDA specifications ensure the quality and performance of the constructed road (2007)

Property	Requirement	Standard
CBR Value (four days soaked)	> 15%	BS1377 Part 4
Liquid Limit	< 50%	BS 1377 Part 2 - 1990
Plastic Index	< 25%	BS 1377 Part 2 - 1990
Optimum Moisture Content (OMC)	10% to 20%	BS 1377 Test 13
Maximum Dry Density (MDD)	> 1.65g/cm^3	BS 1377 Test 13
Gradation Requirements	Upper and Lower limit of gradation curves are given in Fig. 1.	BS1377: 1990, Part 2

These specifications collectively ensure the appropriate composition, strength, and performance of the road construction project.

3 MATERIALS AND METHODOLOGY

3.1 Materials

Soil samples

The materials used in this research were lateritic soil, Natural Rubber Latex, and Ordinary Portland Cement. A lateritic soil sample was collected from Ambanpola, Sri Lanka (7°54'56.8"N, 80°14'31.7"E).

Natural Rubber Latex

NRL was obtained from the Rubber Research Institute – Polgahawela (Polgahawela Substation). Table 2 depicts the properties of NRL.

Insee Sanstha Portland Composite Cement (SLS 1697:2021) with strength class 12.5 N/R which is commonly used in the stabilization of pavement materials, was selected to stabilize the soil. Table 3 depicts the physical and chemical properties of Portland Composite cement.

Table 2 Properties of Natural Rubber Latex (Dananjaya et al., 2022).

Properties	Value
Sludge content (%wt.)	2.46
Coagulum content (%wt.)	0.024
Specific gravity (Gs)	0.96
pH	8
MST value (seconds)	800
Alkalinity % (w/w)	0.7
VFA number	0.1
Proteinaceous substances %	1.2
KOH number	0.70
Mechanical stability, min, seconds	650

Table 3 Physical & Chemical Properties of Insee Sanstha Portland Composite Cement

Property	SLS 1697:2021 Requirement	Insee Sanstha Portland Composite Cement Average
	PHYSICAL PROPERTIES	
Compressive Strength (2 days)	≥ 10 N/mm^2	≥ 20 N/mm^2
Compressive Strength (28 days)	42.5 - 62.5 N/mm^2	> 52 N/mm^2
Initial Setting Time	≥ 60 minutes	130 - 150 minutes
Fineness	Not Specified in Standard	400 - 420 m^2/kg
Soundness	< 10 mm	< 1 mm
Relative Density	Not Specified in Standard	2.96
	CHEMICAL PROPERTIES	
SO_3	≤ 3.0 %	< 2.8 %
Chloride	≤ 0.1 %	< 0.05 %
LOI	Not Specified in Standard	< 3.0 %

3.2 Sample Preparation

Cement and rubber latex were mixed with lateritic soil in the following proportions in weight percentages as depicted in Table 2.

Table 4 Mix proportions of lateritic soil, cement, and natural rubber latex

Lateritic soil %	Cement %	NRL %
100	0	0
90	5	5
80	10	10
70	15	15
60	20	20

3.3 Experimental Procedure

Sieve Analysis test (BS1377: 1990, Part 2), California bearing ratio (CBR) test (Soaked) (BS 1377 Part 4), Proctor compaction test (Modified) (BS 1377 Test 13), Atterberg Limits test (BS 1377 Part 2 - 1990) were conducted according to the standard specifications to evaluate the suitability of the virgin material and blended sample. The results obtained were compared with those of CIDA guidelines to see whether they comply with the local road authority guidelines applicable to rural roads of Sri Lanka.

4 RESULTS AND DISCUSSION

4.1 Results of Virgin Gravel Soil

The Sieve Analysis test, California bearing ratio (CBR) test (four-day Soaked), Proctor compaction test (Modified), and Atterberg Limit tests were carried out on the virgin sample. The grain size distribution is depicted in Fig. 1. According to the Unified Soil Classification system, soil was categorized as Silty gravel (GM). Lower and Upper limits of curves specified in CIDA guidelines are depicted in Fig. 1.

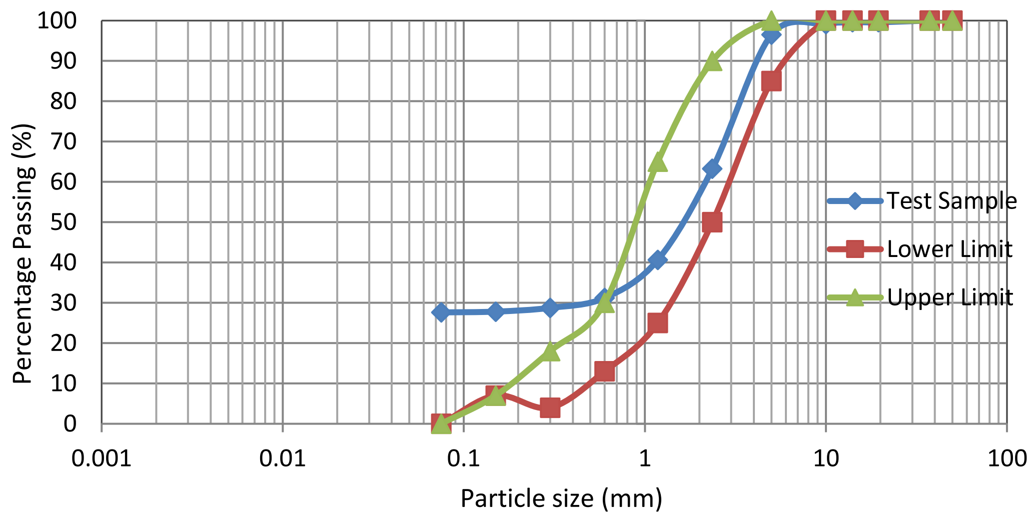

Fig. 1. Particle Size Distribution curve of lateritic soil

Figure 2 shows the Atterberg Limits Test graph of the initial lateritic soil sample. Accordingly, the Liquid limit (LL) for virgin sample is 53.9 %.

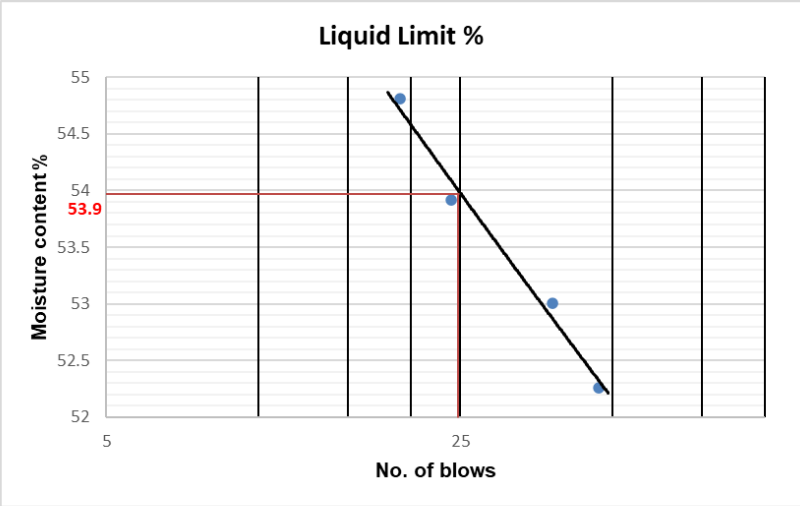

Fig. 2. Liquid Limit Test curve of lateritic soil sample

Fig. 3 shows the Modified Proctor Compaction test. Accordingly, the maximum dry density and optimum moisture content for the virgin lateritic soil sample is 1.72 g/cm^3 and 18.10 %.

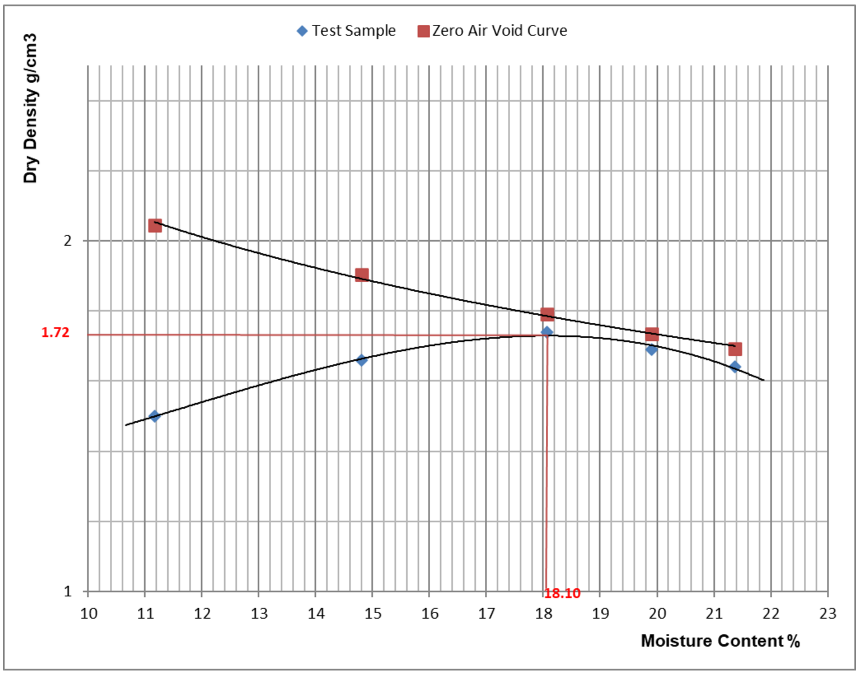

Fig. 3. Variation of Dry Density with moisture content of virgin lateritic soil

Fig. 4 shows the variation of Load against the Penetration of the CBR test for the virgin lateritic soil.

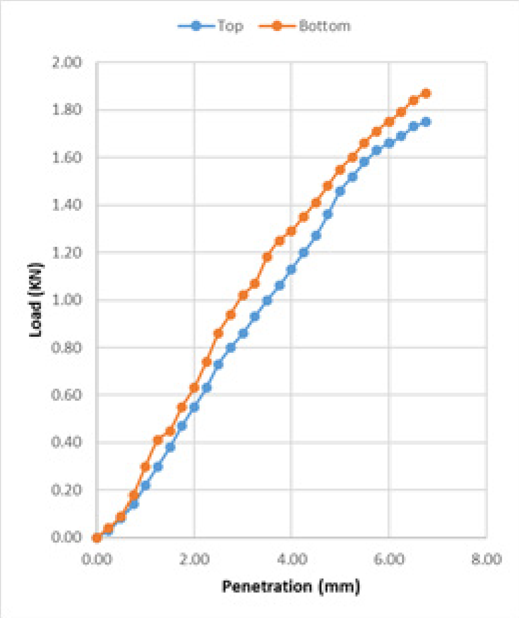

Fig. 4. Variation of Load (kN) with Penetration (mm) of CBR test for the virgin lateritic soil sample

The basic and engineering properties of virgin soil are summarized in Table 5 and were compared with the CIDA (2007) for base and subbase materials. According to the standard of CIDA (2007) the virgin lateritic soil did not meet the minimum requirements of Liquid limit and CBR as can be seen from Table 5.

Table 5 Summary of the test results of virgin gravel soil sample

PARAMETERS	CIDA REQUIREMENTS	RESULTS	ACCEPTABILITY
Liquid limit (LL)	<50%	53.9 %	Not Accepted
Plasticity index (PI)	< 25%	16 %	Satisfied
Laboratory M.D.D of soil	>1.69g/cm^3	1.72 g/cm^3	Satisfied
Laboratory O.M.C of soil	10 – 20 %	18.10 %	Satisfied
CBR (Four Days Soaked)	> 15%	8 %	Not Accepted
Soil description	Silty gravel (GM)		

4.2 Blended Soil Sample

4.2.1 Compaction Characteristics

Figure 5 illustrates the variation of OMC with that of cement and NRL percentages. According to Figure 5, when increasing the cement and NRL %, OMC decreases up to 13.5% and thereafter a very slight increase is observable. The reduction of moisture content is due to the fact that Natural Rubber Latex (NRL) increases soil cohesion and necessitates less water for maximum compaction (Meghana and Raja, 2022). NRL composition is as per the Table 2.

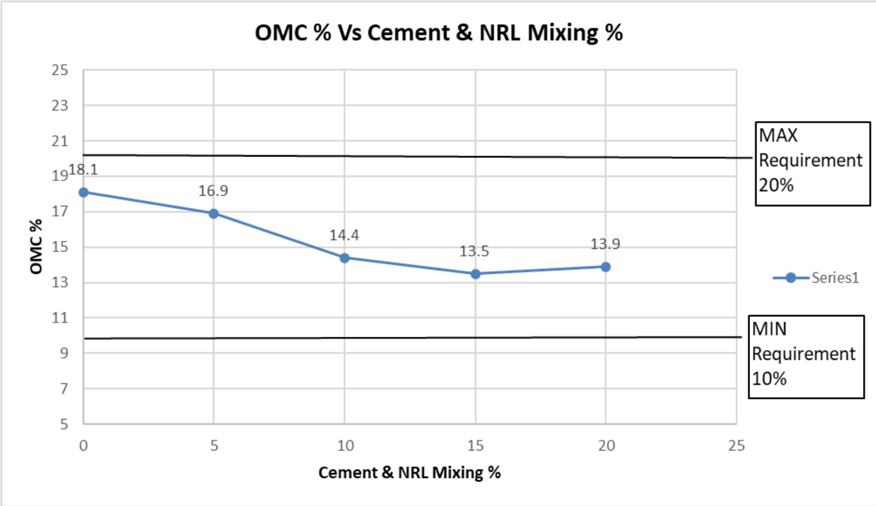

Fig. 5. Variation of OMC with cement and NRL mixing percentages

Figure 6 illustrates the variation of MDD with that of cement and NRL mixing percentages. According to Figure 6, when increasing the cement and NRL %, MDD increases up to 15% and decreases thereafter.

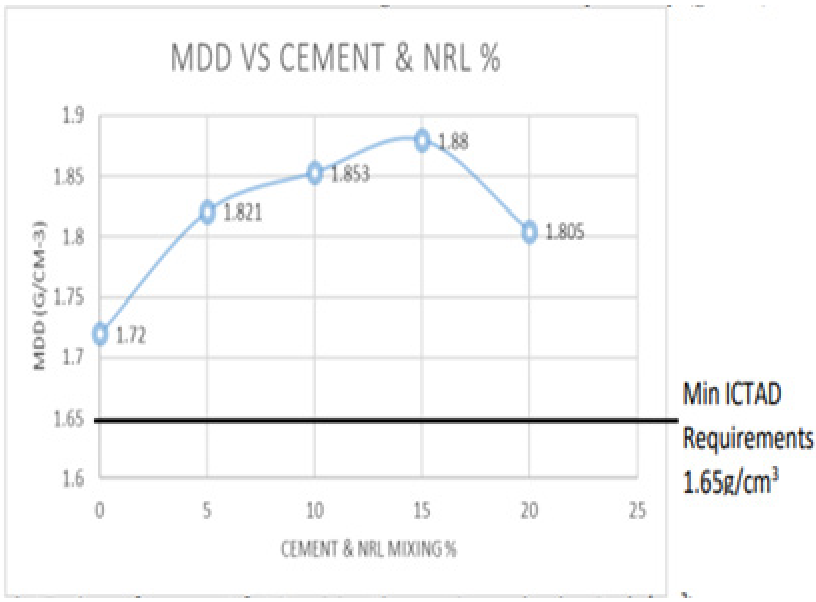

Fig. 6. Variation of MDD with cement and NRL mixing %

According to the test values, the virgin lateritic soil sample produced an MDD value of 1.72 g/cm³ at OMC of 17.60%. When increasing the cement and NRL mixing percentage, OMC decreases. The OMC of lateritic soil is lowered by adding more cement and NRL, as these additives increase soil cohesion and density and necessitate less water for maximum compaction. The OMC is lowered by this densification procedure (Meghana and Raja, 2022). When increasing the cement and NRL mixing percentage, maximum dry density (MDD) increases up to 15% and decreases thereafter. The initial increase in MDD is due to the addition of cement and NRL to gravel soil, which enhances the cohesion and strength of the soil, resulting in a denser and more compacted soil structure. This increased cohesion and density lead to a higher MDD as the soil particles are packed more closely, reducing the air voids. However, an increase in the percentage of cement and NRL beyond the optimal point, cause an excess of these binding agents. This excess can hinder the compaction process, making it more difficult to achieve the same level of compaction compared to the optimal mixture. In addition, excessive cement content can lead to the formation of clumps or agglomerations in the soil, reducing its workability and causing a decrease in MDD (Meghana and Raja, 2022). According to the CIDA requirement, the MDD is 1.65g/cm^3 and OMC should lie between 10% – 20%. The obtained MDD values are 1.821g/cm^3, 1.853g/cm^3, 1.880g/cm^3, and 1.805g/cm^3 and OMC values are 16.9%, 14.4%, 13.5%, and 13.9% for blended soil samples. Hence all the blended samples comply with the requirements specified by CIDA.

4.2.2 CBR Test Results

The CBR test was conducted to determine the bearing value and, thus to evaluate the strength of road subgrade and subbase for pavement thickness design. In this study, CBR tests of four-day soaked have been conducted. The penetration test was carried out at the top and bottom parts of the CBR samples. Figure 7 illustrates the variation of CBR value with that of cement and NRL mixing percentages. According to the test values, the virgin lateritic soil sample CBR (four-day soaked) value is 8%. It is observable that when increasing the cement and NRL %, the CBR value (four days soaked) increases up to 38% and decreases thereafter.

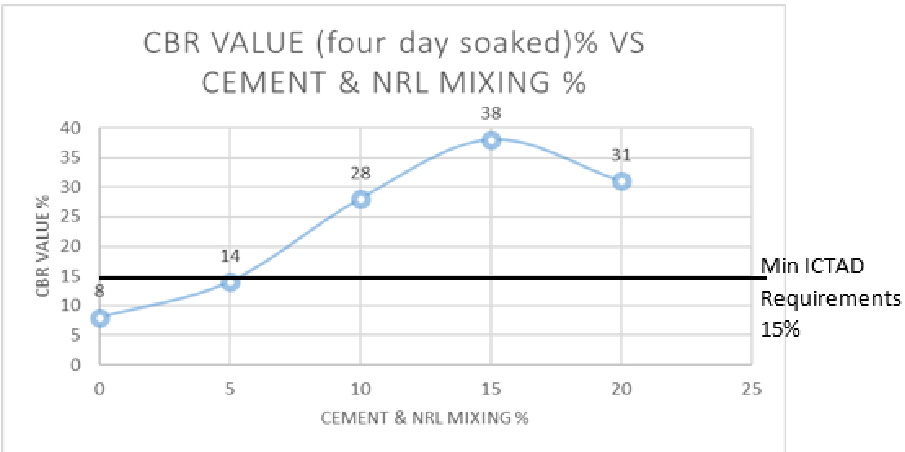

Fig. 7. Variation of CBR value (four-day soaked) with cement and NRL mixing %

The reason for this variation can be explained as follows. The initial increase in CBR value is because when cement and NRL are added to lateritic soil, these enhance the cohesion and strength of the soil, resulting in better compaction and increased CBR values. The binding agents improve the load-bearing capacity and resistance against deformation. Therefore, the initial increase in CBR value is possible. The cause of the decrease in CBR value, beyond the optimal point, would be an excessive amount of cement and NRL leading to problems such as clumping, reduced workability, and decreased compaction efficiency (Juliana et al., 2020). These issues can diminish the load-bearing capacity of soil, causing a decline in the CBR value. According to the CIDA requirement, CBR (four-day soaked) should not be less than 15%. Attained CBR (four-day soaked) values are 14%, 28%, 38%, and 31% for blended soil samples. Hence, a CBR value of 14% (which is less than 15%) does not fulfill the ICTAD requirements. However, the 10%, 15%, and 20% samples did comply with the CBR requirement.

4.2.3 Atterberg Limit Test Results

Figure 8 illustrates the variation of Atterberg limits with cement and NRL mixing percentages. The liquid limit, plastic limit, and plasticity index for the virgin gravel soil sample were 53.9%, 37.6%, and 16.4% respectively. When increasing cement and NRL mixing percentages (5%, 10%, 15%, 20%) it was observed a decline in the liquid limit, plastic limit, and plastic index. Increasing the cement and NRL content in lateritic soil can decrease liquid limit, plasticity limit, and plasticity index due to reduced water absorption and increased binding, resulting in a stiffer and less plastic material although cohesion increases with the additives (Hoy et al., 2023).

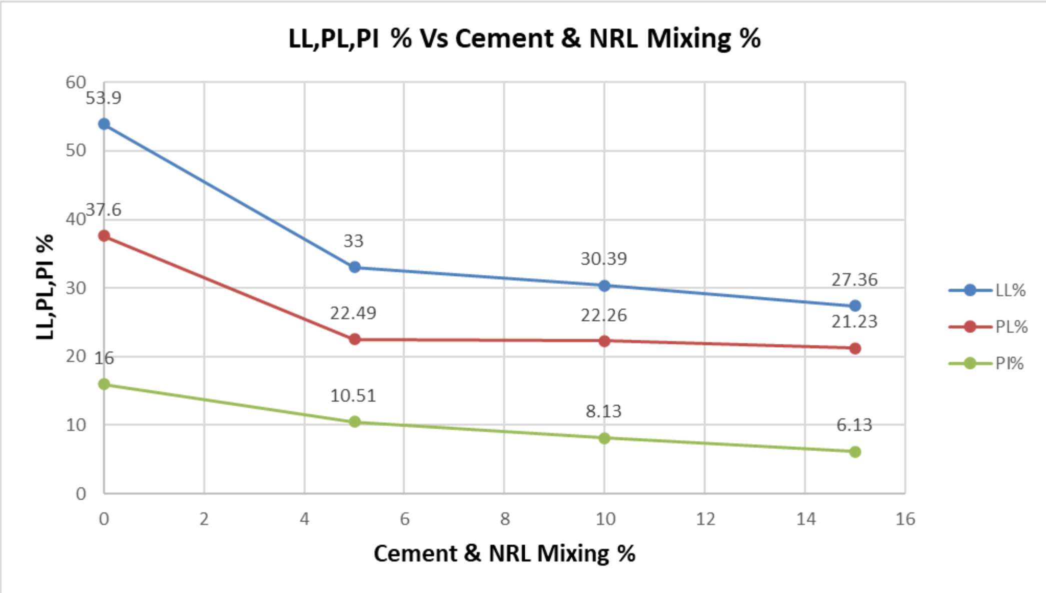

Fig. 8. Variation of Liquid limit, Plasticity Limit & Plasticity Index with cement and NRL mixing %

The summary of test results of the Atterberg limits test, California bearing ratio (CBR) test (four-day Soaked), and Proctor compaction test (Modified) of blended samples are given in Table 6.

Table 6 - Summary of the laboratory test results for the blended soil sample

PROPERTY	RESULTS				
	PROCTOR COMPACTION TEST (MODIFIED)		CALIFORNIA BEARING RATIO (FOUR-DAY SOAKED)	ATTERBERG LIMIT TEST RESULTS	
	M.D.D (g/cm³)	O.M.C	CBR Value (FOUR DAY SOAKED)	LIQUID LIMIT %	PLASTICITY INDEX %
ICTAD requirements	>1.65g/cm3	10 – 20 %	> 15%	< 50%	< 25%
5% C & NRL	1.821 (satisfied)	16.9% (satisfied)	14% (Not satisfied)	33% (satisfied)	10.51% (satisfied)
10% C & NRL	1.853 (satisfied)	14.4% (satisfied)	28% (satisfied)	30.39% (satisfied)	8.13% (satisfied)
15% C & NRL	1.880 (satisfied)	13.5% (satisfied)	38% (satisfied)	27.36% (satisfied)	6.13% (satisfied)
20% C & NRL	1.805 (satisfied)	13.9% (satisfied)	31% (satisfied)	————	————

5 CONCLUSIONS AND RECOMMENDATIONS

This study assessed whether cement and NRL are viable admixtures for the stabilization of gravelly soil to be used in subgrade and sub-base. The results indicate that with increasing the cement and NRL mixing percentage, CBR value (four days soaked) increases up to 15% and decreases afterwards, and with increasing the cement and NRL mixing percentage, the optimum moisture content (OMC) decreases, and maximum dry density (MDD) increases up to 15% and decreases thereafter. The CBR (four-day soaked) values are 14%, 28%, 38%, and 31% for blended soil samples. However, the CBR value of 14% does not fulfill the CIDA requirements. The Atterberg limits of all the blended samples did comply with the CIDA specifications. It can be seen from Table 6, that the percentages of 10% cement and NRL as well as the percentages of 15% cement and NRL do comply with the standards stipulated in the CIDA guidelines. According to Sani et al., (2019), most importantly, the soil subgrade should have sufficient strength to support the structure that is constructed over it. The strength of the soil to be used as subgrade for road pavement is assessed in terms of CBR value. Hence, from these two percentages, 15% cement and NRL can be recommended based on the higher dry density and CBR values compared to the 10% cement and NRL mixing. However, 10% also is a viable option considering the plasticity as lower plasticity hinders better compaction. Therefore, from the results so obtained, it can be recommended an optimum percentage of 15% cement and NRL for the improvement of lateritic soils to be used as subgrades of Sri Lankan roads. The outcome of this research will promote the usage of NRL and cement as sustainable stabilizing agents for improving the properties of lateritic soils for pavement bases and subbases.

6 ACKNOWLEDGMENT

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Improving Crash Worthiness of a Three Wheeler, by Means of a Mid Crumple Zone.

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Abstract *– Three wheelers have become popular in many developing countries due to lower cost and comparatively high fuel economy. However, due to its poor structural design, alarmed the necessity to improve the safety of three wheelers in many fora. This paper discusses an attempt to incorporate a central-crumple zone to its mid-section using a crush tube to the three wheeler without changing its basic structure. The main structure was modified to accommodate two central crush tubes along the length of its mid-section in an impact. To assess the behaviour of passengers during a collision, human crash dummy models were created based on the dimensions and mass specifications of a 50th Male Hybrid III Anthropometric Test Device. The test was carried out as per the test standard of the New Car Assessment programme criteria for Quadricycles. The analysis revealed severe plastic deformation of the conical Square-type crush tubes that were introduced at the mid-section in an impact. , A 47.2 % reduction of G force for driver and 33% reduction of G force for passengers has been achieved, This indicates that a considerable amount of crash energy has been absorbed by the crush tube during the collision.*

Keywords: passenger safety, crush tubes, Automotive Engineering, Crash Worthiness, Transportation

1. INTRODUCTION

The need to enhance the Safety of three wheelers has been emphasised repeatedly by WHO 2018 due to its poor structural design, which poses hazards in accidents. Three wheelers have become popular in many developing countries due to comparatively low initial investments, operational cost, and high fuel economy (Kumarage et.a. 2010).

In contrast to conventional engineering structural design, where the ability of the structure to withstand service loads without yielding or collapsing is considered, the safety criterion of the three wheeler was seemingly ignored at its design stage. Automotive structures are required to be able to plastically deform and absorb energy in a short period during which crash energy is dissipated in a controllable manner during a crash while safeguarding the passengers.

Previous researchers analysed the deformation of a conventional three wheeler in a head-on collision. The solution for head on collision against a rigid barrier at 50 km/h revealed a severe plastic deformation in the front face and mid-structure Jurangpathy & Perera (2023). Among many road accidents, one of the serious accidents is shown in Fig. 1, where a three wheeler crashed into a truck that was stationary at the time of collision, killing two passengers and injuring three other passengers as a result of impact. www.dhakatribune.com.

Fig.1. Head-on collision of a conventional three wheeler against a rigid barrier (Numan 2022).

From Numan (2022), and many similar cases, it is evident that current three wheelers lack crash safety. The main reason for fatal injuries during a head-on collision of a three wheeler is due to deficiencies of basic structural features such as lack of a crumple zone, rigid passenger compartment, and restrain systems Jurangpathy & Perera (2023). However, it is practically impossible to incorporate a crumple zone into the front section of a three wheeler due to the limited space surrounding the front wheel and its body shape. Taking into consideration many factors, previous researchers [Jurangpathy & Perera (2023)] have highlighted the necessity to improve the structural crashworthiness of three wheelers taking into consideration the intrusion of the front face and plastic deformation of the mid-section.

The objective of the current study is to enhance the structural crash-worthiness of conventional three wheelers by incorporating a crumple zone that could absorb crash energy during a collision, thus protecting the passenger shell ensuring passenger's safety.

2. METHODOLOGY

In this study, an attempt was made to incorporate a central crumple zone by means of a crush tube while keeping the rest of the design as per the analysis carried out by Jurangpathy & Perera (2023). In the design of crumple zones, there are two primary means of absorbing energy, which is also known as collapse modes where the components absorb energy through controlled deformations in two collapse modes. They are;

- Axial mode of collapse
- Bending mode of collapse

Each mode utilises thin wall sheet metal beam-type structures. Real-world accidents are unpredictable, and it is very rare to obtain a purely single mode of collapse in crumple zone structures, thus mixed modes of collapse are often used.

However, in a well-designed and executed energy-absorbing structure, the mixed modes are avoided to ensure predictable performance during crashes Bois, P. D. et al (2004). 2008). For this solution model, an axial mode of collapse-type crumple zone was selected owing to higher energy absorption capacity.

Crush tubes are a common feature in vehicles and absorb energy via axial mode of collapse. It is unique under axial collapse that it produces a unique folding pattern with a degree of regularity which, depends on the structural member's size-to-thickness ratio, geometric stiffness, and shape. An ideal centralized crush tube should be able to handle loads under normal running conditions and collapse only in the event of a frontal collision. The design of crush tubes relies on empirical formulae following the notable works of Wierzbicki & Abramowicz (1983) and Mahmood & Paluszny (1981). The collapse strength of a given section is related to its ratio of width over thickness (t/b) and material properties.

To ensure the stability of the collapse of crush tubes, they should be; considered as a 'compact section' of geometrical cross section with most stability under varying angles of loading.

Compact sections are of t/b ratio exceeding its threshold value where the elastic buckling strength exceeds the material yield strength thus the material strength properties are expected to govern the mode of collapse (Wierzbicki & Abramowicz 1983 and Mahmood & Paluszny 1981). Following the work of Witteman, (1999), who analyzed the stability of crush tube columns of varying cross-sections under the axial collapse of varying degrees, it was found that the most stable geometry is a rectangle in a lying position followed by a square cross-section. When selecting a suitable crush tube it was kept in mind that it should be easily integrated into the base structure without significant changes in cross-section.

In addition, it is essential to include in this design a trigger in the crush tube to initiate the collapse as well as to ensure a stable force level over the entire length. By applying a specific weakness at the right position at the front end of the beam, a stable regular folding process will initiate at that point with a lower initial peak force level to introduce the first fold.

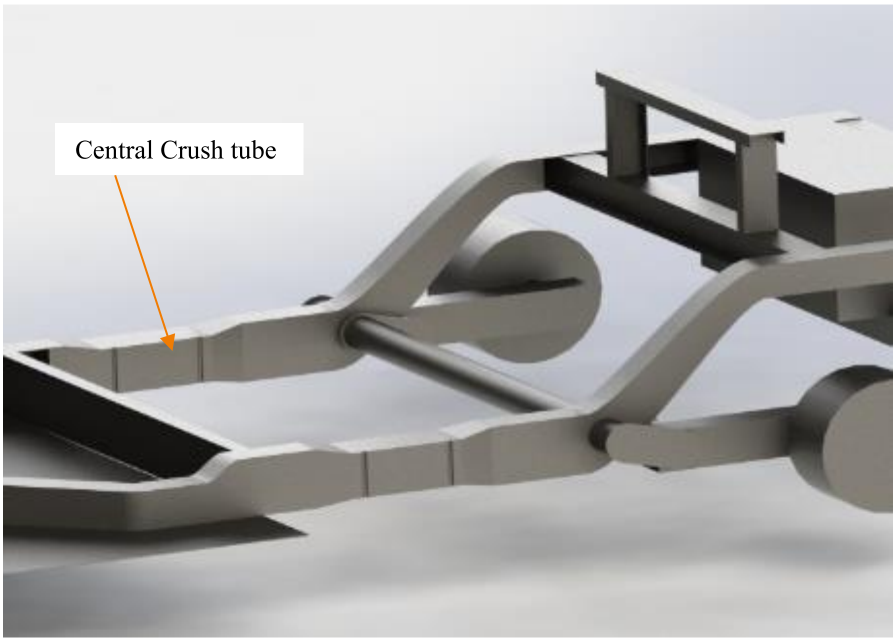

Fig.2. Structure incorporating the mid crumple zone

A new passenger shell was designed that incorporated a roof structure with an "A" pillar that will connect to the front face of the three wheeler and its base structure as seen in Fig. 4. Its seating space was modified to be more ergonomic and the floor space was adjusted allowing space for the crush tubes to collapse safely without affecting the passenger space during a severe crash. The main structure was modified to accommodate two central crush tubes along the length of its mid-section as shown in Fig.2 and Fig.3.

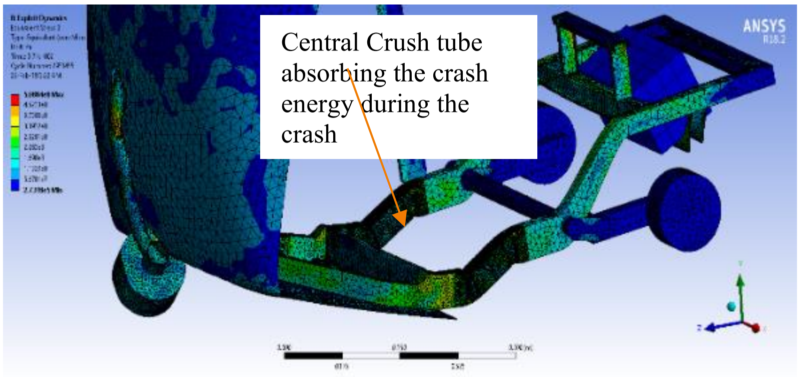

Fig. 3. Deformation of the crumple zone during a collision.

The simulation model was created using SolidWorks Software and was solved by exporting the model to ANSYS Software. ANSYS Explicit STR was selected for the analysis utilizing a medium mesh with a total of 215,526 elements.

The Von Mises criteria was used as the failure criterion. Simulation was carried out when the three wheeler hit a rigid barrier at 50 km/h velocity. Full Width Frontal Impact Testing Protocol for Quadri cycles (safety of quadricycles). The barrier, as per the standards was 3 m wide and 1.5 m tall. It was modelled as a rigid object along with a floor to support the motion of the Three Wheeler.

A block mass to represent the engine and transmission and human crash dummy models to represent the driver and passengers were placed in appropriate locations. The barrier, as per the Euro New Car Assessment Programme (NCAP) standard (safety of quadricycles), was 3 m wide and 1.5 m tall. It was modelled as a rigid object along with a floor to support the motion of the three wheeler. The test setup is shown in Fig. 4.

Fig. 4. Final Setup of the proposed design with Occupants

As per the requirements extracted from the NCAP Safety of Quadricycles, the analysis was carried out mainly on the following aspects.

1. Full-width frontal Impact Collision with Occupants without the restrain system for the solution model

2. Full-width Frontal Impact Collision with seat belt with occupants with the restrain system for the solution model

All impact tests were carried out at an initial velocity of 50 km/h and the variation of velocity after the crash with time was measured. The human crash dummy model created was based on dimensions and mass specifications of a 50th Male Hybrid III Anthropometric Test Device Safety of Quadricycles. The CAD model of the crash test dummy is shown in Fig. 5.

Fig. 5. Custom Human Hybrid III 50th Male Model

The material assigned was a modified Steel 1006 which brought the total mass of the dummy to 88kg. The final setup of a typical crash test dummy is illustrated in Fig. 5.

3 RESULTS AND DISCUSSION

Significant plastic deformation was observed on the front face (notably at the 'A-Pillars' which are connected to the roof structure) and the steering column as observed in the original design of the conventional three wheeler 2)Jurangpathy & Perera (2023). However, it was interesting to observe that the Conical Square-type crush tubes underwent collapse as well with severe plastic deformation. This is illustrated in Fig. 7.

The conventional three wheeler does not have a rigid structure to form a passenger shell, and expectedly, a severe deformation to the structure of the conventional three wheeler as shown in Fig.6 has occurred. The proposed design has been able to keep the passenger compartment intact however, a moderate intrusion to the driver compartment can be seen. the FEM model of the proposed design shows a severe plastic deformation at the crush tube location compared to the same area of the conventional three wheeler analyzed by Jurangpathy & Perera (2023).

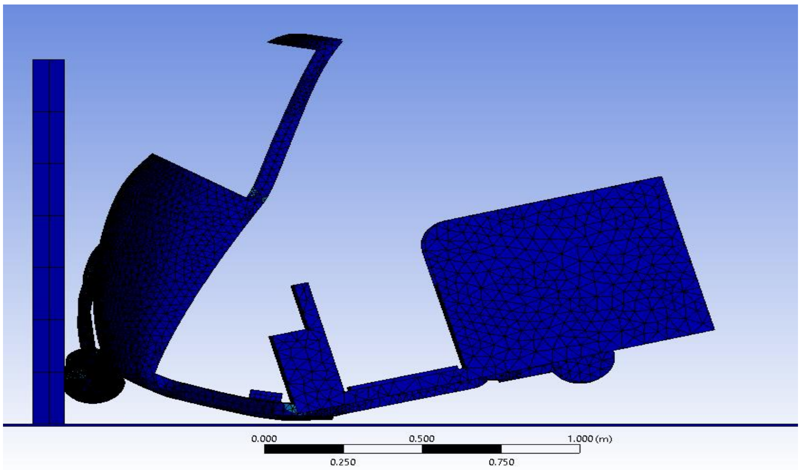

Fig. 6. Conventional three wheeler at Full Width Frontal Impact Test (from Jurangpathy & Perera 2023)

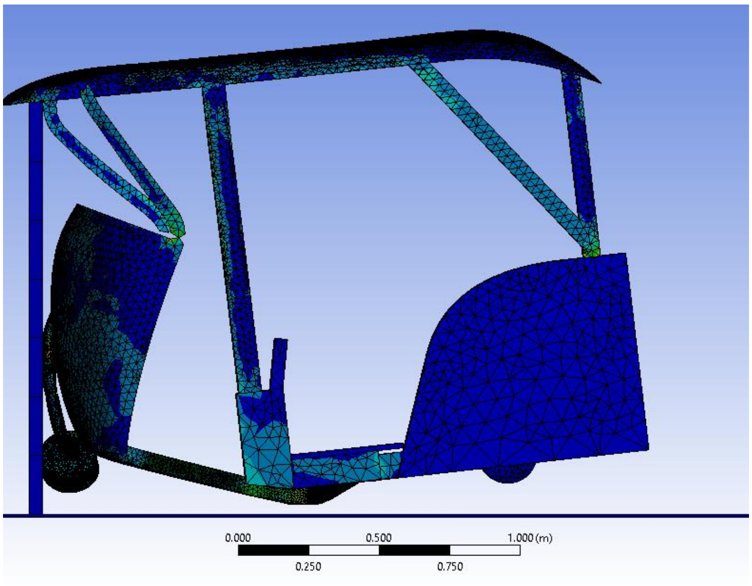

Fig.7. Proposed design at Full Width Frontal Impact Test

Fig. 8 depicts the velocity vs time graph of passengers and the driver during the collision without the restrain system for the proposed design.

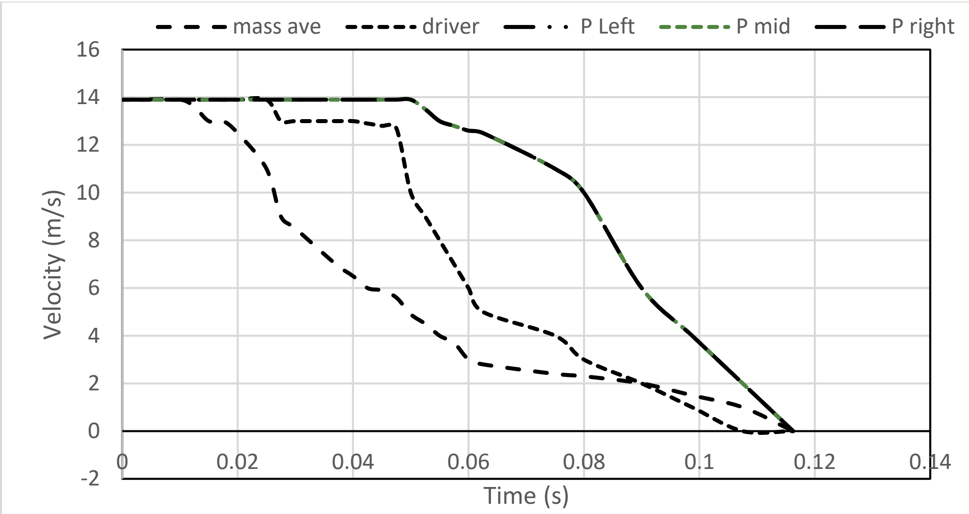

Fig. 8. Mass Average Velocity signature with passengers and driver for proposed design without restrain system

The total time for the conventional three wheeler to stall during Full Width Frontal Impact Collision for the conventional three wheeler was 0.09 seconds Jurangpathy & Perera (2023). The analysis of Fig. 8 reveals that the impact time has prolonged up to 0.12 seconds for the solution model. The prolonged time of the proposed three wheeler indicates its shower acceleration three wheeler during the Full Width Frontal Impact Collision This behavior of the proposed model was obtained by subjecting the crush tube to fail by absorbing impact energy during collision. All passengers undergo a lower deceleration than before. A comparison of G force each occupant is subjected to is compared in Table 1 against those obtained for a conventional three wheeler presented by Jurangpathy & Perera (2023).

Table 1 Occupant Dynamic Motion Data without the restrain system for the conventional design and the proposed design

Occupant	Maximum G Force for the conventional three wheeler	Maximum G Force of Proposed model
Driver	81 G	13.3 G
Passenger (Left)	47 G	20 G
Passenger (Mid)	47 G	20 G
Passenger (Right)	47 G	20 G

This comparison of acceleration for the conventional three wheeler against those for the proposed design reveals that the severity from the collision on occupants in the proposed model has significantly reduced. The acceleration of the driver was 6 times higher in the conventional three-wheeler compared to that of the proposed design. The acceleration of the passengers was 2.35 times higher in the conventional three wheeler compared to those of the proposed design.

Fig 9 Illustrates the velocity vs time graph for the proposed design with seat belts being worn by the passengers and the driver during the collision.

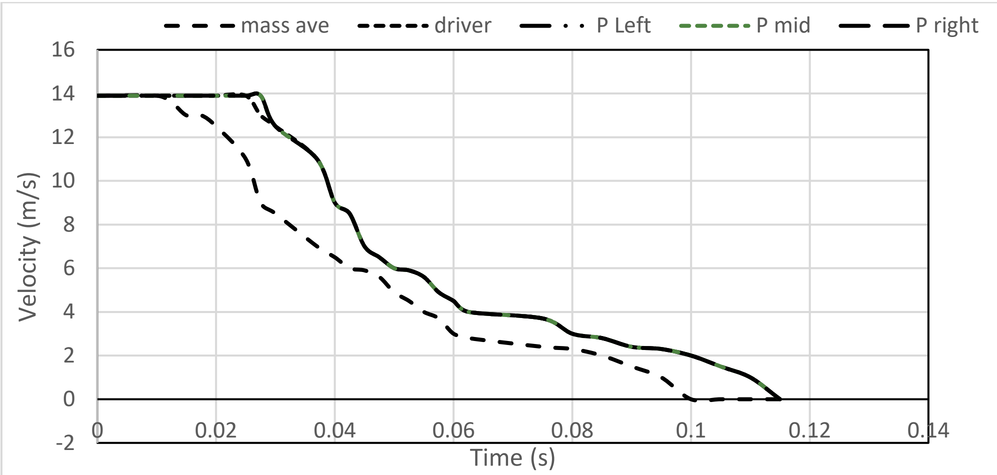

Fig. 9. Mass Average Velocity signature with passengers and driver for proposed design with restraint system

Previous findings of Jurangpathy & Perera (2023) on Full Width Frontal Impact Collision for a conventional three wheeler revealed that the maximum G force experienced by the driver as 25 G and 20 G for all passengers with seat belts being worn. Contrary to the above, he analysis of the velocity time signature of the proposed design reveals that the maximum G force experienced by the driver has been reduced to 13.2 G and up to 13.4 G with all passengers. A comparison of the maximum G forces experienced by the driver and passengers for conventional three wheeler and the proposed design is given in Table 2.

Table 2 Comparison of Occupant Dynamic Motion Data with restrain system for the conventional three wheeler and proposed model

Occupant	**Maximum G Force of conventional three wheeler from ref 2**	**Maximum G Force of Proposed Model**
Driver	25 G	13.2 G
Passenger (Left)	20 G	13.4 G
Passenger (Mid)	20 G	13.4 G
Passenger (Right)	20 G	13.4 G

It was a challenging exercise to incorporate a crumple zone without making drastic changes to the existing body shape of three wheelers. Changes to body features in the front would not be acceptable to current users. In order to maintain the exterior features of the three wheeler, a central crumple zone was designed. The design of the crumple zone was developed to attain a sufficiently high threshold to make the central crumple zone feasible, with the design revolving around an axial mode of collapse type comprised mainly of crush tubes. The concept was to replace a portion of the main structure with crush tubes designed to collapse axially and absorb impact energy. A side-by-side comparison of the solution model with the conventional three wheeler showed that the front face deformed far less than the original model and a mixed mode collapse was observed at the crumple zone of the proposed design. Furthermore, it prevented the front face of the model from folding in as much as it did before, reducing the likelihood of fatalities on the driver. With an effective restraint system in place, the survivability of the occupants can be further increased.

4 CONCLUSIONS

Conventional three wheelers lack passenger safety. A way of absorbing crash energy while maintaining the integrity of passenger shell is required to enhance safety. The central crumple zone introduced to the conventional three wheeler has been able to enhance crash safety compared to that of the conventional three wheeler.

Compared to results obtained for the conventional three wheeler with seat belts for passengers and the driver by Jurangpaty and Perera, a 47.2 % reduction of G force for the driver and 33% reduction of G force for passengers has been achieved for the proposed design. This suggests that a considerable amount of crash energy has been absorbed by the crush tube during the collision.

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Evaluation of Yield and Yield-related Characteristics of Selected Advance Rice Breeding Lines under Low Country Wet Zone Conditions in Sri Lanka

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Abstract – *Rice (Oryza sativa L.) is the most important staple food, it is important to enhance rice production to meet the demand of the world's population. To face this challenge, it needs to identify proper genetic materials with reliable characteristics to enhance the rice yield per unit area. Therefore this experiment was conducted at the Regional Rice Research and Development Centre, Bombuwala in the 2022 Yala season to evaluate the five selected elite advanced breeding lines, which were selected from different cross combinations was evaluated with their respective standard varieties under low country wet zone conditions in Sri Lanka. The experiment was laid out in a Randomized Complete Block Design (RCBD) with five treatments randomized in three replicates. The five selected advanced rice breeding lines of Bw20-1281, Bw20-1285, Bw 20-612, Bw19-1398, Bw19-1430 and two respective standard varieties of Bw 451 and Bg 403 were used as treatments. All the cultural and agronomic practices were done according to the Department of Agriculture recommendations. Data were collected on growth, yield, and yield-related parameters on the selected rice breeding lines. The data obtained were tabulated and analyzed by using the Statistical Analysis System (SAS). Duncan's Mulpiple Range Test (DMRT) was performed to compare the differences among treatment means at p=0.05. All the tested characters showed significantly different (p>0.05) among the tested entries and standard varieties. Considering yield components such as the number of panicles per unit area and thousand grain weight, Bw 20-612 performed better than the other tested entries and it has nonlodging type steady plant architecture also. Therefore, Bw 20-612 can be selected as the potential rice germplasm to be used in further varietal improvement and evaluation purposes in major yield trials of the Research Centre.*

Key Words: Advanced breeding lines, Rice, Yield, Agronomic characters

Nomenclature

Bw - Bombuwala *Bg - Bathalagoda*
RCBD - Randomized Complete Block Design
DMRT - Duncan's Mulpiple Range Test

1 INTRODUCTION

Rice (*Oryza sativa* L.) is an important staple food of more than half of the world's population. It is dominantly produced and consumed in Asia. In Sri Lanka, Rice is the staple food and is the livelihood of more than 1.8 million farmers (Sandika and Dushani 2011). An increase in rice production must be achieved largely by increasing yield per unit area. Improving rice yield has accordingly become one of the major objectives of breeders and growers in many countries over the past several decades. Rice is uniquely suited to wet environments in which other crops would not survive, hence its widespread popularity across Asia. In Sri Lanka, rice is grown under a wide range of ecological environments such as different elevations, different soil conditions, and different agroecological regimes. The Department of Agriculture in Sri Lanka released 92 of rice varieties under different age groups for the farmer population in Sri Lanka (Hamangoda and pushpakumari 2018). With the higher population growth rate available land for paddy cultivation is decreasing leaving a limited land area for paddy cultivation in Sri Lanka. Therefore, the solution for that situation could be development of rice varieties with high-yielding ability with tolerance to biotic and abiotic stress. The growth and yield characteristics of genotypes depend on genetic and environmental factors (Akrum et al. 2007). In this situation rice breeding and selection programs conducted in research stations focus on developing selected advanced breeding lines for their yield and yield-related characters. The mandate of the Regional Agricultural Research and Development Center (RRRDC), Bombuwela is to develop high-yielding both red and white rice varieties particularly tolerant to iron toxicity and associated technologies for Low Country Wet Zone (LCWZ) problem soils and ecosystems. The rice breeding and selection programmes of the country target to evaluate selected advanced breeding lines for their yield performance and agronomic characters before being nominated to the national coordinated rice varietal testing programme of the country.

2 METHODOLOGY

The experiment was conducted at the Regional Rice Research and Development Centre (RRRDC), Bombuwela, Kalutara, Sri Lanka 2022 during *the Yala* season. The research station was located in $6^0.57''$N latitude and $80^0.01''$E longitudes and belonging to the agro ecological zone WL_{1a}. The soil type of this area is low humic glay soil Soil pH was 6.4. The five selected advanced breeding lines (ABL) and two respective standard varieties were used as the treatments in this research (Table 1). The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. There were 7 plots of 12 m^2 in size in each of the three replications resulting in 21 plots in total. The distance maintained between two blocks and two plots was 30 cm, respectively.

Table 1 Characters of the selected advanced breeding lines and respective standard varieties used for the study

Treatments (Lines/ Varieties)	Parentage	Colour of pericarp	Type of grain
Bw 20-1281	Bg 360/Bw 367	White	Short round
Bw 20-1285	At 362/Bw 272-6b	White	Short round
Bw 20-612	Bw 367/At 373	White	Long medium
Bw 19-1398	At 362/Bw 272-6b	White	Short round
Bw 19-1430	Bw 05-1805/Bw 363/Bw 05-1805	Red	Long medium
Bw 451*	Bg 400-1/Bg 11-11	White	Short round
Bg 403*	Bg 83-1026/Bg 379-2	White	Intermediate Bold

* Standard recommended varieties

The pre-germinated seed materials of each tested varieties and respective standard varieties were broadcast in the experimental plots and all cultural and management practices were done according to the recommendations given by the Department of Agriculture (DOA). Agronomic characters such as plant height, culm length and reproductive characters such as panicle length, days to 50% flowering, days taken to 85% maturity and yield related characters, i.e. number of panicles per square meter, number of productive tillers per plant, thousand grain weight and number of filled grains per panicle were determined at various growth stages of the each tested varieties using the Standard Evaluation System (SES 2014) for rice developed by the International Rice Research Institute (IRRI). Data were analyzed using Statistical analysis software (SAS) package and mean separation was done according to the Duncan's multiple range test (DMRT).

3 RESULTS AND DISCUSSION

3.1 Agronomic Characters

3.1.1 Plant Height

Plant height is an important character for standing the plant in the field. When the plant height more, the rice plant cannot stand properly and it will be subjected to lodged. Also, shorter height is not accepted due harvesting difficulties. According to the results of tested advanced breeding lines and standard varieties there was significant difference among the plant height ($p<0.05$). The highest plant height (106.37 cm) was recorded by Bw 451.The lowest plant height (81.9 cm) was recorded by Bw 20-612. Because of lower plant height Bw 20-612 was performed well in field condition (Table 2). It was recorded non lodging type breeding line.

3.1.2 Panicle Length

Panicle length is an important trait for improving panicle architecture and grain yield in rice (*Oryza sativa L.*). According to the results of panicle length of tested entries and standard varieties were recorded significant different ($p<0.05$). The highest panicle length was recorded by Bg 403 (24.9 cm). The lowest panicle length was recorded by Bw 20-612 (20.36 cm) (Table 2). Among the tested entries panicle lengths were varied in between 20.36cm to 24.95cm. Rice plants with long panicles potentially have a high number of grain total and high yield because there is a positive correlation between panicle length and the number of grains per panicle, (Haryanto et al. 2008).

3.1.3 Number of Productive Tillers per Plant

Number of reproductive tillers and number of spikelets per panicle provide useful information for the rice breeders and those characters have direct effect on yield per plant (Sadeghi 2011). Considering about number of productive tillers per plant of tested entries and standard varieties there were no significant difference can be observed between them ($p<0.05$). Bw 20-1281, Bw 20-1285, Bw 20-612, Bw 19-1430, Bw 19-1398, Bw 451,Bg 403 mean value for number of productive tillers per plant was 1.76 (Table 2).

3.1.4 Time Taken to 85% Maturity of Rice Plants

Yield is depending on the flowering. When the optimal time yield are maximized. Flowering duration as an important factor to get uniform seed setting rate. By consider these days to 85% maturity we can be predicted how many days taken to harvest that entries and standard varieties. Bw 19-1430 was the earliest line (mean value 94.66), that was taken very low days to 85 % maturity. So can be harvest earlier than others. Lower age varieties are important for wet zone rice cultivation because of unpredicted environmental changes (Table 2). In timely harvesting of rice ensures good quality with higher yield (Ali et al. 1990). Grain yield and its quality depend on the right judgment at harvesting. Rice production is highly seasonal, and timely operation has a relatively significant impact on its yields, especially the appropriate timing of the harvest (J. Wang et.al.2004, A. Kessler et.al.2020).

3.1.5 Time Taken to 50% Flowering

There are no significant difference between tested entries of Bw 20-1281, Bw 20-1285, Bw 20-612, Bw 19-1398, Bg 403 (mean value 76.0) ($p < 0.05$). In addition to that, Bw 19-1430 Breeding line flowered earlier than others (mean value 37.0). Bw 451 mean value was 86.33. So that variety was already released by DOA under 4-4 ½ months age group (Table 2). Among many agronomic characteristics, days to flowering, plant height and yield potential determine the economical production of any crop including rice (Xue et al. 2008). Days to flowering recorded positive and significant correlation with plant height and negative and significant association with grain yield per plant (Babu VR et al.2012).

Table 2 Agronomic characters of selected entries and standard varieties of Rice

Treatments (Lines/Varieties)	Plant height (cm)	Panicle length (cm)	Number of productive tillers per plant	Time taken (days) to 85% maturity	Time taken (days) to 50% flowering
Bw 20-1281	98.88^{b}	23.93^{ab}	1.0^{a}	97.33^{b}	76.0^{b}
Bw 20-1285	102.2^{ab}	23.7^{ab}	2.0^{a}	98.0^{b}	78.0^{b}
Bw 20-612	81.9^{c}	20.37^{c}	1.33^{a}	96.0^{bc}	75.66^{b}
Bw 19-1398	98.87^{b}	23.1^{b}	1.67^{a}	97.33^{b}	76.33^{b}
Bw 19-1430	99.43^{ab}	22.97^{b}	2.0^{a}	94.66^{c}	37.0^{c}
Bw 451	106.37^{a}	21.03^{c}	2.33^{a}	109.0^{a}	86.33^{a}
Bg 403	86.03^{c}	24.95^{a}	2.0a	96.66^{bc}	74.0^{b}
CV	4.09	4.54	29.93	1.14	3.35

Mean values of each column with the same letter are not significantly different at $p<0.05$
CV –Coefficient of Variance

3.2 Yield related characters

3.2.1 Number of Filled Grains per Panicle

There were significant different can be observed among tested entries and standard varieties ($p<0.05$). The Bw 20-1281 were recorded the highest number of filled grains per panicle (165.0).The Bw 19-1430 were recorded the lowest number of filled grains per panicle (61.6) (Table 3). Filled grains per panicle is a most important factor which mainly determine the yield of a variety (Hussain et al.,2014). The fertile grain number per panicle is one of the important yield attributing traits. Grevois and Helms (1992) also observed positive direct effects for filled fertile grains per panicle on rice yield.

3.2.2 Number of panicles per unit area

Grain yield in rice is mainly determined by the number of panicles, number of grains per panicle and grain weight, all of which are typical quantitative traits (Xing and Zhang 2010). There were no significant variation can be observed among tested entries and standard varieties ($p<0.05$). But compared to each tested entries comparatively Bw 20-612 was achieved highest value of number of panicles per unit area (57.33). Comparatively the Bw 19-1430 was recorded the lowest value of number of panicles per unit area (31.3). The number of panicles per unit area (usually consider about panicles/ft^2) is determined by the number of established seedlings and tillers produced per seedling. In general, 60 to 70 panicles/ft^2 are needed to achieve good yields (Table 3).

3.2.3 *Thousand Grain Weight (g)*

Thousand-grain weight (TGW) is one of the most important determinants of rice grain yield and is determined by grain length (GL), grain width (GW) and grain thickness. According to the table 3, thousand grain weight was significantly varied among the tested entries. The maximum thousand grain weight was reported Bw 19-1430 (35.67 g) and the minimum weight of thousand grain was reported by Bw 20-1281 (24.33 g).
Yoshida (1981) stated that grain filling during the ripening is characterized by the increase in size and weight of kernels as starch and sugars are translocate from culms and leaves. Sarwar *et al.*, (2012) found that there are significant differences regarding the values of morphological characters of rice grains. Grain size is the most important factor which influences the yield of rice quality.

3.2.4 *Grain Yield (t/ha)*

According to the literature in rice, yield is indirectly determined by traits like plant height, growth period, tillering ability, panicle length, seed length, seed setting rate and grains per panicle and it was directly determined by traits like panicle number per unit area / per plant, filled grains per panicle and 1000 grain weight (Sakamoto and Matsuoka,2008). However, in the present study, there is no significant difference observed among all the entries including slandered varieties. However, standard variety Bg 403 recorded comparatively higher yield of 3.06t/ha while Bw 20-612 rice line was recorded 2.67t/ha (Table 3).

3.2.5 *Grain Shattering Percentage*

A moderate degree of seed shattering in cultivated species is usually preferred, the degree of seed shattering in rice cultivars depends on the harvesting methods followed in different geographic regions. Moderate shattering rice varieties are preferred for both hand and combine harvesting, but harvesting by small head feeding combines requires hard to thresh or non -shattering varieties. In this study, Bw 20-1285 was showed high shattering percentage (37.2). It is not a acceptable character for good paddy variety. Bg 403 standard variety showed the lowest shattering percentage (1.6). Compared the tested entries, Bw 20-612 showed the moderately shattering percentage of 13.33. Among the tested entries lowest shattering percentage recorded by Bw 19-1430 (4.33) (Table 3).

3.3 Grain Quality Characters (Milling Quality)

Consider about milling quality parameters of tested entries and standard varieties there were significant variation can be observed from percentage of brown rice, no significant difference can be observed from percentage of milled rice and percentage of head grain among tested entries and standard varieties ($p<0.05$). Among different treatment combinations tested, compared comparatively the highest brown rice recovery was recored by Bw 20-1285 (82.96), highest total mill rice recovery was recorded by Bw 20-1285 (80.13). On the other hand, the lowest brown rice recovery (77.5) was recorded from Bw 19-1430 total milled rice recovery (74.3) was recorded from Bw 19-1430 and lowest Head grain recovery (42.35) recorded from Bw 19-1430. Bw 20-612 was recorded the percentage of brown rice (77.73), percentage of milled rice (74.66), percentage of head grain (69.82) (Table 4).

Table 3 Yield parameters of selected entries and standard varieties of Rice

Treatments (Lines/Varieties)	Number of filled grains per panicle	Number of panicles per unit area (30 cm*30 cm)	Thousand grain weight (g)	Grain Yield (t/ha)	Grain Shattering%
Bw 20-1281	165.0 [a]	39.67[a]	24.33 [d]	1.58[a]	18.67[a]
Bw 20-1285	117.33 [b]	38.0[a]	25.0 [cd]	2.37[a]	37.2[a]
Bw 20-612	132.33 [ab]	57.33[a]	26.67[bc]	2.67[a]	13.33[a]
Bw 19-1398	162.33 [a]	37.0[a]	25.33 [bcd]	1.99[a]	24.93[a]
Bw 19-1430	61.67 [c]	31.33[a]	35.67 [a]	2.19[a]	4.33[a]
Bw 451	133.0 [ab]	37.33[a]	27.33 [b]	2.07[a]	11.73[a]
Bg 403	73.67 [c]	34.0[a]	25.33[bcd]	3.06[a]	1.6[a]
CV	19.05	21.97	4.82	28.63	99.08

Mean values of each column with the same letter are not significantly different at p<0.05

CV –Coefficient of Variance

Table 4 Grain quality characteristics of selected entries and standard varieties

Treatments (Lines/Varieties)	Percentage of brown rice	Percentage of milled rice	Percentage of head grain
Bw 20-612	77.73[c]	74.66[a]	69.82[a]
Bw 20-1285	82.96[a]	80.13[a]	74.02[a]
Bw 20-1281	81.33[ab]	77.53[a]	76.12[a]
Bw 19-1398	81.33[ab]	76.8[a]	71.80[a]
Bw 19-1430	77.5[c]	74.3[a]	42.35[b]
Bw 451	78.03[bc]	75.3[a]	74.77[a]
Bg 403	80.66[abc]	78.46[a]	52.76[b]
CV	1.726	2.445	6.067

Mean values of each column with the same letter are not significantly different at p<0.05
CV –Co efficient of Variance

Grain yield per plant exhibited highly significant and positively correlation with Number of productive tillers (0.173), Number of panicles per unit area (0.270), Panicle length (0.103). The plant height (-0.50), Culm length (-0.553), Days to 50% flowering (-0.027), Days to 85% maturity (-0.111), Number of filled grains per panicle (- 0.396), Panicle weight (-0.006), Thousand grain weight (-0.067) showed the highly significant and negative correlation with grain yield (Table 5).

Table 5 Estimation of Reproductive characters correlation between yield characters and Grain yield of tested entries

Characters	Panicle length(cm)	Panicle weight(g)	Number of productive tillers per plant	Thousand grain weight(g)	Number of panicles per unit area	Number of filled grains per panicle	Grain yield(t/ha)
Panicle length	1	0.524*	0.440*	0.503*	-0.496*	0.359	-0.500*
Panicle weight	0.524*	1	0.105	0.930**	-0.411	0.255	-0.006
Number of productive tillers	0.084	0.105	1	0.026	-0.031	-0.301	0.173
Thousand grain weight	0.104	0.930**	0.026	1	-0.446*	0.192	-0.067
Number of panicles per unit area	-0.604**	-0.411	-0.031	-0.446*	1	-0.019	0.270
Number of filled grains per panicle	-0.011	0.255	-0.301	0.192	-0.019	1	-0.396
Grain yield	0.103	-0.006	0.173	-0.067	0.270	-0.396	1

**Correlation is significant at the 0.05 level (2- tailed)*
*** Correlation is significant at the 0.01 level (2-tailed)*

4 CONCLUSIONS

Among the tested five advance breeding lines compared with their recommended standard varieties advance breeding line Bw 20-612 performed better than the other advance breeding lines. Consider about agronomic characters of plant height (81.9 cm), culm length (60.87 cm), days to 50% flowering (75.6), days to 85% maturity (96.0) Bw 20-612 breeding line was achieved preferable values. In field conditions Bw 20-612 advance breeding line was showed non lodging type steady plant architecture. Considering yield related characters, one of the major yield component of the number of panicles per unit area, highest value was recorded by Bw 20-612 (57.33). So maximum grain yield was recorded by Bw 20-612 (2.67t/ha). Considering reproductive characters, grain shattering percentage of Bw 20-612 was recorded moderate shattering percentage (13.33). It was farmer preferable character when harvesting and threshing of paddy. Among the tested entries considering about pest and disease reactions Bw 20-612 was recorded resistant to the blast and bacterial leaf blight disease, moderately resistant to the brown plant hopper those characters are very important during the further advancement of the rice lines. According to the grain quality characters of tested entries Bw 20-612 was achieved moderate percentage of brown rice (77.73), milled rice (74.66) and head grain (69.82) recovery values. When considering the correlation analysis, grain yield per plant exhibited highly significant and positive correlation with number of productive tillers and number of panicles per unit area, panicle length. The number of days taken to 50% flowering was highly significant and positive correlation with days to 85% maturity. The numbers of productive tillers, number of filled grains per panicle, panicle weight and, thousand grain weight showed highly significant and positively correlated with days to 85% maturity. According to the results of the correlation analysis, it can be concluded that the grain yield exhibited significant and positive correlation with number of panicles per unit area and number of productive tillers. In comparison of advanced breeding lines with recommended existing local rice varieties Bw 20-612 performed better during the study period. Therefore, Bw 20-612 has been selected as an advance parental breeding line for further evaluation purposes. However further study can be extended to be *maha* season as well to confirm the results.

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Effect of Green Synthesized Ferrous Oxide Nanoparticles on Seed Germination in Tomato (*Solanum lycopersicum*) and Eggplant (*Solanum melongena*)

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Abstract *– Seed treatments are effective in increasing seed germination. Nanotechnology has been developed as a seed-priming technology for smart agriculture. Fe is one of the essential micronutrients for plants. The aim of the present study is to investigate the effect of green synthesized Ferrous oxide (FeO) nanoparticles on seed germination. Salvinia molesta leaf extract was used to react with 0.1 M Ferric Chloride concentration. Synthesized nanoparticles were characterized using an Ultraviolet-visible spectrometer (UV-Vis) and Scanning Electron Microscopy (SEM). The average size of nanoparticles was 42.33 nm. UV-visible spectroscopy at 339 nm confirmed the formation of Ferrous Oxide nanoparticles. Seeds of tomato (Solanum lycopersicum) cultivar Tillina and eggplant (Solanum melongena) cultivar Lena Iri belonging to the family Solanaceae* were used in the seed germination test. *Surface sterilized seeds in Petri dishes were treated with different volumes; 2 ml (T1), 1 ml (T2), 0.5 ml (T3) of synthesized Ferrous Oxide nanoparticles. 2 ml Salvinia leaf extract (R1), and 2 ml distilled water (R2) are the two controls. Twenty seeds from each cultivar were placed on filter paper in a Petri dish and three replicates per treatment. Distilled water was added to each treatment at 2-day intervals to provide water requirement for germination. After seven days of each treatment, the effect on seed germination was evaluated by measuring shoot and root length and fresh weight. According to statistical analyses, Ferrous Oxide NPs 1 ml and 0.5 ml (T2 and T3) significantly promoted the % seed germination, root length, shoot height, and fresh weight. However, 2 ml strength (T1) of the NPs showed a negative effect for both root and shoot growth. The results confirmed that low strengths of Ferrous Oxide NPs promoted seed germination, shoot, and root growth rate. The higher strength of Fe_2O_4 metallic nanoparticles did not promote the germination rate.*

Keywords*: green nanotechnology, Ferrous Oxide Nanoparticles, Family- Solanaceae, Solanum lycopersicum*, *Solanum melongena*

1. INTRODUCTION

Seed treatments are effective in increasing seed germination, plant growth, and potential yield, which will lead to economic sustainability in commercial agriculture. More recently, nanotechnology has been developed as a seed-priming technology for smart agriculture. Due to their unique characteristics such as higher surface area to its mass higher active nature and advanced optical electrical, thermal, and physical properties, nanoparticles (NPs) can deliver the substances efficiently (Hamdy *et al.*, 2022). Because of the higher surfaces area, higher reactivity, and higher solubility, they can easily interact with cell membrane and other cellular components like proteins, lipids. Numerous reports indicate that NPs can increase crop production by enhancing various physiological processes including seed germination, plant growth, etc (Feng *et al*., 2022). Metallic nanoparticles and their carriers have the potential to act as a carrier agent in biological systems (Abid *et al*., 2022). Seed priming with nanoparticles is an arguable and most attractive topic in the current field of research. Literature is available on the performances of different nanoparticles on plants in various manners, CuO nanoparticles can inhibit seed germination while TiO NPs have rapid action on seed germination (Feng *et al*., 2022). Seed treatment with metallic NPs promote vigorous seedling growth, increase the seeding emergence speed. In addition, primary seed treatment induces enzymatic activity like protease, amylase, and the breakdown of the required macromolecules in the embryo that required for the emergence (Abid *et al*., 2022). Therefore, the cultivators can reduce the expenses for re-seedlings, time, and cost, and extra irrigation, fertilizer also.

The biological synthesis of NPs contributes to the development of both environmental and health. It has a simple protocol, low energy consumption, and low production cost compared to chemical and physical methods. Plants, microorganisms, algae, and yeast extracts are biological sources used as stabilizing and encapsulating agents in green NP synthesis. According to Demirezen *et al*., 2018, terpinols, polyphenols, and sugars are mainly responsible for determining the morphology of the biosynthesised nanoparticle. Interestingly, Ferrous Oxide NPs are biodegradable, biocompatible, nontoxic for human (Duffy *et al*., 2018). Ferrous is one of the essential micronutrients for plants which can regulate the number of growth process of the plant's chlorophyll biosynthesis, photosynthesis, chloroplast development, and dark respiration (Feng *et al*., 2022). Thus, iron deficiency causes structural and functional changes in the photosynthetic process. According to Feng *et al*., 2022, Fe_2O_4 nanoparticles improve the growth parameters and induce the germination of wheat grains.

Tomato (*Solanum lycopersicum*) is a demanding and widely cultivated vegetable plant mainly grown by medium-scale commercial farmers in Sri Lanka. Tomato is consumed or utilized in miscellaneous ways including raw fruit, cooked food, as a drink, and a vegetable (Zhao *et al*., 2021). Abiotic factors and diseases are the main limiting factors for tomato production. It is susceptible to a number of diseases caused by microorganisms that include fungi, bacteria, viruses, and nematodes (Bala Raju *et al*., 2017). Eggplant (*Solanum melongena*) has a relatively low seed germination ability with the sought-after vegetables that have a health-promoting effect and can cure diseases such as disease exacerbations (Gonzales, 2015). In addition to various abiotic factors, seed genetic characteristics are accountable for seed germination and viability. The present study hypothesized that seed priming with plant-based nanoparticles would improve the germination rate/emergence rate, seedling vigour, and other growth parameters of tomato and eggplant. Currently, a few studies are reported on identifying the effect of green synthesized nanoparticles on the seed germination process. This study investigates the effects of green synthesized ferrous Oxide nanoparticles on tomato and eggplant seed germination and their shoot, root performances under different concentrations.

2. MATERIALS AND METHODOLOGY

2.1 Green Synthesis of Nanoparticles

FeO NPs synthesis using *Salvinia molesta* leaf extract *S. molesta* plants were collected from the Beddagana wetland park, Sri Jayawardhanapura, Kotte in June 2022. Plants were washed with tap water for three times and rinsed with de-ironized water for 30 minutes. The samples were then dried in an air dryer at 42^{o}C overnight. Dried leaf samples were grounded using a blender and 5 g of grounded sample was mixed with 80 ml of deionized water at 60°C of temperature. The extraction was filtered using Whitman's filter paper no 01 three times. Leaf extraction was stored in the refrigerator for future use.

Thirty ml (30 ml) of 0.1 M $FeCl_3$. $6H_2O$ was prepared and stirred for 10 minutes using a magnetic stirrer. Then leaf extract was added to $FeCl_3$. $6H_2O$ at 2:3 ratio. pH was adjusted to 8 by adding (1 M) NaOH. The reaction mixture was stored at room temperature for about 24 h and the mixture was centrifuged at 1400 rpm for 15 min. The supernatant was removed, and the pellet was washed using de-ionized water.

2.2 Nano Particle Characterization

2.2.1 SEM analysis and UV-Vis Spectroscopy

UV–Vis Spectrometry analysis was carried out by using CT-2600 UV-Vis Spectrometers (BioTek©) with a resolution of 1 nm between 200 and 700 nm. The resulting FeO NPs pellets were re-suspended in deionized water and used for characterization. SU6600 Scanning Electron Microscope, (HITACHI) was used for the morphology, size, and analysis of the particle distribution of Ferrous Oxide nanoparticles and microscopic structure was observed at 50.00 KV and 100 KV and under multiple (KX) magnifications.

2.3 Preparing Seeds

The prepared NPs pellet was diluted with 5 ml of deionized water and to avoid agitation and disperse the particles equally using (CLASSIC) Advanced vortex mixture (120 v) for 30 min. 0.1 M NPs were prepared in different volumes: 2 ml, 1 ml, and 0.5 ml.

S. lycopersicum and *S. melongena* seeds were purchased from Agri Acardy (SA/MTG/02642) (Purity Percentage, 98%, germination percentage 75 – 80 %). *Tillina* tomato cultivar and *Lena Iri* eggplant cultivar were used for the study. Seeds were sterilized in a 1:1:1 ratio of tap water, 2% sodium hypochlorite, and deionized water to ensure surface sterility. There were five treatments *ie*. T1 - 2 ml, T2 - 1 ml, T3 - 0,5 ml 0.1 M FeO NPs, Control 1 (R1) - 2 ml *Salvinia* leaf extract and Control 2 (R2) -2 ml distilled water. Seeds were soaked for about 4 hours in these treatment solutions separately. 20 seeds from each variety were placed in a petri dish on filter paper and there were three replicates per each treatment. The treatment solutions were added to separate Petri dishes with seeds and covered, sealed, and kept in the incubator. Distilled water was added to each treatment at 2-day intervals to provide water requirement for germination. After seven days, germination percentage was counted.

2.4 Determination of growth characteristics

2.4.1 Percentage Seed Germination

The number of germinated seeds was recorded after 7 days. Shoot emerged from half of the seed length is considered as the seed was germinated (Umar, 2016). % seed germination was calculated as a proportion to the total number of seeds (Feng *et al*., 2022).

The germination percentage was calculated using sixty (60) seeds per treatment as per the equation given below.

$$\text{Germination (\%)} = {\text{Number of germinated seed}}\big/{\text{Number of incubated seeds}} \ \text{X } 100$$

2.4.2 Shoot Length, Root Length and Fresh Weight of Seedlings

Seeds were wetted with 2 ml of de-ionized water in 2-day intervals. After 7 days seedlings were harvested and measured root length (RL= distance from the root base to the root tip), shoot length (SL= distance from the leaf base to the leaf tip), and fresh weight.

2.5 Data Analysis

For the analysis of the SAS statistical software was used. ANOVA, Least Significant Difference, T test was used to identify the significant in strength (2, 1, 0.5 mL) of the nanoparticles along with the two controls (R1 – seeds were treated with *Salvinia* leaf extract and R2 - seeds were treated with distilled water). A value of $p<0.0001$ was statistically significant, compared to the controls.

3. RESULTS AND DISCUSSION

Fig.1 shows the color change before and after the formation of nanoparticles in the reaction medium. *S. molesta* leaf extract color change confirmed the formation of FeO NPs. Color change (as shown in Fig. 1) of *Salvinia* plant extract is from greyish brown to brown color after adding $FeCl_3$. $6H_2O$ and it turned brownish black after adjusting the pH value to 8 in the mixture. This is due to the presence of a number of phytochemicals in the leaf extract, which play as a reducing agent of the metallic irons into its Nano form. These phytochemicals are bound with metallic nanoparticles and disperse in the aqueous liquid. Similar results have been observed in Ferrous Oxide Nanoparticles synthesised using *Pometia pinnata* leaf extract (Umar, 2016).

UV-Vis Spectroscopy of green synthesized FeO NPs of *S. lycopersicum* and *S. melongena.* confirmed by recording the absorbances of UV-Vis spectra in the range of 200- 800 nm (Fig. 02). In this study (SPR) the surface plasmon resonance at 339 nm was observed in FeO NPs extracted using *Salvinia* leaf extract. SEM image of the nanoparticles is a grain in shape and mean particle size 42.33 nm in diameter. The sizes, shape and particles distribution were characterized using the SEM (HITACHI) SU6600 Scanning Electron Microscope (Fig. 03). As shown in Fig.4, NPs are poly-dispersed without showing agglomeration. It demonstrates that nanoparticles are grain in shape and mean particle size 42.33 nm in diameter. The particle size distribution of green synthesized FeO NPs depicts that most particles are distributed in the range of 11 to 30 nm. The Ferrous oxide nanoparticle synthesis using *Trigonella* and tomato extracts in the range of 27.91 to 40.94 nm in sizes were previously reported (Abid *et al*., 2022).

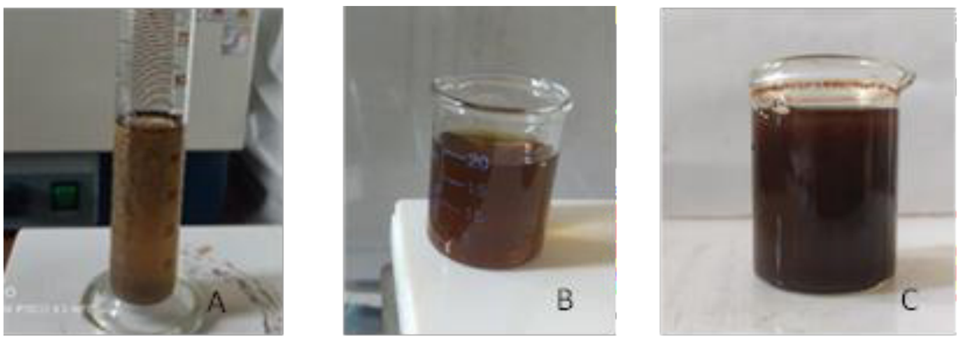
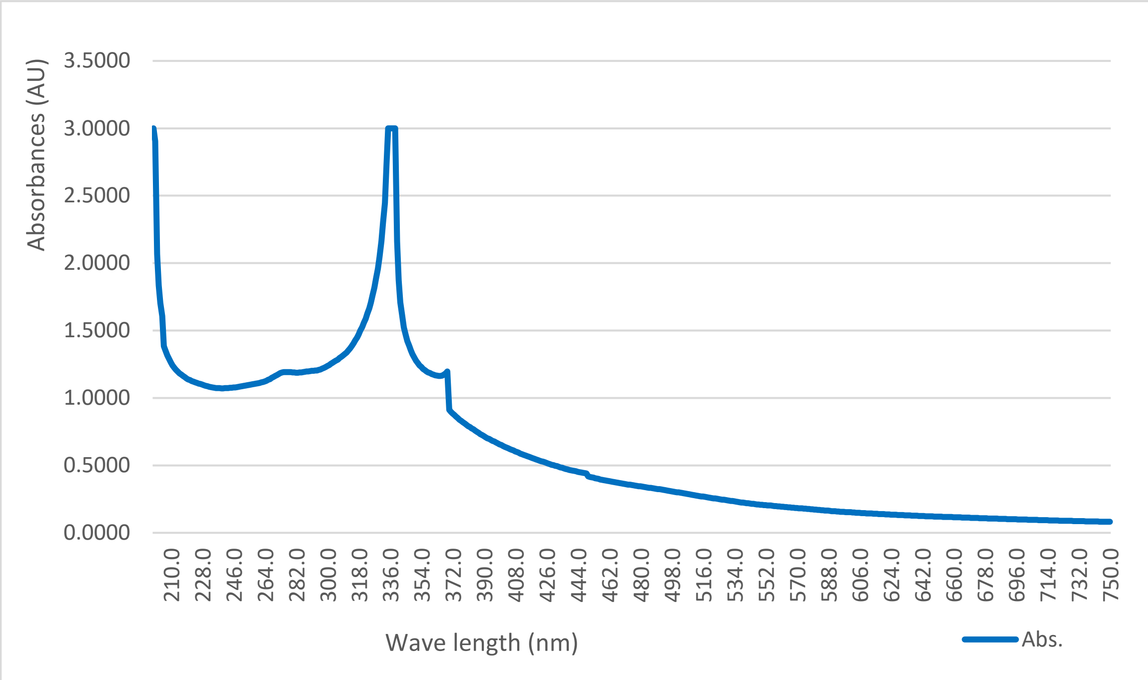
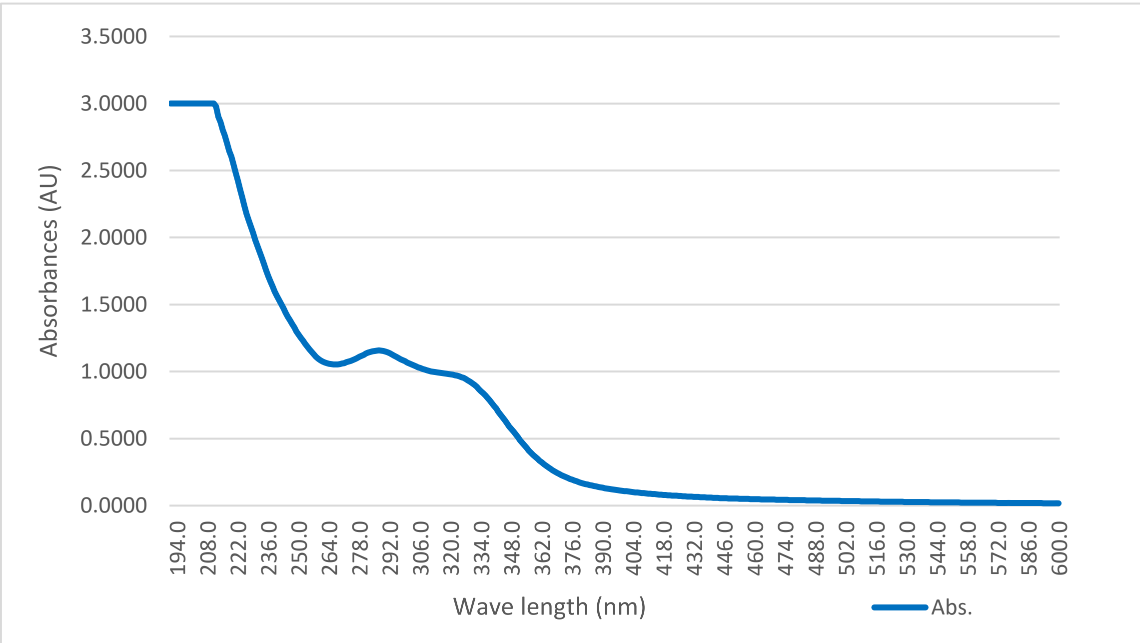


Fig. 1. (A): Colour of the S. molesta leaf extract, (B): Reaction mixture, (C): Colour of the reaction mixture after 24 hours

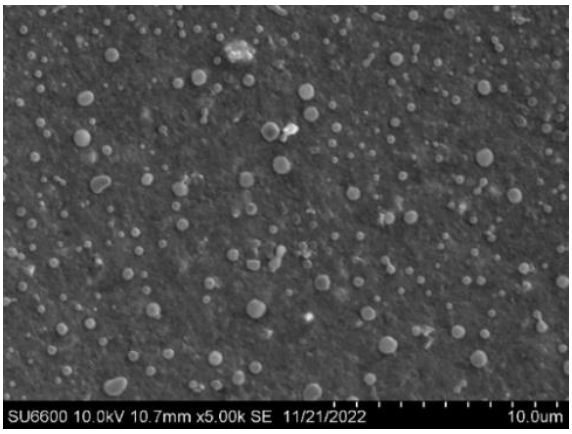


(a)



(b)

Fig. 2. UV-Vis Spectroscopy of green synthesised FeO NPs of (a) *S. lycopersicum* and (b) *S. melongena*



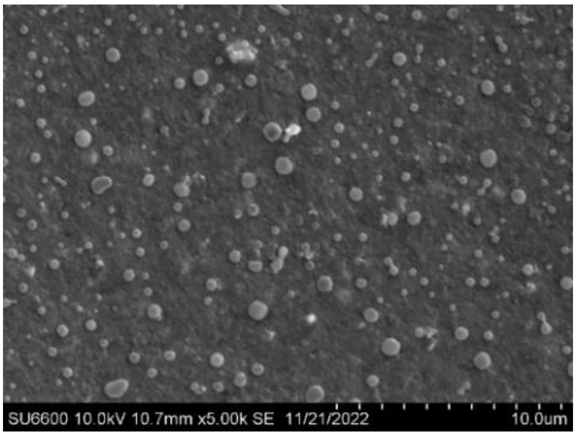


Fig.3. SEM image on green synthesised FeO NPs

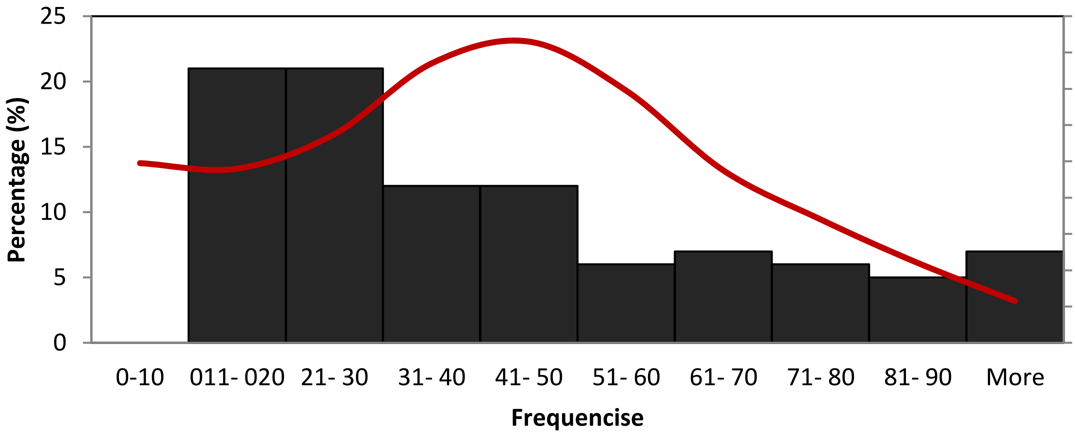
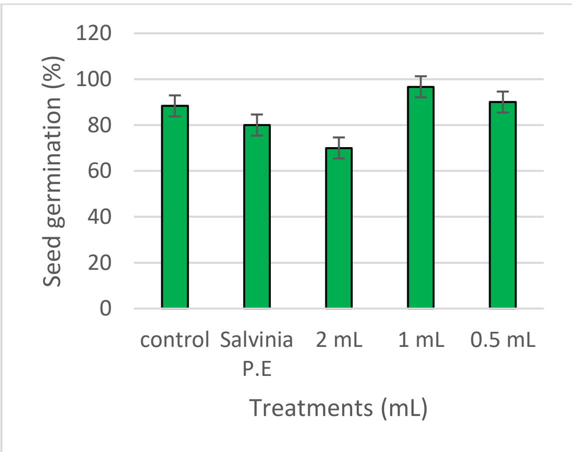
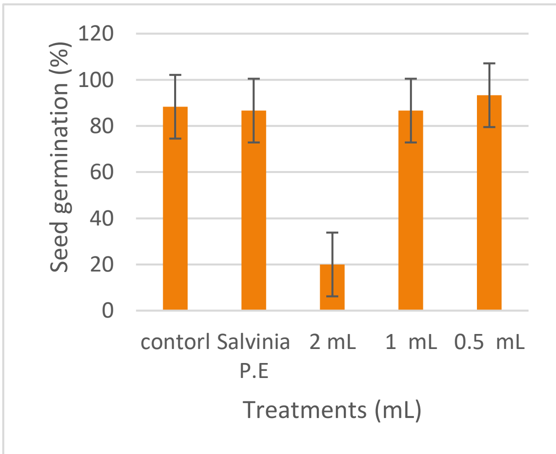


Fig.4. Partical sizes distribution of green synthesisied FeO NPs.

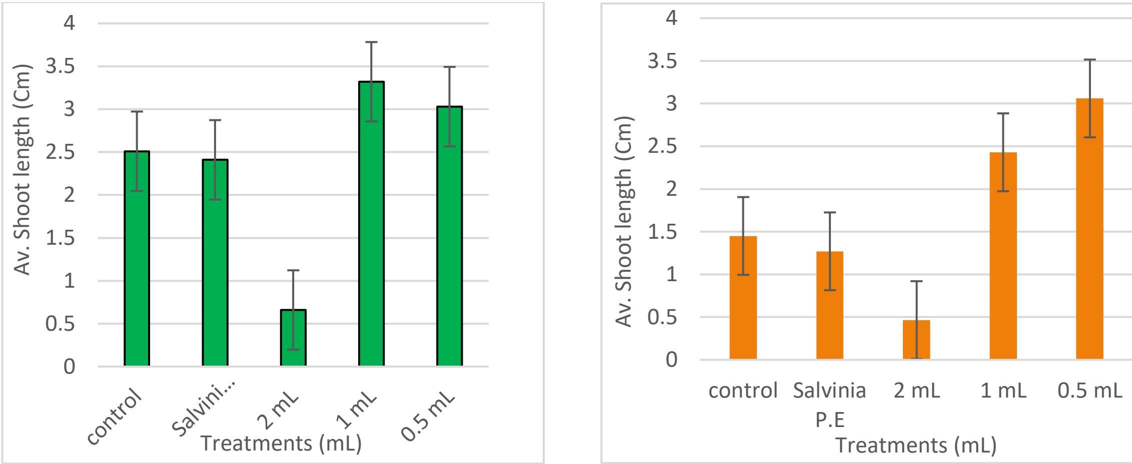


(a)



(b)

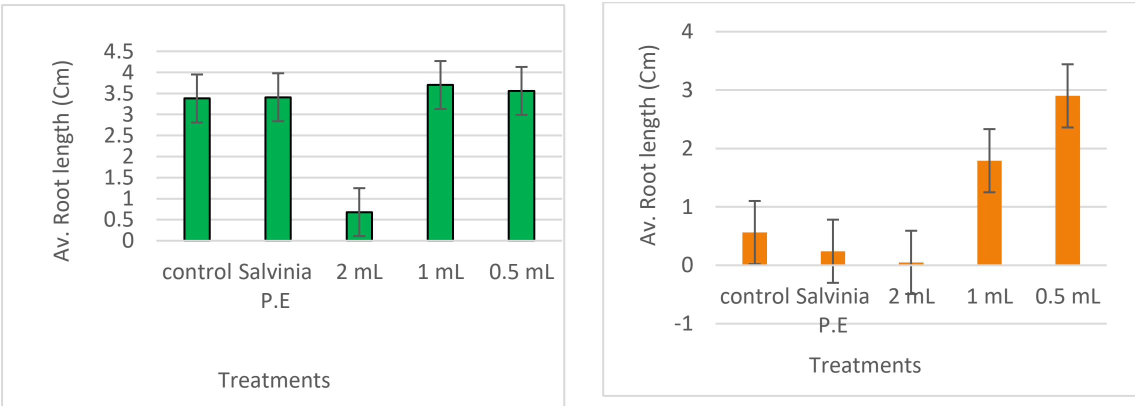
Fig. 5. Effect of FeO NPs on (a) *S. lycopersicum* and (b) *S. melongena* seed germination



(a) (b)

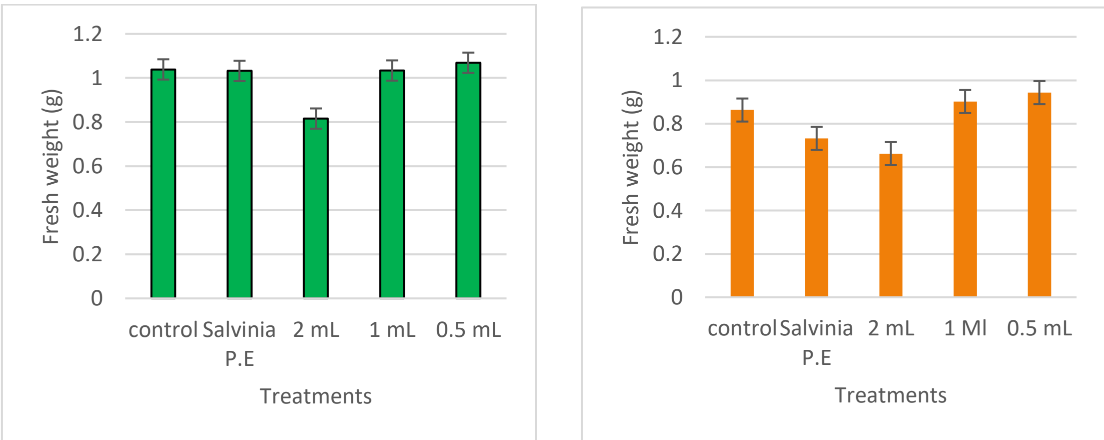
Fig.6. Effect of FeO NPs on (a) *S. lycopersicum* and (b) *S. melongena* shoot length.

The % seed germination was calculated 7 days after each seed treatment. It was around 75 - 80% in both cultivars. According to Fig.5 (a) and (b), % seed germination is considerably high in T3 - 0.5 ml metallic NPs in *S. lycopersicum* and *S. melongena* compared to Control 1 (R1), Control 2 (R2) and other treatments. There was a considerable reduction in the % seed germination with T1-2 ml metallic NPs treated seeds.



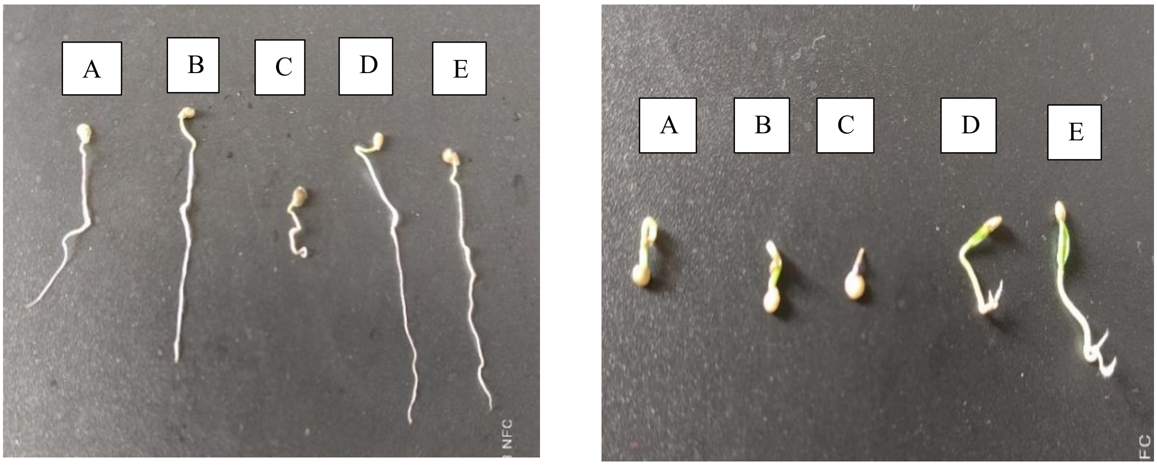
(a) (b)

Fig. 7. Effect of FeO NPs on (a) *S. lycopersicum* and (b) *S. melongena* root length



(a) (b)

Fig.8. Effect of FeO NPs on (a) *S. lycopersicum* and (b) *S. melongena* fresh weight



(a) (b)

Fig.9. Growth of seedlings of (a) *S. lycopersicum* and (b) *S. melongena* after applying treatments (A - Control 1 - 2 mL Distilled water, B - Control 2 - 2 mL *Salvinia* leaf extract, C-T1-2 mL FeO NPs, D-T2-1 mL FeO NPs, E-T3-0.5 mL FeO NPs)

According to Fig.6 (a) and (b) as well as Fig. 7 (a) and (b), the average shoot and root length of S. *lycopersicum* is considerably high with T2 - 1 mL metallic NPs and in *S. melongena* it is high with T3 - 0.5 ml metallic NPs. Fig. 8 (a) and (b) explains the variation in fresh weight of *S. lycopersicum* and *S. melongena.* T3- 0.5 ml showed the highest fresh weight in *S. lycopersicum* as well as *S. melongena* seedlings. Tables 1 and 2 showed significant differences in the growth rate of seedlings compared to the two controls R1 and R2. Shoot and root growth of both *S. melongena* and *S. lycopersicum* seedlings showed significant differences with the control samples. Since iron is an essential micronutrient for plant growth, under 1.0 ml, and 0.5 ml of FeO NPs it showed significant growth in both shoot and root of seedling. In the study of (Hao *et al*., 2016; Devi and Singh, 2016). demonstrated the bio-effect of Fe_2O_3 nanoparticles on germination of rice seed, root and shoot length, and fresh weight. The effect of NPs depends on particle sizes, morphology, and surface response, and exposure status of NPs (Verma *et al*., 2020), it directly affects the uptake and translocation of the particles.

The average shoot and root length of *S. lycopersicum* and *S. melongena* have significantly reduced with T1-2 ml metallic NPs. Thus, there was no clear trend observed in the root growth of *S. lycopersicum* seedlings comparative to the controls (Table 1). According to Fig. 8 (a) and (b) and 9 (a) and (b), all treatments except T1-2 ml of metallic NPs have a more or less similar impact on the fresh weight of S. *lycopersicum* and *S. melongena* seedlings. These results provide evidence (Fig.9 (a) and (b)) that metallic NPs could affect the seed germination, root length, shoot length and fresh weight of seedlings depending on the strength of NPs.

Table 1. ANOVA, LSD, T test shoot output

T grouping	Mean	Treatments
A	3.0600	T3 - 0.5 ml
B	2.4300	T2 - 1 ml
C	1.4500	R1 control 1
C	1.2700	R2 control 2
D	0.4650	T1- 2 ml

Table 2. ANOVA LSD, T test Root output

T grouping	Mean	Treatments
A	2.90	T3 - 0.5 ml
B	1.79	T2 - 1 ml
C	0.56	R1 control 1
C	0.24	R2 control 2
D	0.05	T1 - 2 ml

Overall, all the treatments show significant influence ($p<0.0001$) on the shoot and root of *S. lycopersicum* and *S. melongena* plants with different strengths of green synthesised Ferrous Oxide NPs (Fig.6 and 7, Table 1 and 2). 0.5 ml (T3) of green synthesized Ferrous Oxide NPs gave significantly highest shoot and root length in seedling of *S. lycopersicum* and *S. melongena* than all the other treatments. 1 ml (T2) green synthesized Ferrous Oxide NPs showed next significant effect on shoot and root length of *S. lycopersicum* and *S. melongena* seedlings than the control treatments, R1 and R2 and T1 treatment. R1, R2 (Control treatments) showed significantly lower shoot and root length in seedlings of *S. lycopersicum* and *S. melongena* than the two treatments T3 (0. 5 ml) and T2 (1 ml) green synthesised FeO NPs. However, within R1 and R2 treatments, there was no significant differences between each other. T1 (2 ml) green synthesised FeO NPs treatment recorded the lowest significant effect on shoot and root length in seedlings of *S. lycopersicum* and *S. melongena*.

According to (Feng et al., 2022) this positive effect is due to the higher solubility of the Iron Oxide particles and the effect on the seed radicals. In addition to the particle concentration, the shape of the synthesised nanoparticles also depends on the performance of the seeds. According to (Sandeep et al, 2019; Montanha et al., 2020), germination, root length, shoot length, seedling dry weight and seedling vigour index were significantly increased in Soybean with Ag and Fe NPs and (Zhao et al., 2021) reported that Fe2O3 enhances the seed germination ratio of Spanish plant during the hydroponics.

5. CONCLUSIONS

The present study investigated the impact of Ferrous Oxide NPs synthesized using *Salvinia molesta* leaf extract on seed germination, root, shoot length, and fresh weight of *S. lycopersicum* and *S. melongena* seedlings. Nanoparticles at lower strengths (0.5 ml and 1 ml) can promote % seed germination, root length, shoot height, and fresh weight. According to statistical analyses, 0.5 ml of Ferrous Oxide NPs was identified as the highly performing treatment for shoot and root length of *S. lycopersicum* and *S. melongena* seedlings. This could be due to requirement of Fe as a trace metallic element for plant growth and other biological activities. The findings could be used as an alternative methodology to promote seed germination and other related growth factors of seedlings.

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