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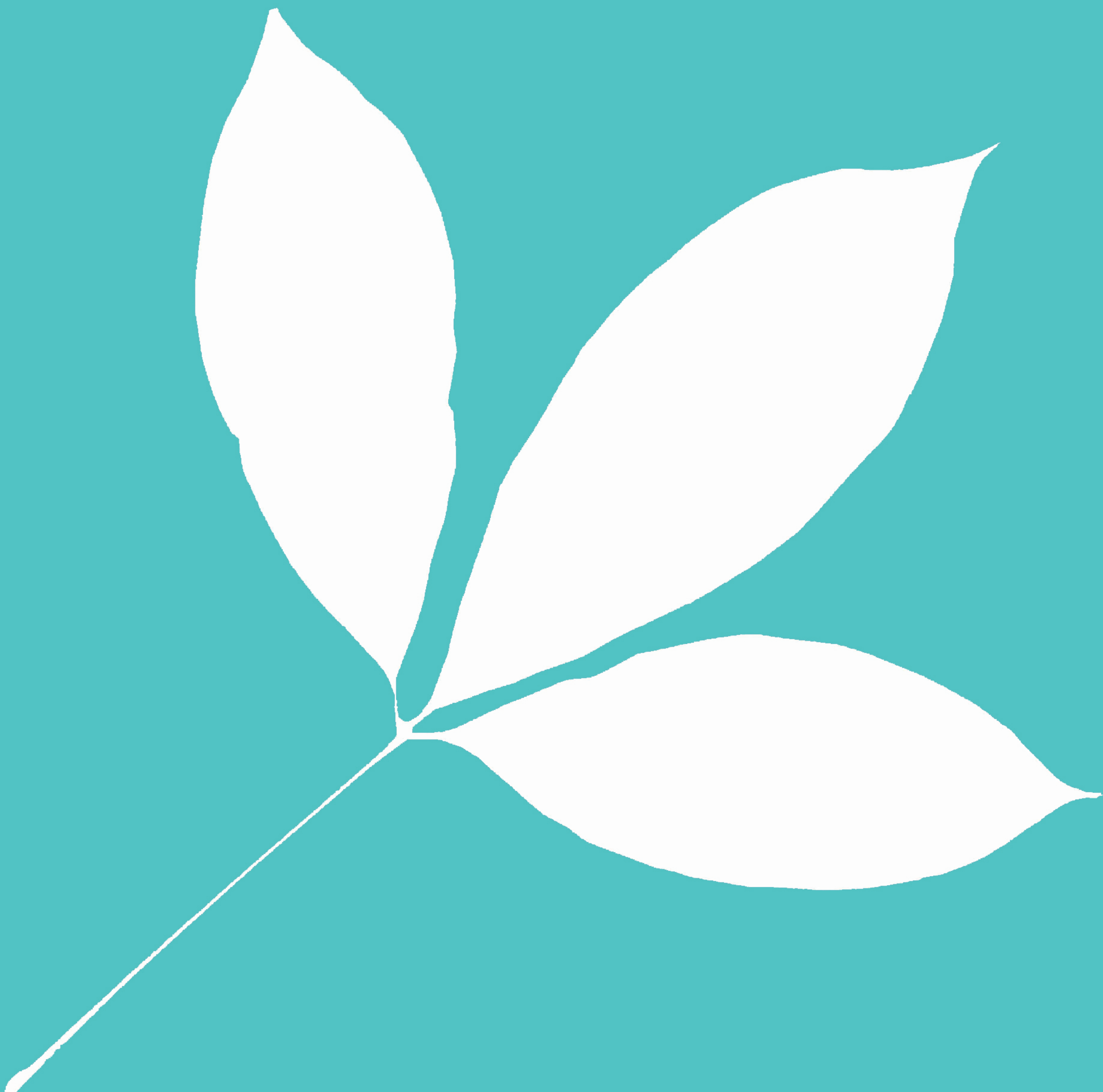

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Physical properties of natural rubber latex foams produced with processed mica waste powder and creamed natural rubber latex

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Abstract
Incorporation of finely powdered mica waste into natural rubber latex processed into foam rubber, consuming a minimum amount of energy could contribute to progress towards a greener environment. In this study, mica waste generated in the mining industry was finely powdered and incorporated into creamed natural rubber latex which is an alternative form of concentrated latex manufactured using a green process known as the creaming process. Finely powdered processed mica waste (PMW) was added as a filler into latex varying the loading from 0 to 10 pphr at 2 pphr intervals. The latex foam was then converted into a vulcanized natural rubber latex foam (NRLF). Effects of mica loading on certain properties of the foam rubber produced from creamed natural rubber latex were studied. It was found that the density and hardness of the mica powder incorporated foam rubber increased with increasing filler loading. Fourier transformed infrared spectroscopy (FTIR) studies confirmed that no structural changes occurred in natural rubber due to the addition of PMW. The overall results of the study showed the potential of utilization of mica waste and creamed natural rubber latex to manufacture greener natural rubber foam composites in cottage-level foam manufacturing industries.

***Key words*:** creamed natural rubber latex, foam rubber, green foam composites, mica waste, physical properties

Introduction
The scientific community in the world has been paying higher attention to greener materials and processes due to the ever-increasing environmental issues faced by the entire world (Ciambelli *et al.,* 2020; Oksman *et al*., 2014; Yue *et al.,* 2020). Today, social and environmental impacts have become key parameters that influence consumer preferences for products and services. Simultaneously, international and local regulations enforced by authorities are encouraged by environmentally friendly industries (Zhang & Cao, 2020). Consequently, numerous studies have been conducted on energy-efficient recycled materials, biodegradable products, and even processing techniques to promote the sustainability of the products and services through the use of green

materials and environmentally friendly material processing techniques.

Being one of the most widely used biodegradable and renewable industrial raw materials; natural rubber is continuously contributing towards a green environment for more than a century. In the face of growing interest in the green concept, studies on further improvement of green manufacturing of natural rubber products by the use of more energy-efficient manufacturing processes and utilizing industrial waste materials have become an emerging area in the natural rubber industry. In natural rubber latex-based industries, centrifuged latex is the widely used form of concentrated latex and is produced by a high-energy-consuming centrifuging process. Latex is also concentrated by the creaming process, where preserved latex is allowed to separate and creamed under gravitational force without using an electrical energy. Therefore, this creaming process could be considered a green manufacturing process and thus the resultant product, *i.e.* creamed latex is a greener product. However, there are quality variations between centrifuged latex and creamed latex. Creamed latex has smaller rubber particles with a wider particle size distribution, higher total solid content (TSC), dry rubber content (DRC), and viscosity than centrifuged latex (Suksup *et al*., 2017). These variations may influence the manufacturing process and performance of products produced from creamed latex. Suksup *et al.* have recently compared the behavior of unfilled foam rubber manufactured from centrifuged latex and creamed latex separately (Suksup *et al.*, 2017). It has been reported that creamed latex could also be successfully used to manufacture foam rubber (Suksup *et al.*, 2017).

In addition to the selection of creamed latex, the use of fillers derived from agricultural or industrial waste replacing synthetic commercial fillers could further improve the green nature of rubber products. Muniandy *et al.* applied rattan powder for the partial replacement of two commercial fillers namely carbon black and $CaCO_3$ in preparation for biocomposites based on natural rubber (Muniandy *et al.*, 2012). The results have shown the possibility of the generation of composites with some improved properties. Most of the work reported on green rubber composites consist of hybrid filler systems such as cocoa pod husks, rubber-seed shell powder, silica, and wood flour have shown similar trends (Okieimen & Imanah, 2006; Zhou *et al.*, 2015). Roy *et al*. have reviewed several research articles available in the literature on the use of natural fibers and particulate fillers derived from bio-based materials to prepare environment-friendly rubber composites (Roy *et al.*, 2020).

However, most of the work associated with fillers derived from waste materials including mica is based on the development of dry natural rubber composites. Compared to the number of studies carried out on such dry rubber composites, studies carried out on latex-based composites are limited. Our research group recently reported the incorporation of processed waste mica generated in the mica mining industry into centrifuged natural rubber latex to prepare mica-filled natural rubber latex foam composites (Dananjaya *et al.*, 2022). The study disclosed that the processed waste mica could be used as a promising filler for centrifuged natural rubber latex composites.

In this study, processed waste mica was incorporated into creamed natural rubber latex, which is considered a greener form of concentrated latex with some different latex properties compared to centrifuged latex. The objective of the study is to determine the effect of the use of creamed latex and processed mica waste for the manufacture of natural rubber latex foams with improved physical properties.

Materials and Methods

Natural rubber field latex (30% DRC) was provided by Rubber Research Institute, Ratmalana, Sri Lanka. Waste mica powder was obtained from a mica processing factory in Matale, Sri Lanka. Diammonium hydrogen phosphate (DAHP), sodium alginate (SA), and other industrial-grade compounding ingredients including, ammonia, potassium oleate soap, sodium laurate sulfate (SLS), poly(dicyclopentadiene-co-P-cresol)), sulfur, zinc oxide (ZnO), diphenylguanidine (DPG), sodium silico fluoride (SSF), zinc diethyldithio-carbamate (ZDEC) and zinc 2-mercaptobenzhiolate (ZMBT) were supplied by Richard Peiris Natural Foams Ltd. in Biyagama, Sri Lanka.

Preparation of creamed latex

20 L of field latex (NRL) was collected and preserved with ammonia 0.7% (w/w). For the removal of magnesium ions (Mg^{2+}) present, 36 mL of 10% (w/w) DAHP solution was added, mixed and the mixture was kept undisturbed for an hour. Then to stabilize the latex, 220 mL of 10% potassium oleate soap solution was added and mixed for 15 minutes. Then, 800 mL of 10% sodium alginate, the creaming agent, was added to the latex and mixed vigorously for another 15 minutes. Finally, the mixture was kept undisturbed for 14 days allowing for creaming.

Determination of properties of creamed natural rubber latex

Latex properties of creamed latex were evaluated following the standard test methods mentioned in Table 1.

Table 1. *Standard test methods for evaluation of properties/parameters*

Test	Test method
Dry rubber content (DRC)	ISO 126:2005
Total solid content (TSC)	ISO 124: 2014
Volatile fatty acid number (VFA)	ISO 506: 2020
Mechanical stability time (MST)	ISO 35: 2004 (En)
Alkalinity	ISO 125: 2020

Preparation of processed mica waste (PMW) dispersion

Finely powdered PMW with an average particle size of 19.62±12.52 µm used in this study was previously prepared and characterized (Dananjaya, *et al.*, 2022b). In brief, PMW dispersions were made by ball milling 90 g of sieved mica waste along with 100 g of water and dispersion agents (5 g of dispersol LR and bentonite clay) for 7 days at 100 rpm. Composition analysis, average particle size distribution, and crystal morphology of PMW were determined by inductively coupled plasma–optical emission spectrometer (ICP-OES), particle size analyzer, and scanning electron microscopy (SEM). The characteriza-tion results were published in the previous studies conducted by the same research group (Dananjaya, *et al*., 2022a; Dananjaya, *et al*., 2022b).

Preparation of natural rubber latex foams (NRLFs)

Following the Dunlop process, NRLFs were manufactured using a latex compound prepared according to the formulation shown in Table 2. First, creamed latex was stirred under a continuous air flow for 15 minutes using a laboratory-scale mechanical agitator rotating at 50 rpm to remove the excess ammonia. Then, the mixture was stirred for 20 minutes after adding potassium oleate soap and sodium lauryl sulfate (SLS) into the latex using a magnetic stirrer. Subsequently, sulphur, ZMBT, ZDEC, antioxidants [poly (dicyclopentadiene-co-P-cresol)], and freshly prepared PMW filler dispersions were added into the latex mixture and mixed for another 20 minutes. After maturation for 8 hours at room temperature (28 ˚C), the latex compound was beaten using a hand mixer (Phillips HR-3740) until the volume reached approximately 3 times the initial volume (approximately within 3 minutes). After the required level of foaming was achieved, ZnO and the gelling agents (SSF and DPG) were added together into the mixture and mixed for another 30 seconds using a hand mixer (speed level 3) under the same conditions. Then the latex compound was immediately charged into an aluminum mold and placed in an oven operating at 100 ˚C for 2 hours to complete the vulcanization of the foam sample. Finally, the foam was washed thoroughly with pure water and squeezed well followed by drying in the oven at 70 ˚C for 8 hours. The same technique was used for the preparation of the control foam rubber sample without adding PMW.

Table 2. *Formulation and designation of filled natural rubber latex foams*

Ingredient	**Pphr**					
	R0	**R1**	**R2**	**R3**	**R4**	**R5**
Creamed Latex	100	100	100	100	100	100
50% Potassium oleate soap	6	6	6	6	6	6
50% SLS	0.25	0.25	0.25	0.25	0.25	0.25

Ingredient	Pphr					
	R0	R1	R2	R3	R4	R5
50% ZDEC	1.5	1.5	1.5	1.5	1.5	1.5
50% ZMBT	1.5	1.5	1.5	1.5	1.5	1.5
PMW	0	2	4	6	8	10
50% Sulphur	2.5	2.5	2.5	2.5	2.5	2.5
50% poly (dicyclopentadiene-co-P-cresol)	1.5	1.5	1.5	1.5	1.5	1.5
50% DPG	2	2	2	2	2	2
50% ZnO	6	6	6	6	6	6
12.5% SSF	7	7	7	7	7	7

Density

The density of NRLF samples (5×5×5 cm- l×w×t) was determined following the ASTM D1622-03. Equation 1 was used to calculate the density values.

$$\text{Density} = \frac{\mathrm{M}}{(\mathrm{l} \times \mathrm{w} \times \mathrm{t})} \quad (1)$$

Where, M, l, w, and t stands for mass, length, width, and thickness of the samples, respectively.

Hardness

According to ISO 3386 standard, the hardness of the foam rubber samples having the dimensions of 55 mm (length), 30 mm (width), and 25 mm (thickness) were measured using an Indentation Load Deflection machine (Model HD-F750, China).

Gelling time

The gelling time was taken as the time between the stopping of beating the latex compound and the time at which the latex compound became non-sticky (Dananjaya, *et al*., 2022b).

Fourier transform infrared spectroscopy (FTIR)

Fourier-transform infrared (FTIR) spectra of foam samples were recorded on an FTIR spectrophotometer (Perkin-Elmer Spectrum2, USA) using ATR (attenuated total reflectance) mode (Pike MIRacle single reflection ATR). All the spectra were obtained from 4000 to 400 cm^{-1} at the resolution of 4 cm^{-1} over 8 scans.

Results and Discussion

Latex properties of natural rubber creamed latex

Table 3 shows the characteristics of the creamed latex used in this study. It could be seen that creamed latex used has a dry rubber content (DRC) of 68.6% whereas centrifuged latex has a set value of much lower DRC based on the internationally accepted constant dry rubber content (60±0.02). One of the other major quality parameters is the percentage of the non-rubber present in creamed latex which is calculated as 1.2% and there was not much difference as far as that of the centrifuged latex is concerned.

Table 3. *Characteristics of creamed latex*

Parameter	Value
Total solid content % (w/w)	68.6
Dry rubber content % (w/w)	67.4
VFA number	0.1
Alkalinity % (w/w)	0.7
MST value (seconds)	800

The density of NRLF composites

Figure 1 depicts the density of the NRLF composites showing similar observations reported for NRLF composites filled with different fillers such as kenaf powder, chitin, and eggshell powder (Bashir *et al.*, 2017; Surya *et al.*, 2019; Zhang & Cao, 2020). The density increased in a narrow range from 0.31 to 0.41 g/cm^3 as filler is increased from 0 to 10 phr. PMW has a remarkably higher density (1.8 g cm^{-3}) when compared to the density of natural rubber (0.92 g cm^{-3}). Therefore, the incorporation of dense PMW into the lighter rubber phase increases the density of composites. As a result, the weight of the composite in a unit volume is increased. It should be noted that the hardness values of the composites do not follow the additive rule probably due to the unique porous structure of foam rubber. Even at a level of 10 phr, the density increased only by 25% of that in gum composite, suggesting its possibility to be used in light foam rubber products without having much effect on the weight of the products made out of PMW-filled foam composites. Further, this reduces the cost per unit volume increasing the economic viability of the product.

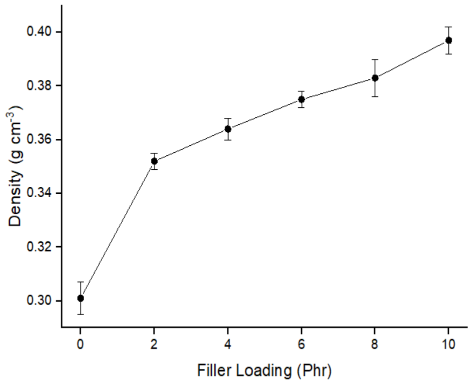

Fig. 1. The effect of PMW loading on the density of NRLFs

Hardness

Figure 2 represents the relation between the hardness of NRLF and mica loading. The hardness mainly denotes the ability of rubber to resist small indentation deformation caused by a hard object. As shown in Figure 2, a gradual improvement in hardness is observed with increasing PMW loading. This trend is also analogous to the general trend reported in the literature for the hardness of filled natural rubber composites (Ramasamy *et al*., 2012; Surya *et al.*, 2019). The hardness of the composites could be improved due to the incorporation of harder rigid filler into the rubber matrix. In addition, resistance exerted by filler particles on the mobilization of natural rubber macromolecules could also contribute to the increased hardness. (Bashir *et al.*, 2017).

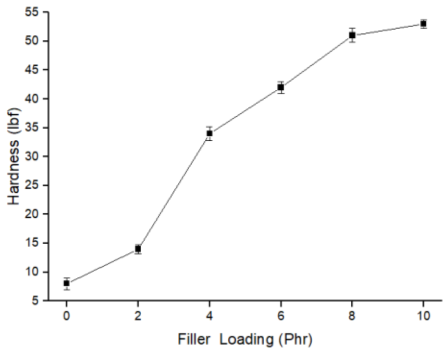

Fig. 2. The effect of PMW loading on the hardness of NRLFs

Gelling time

Gelling time of NRLF with varying PMW loading is illustrated in Figure 3. Gelling time is the period that has taken for the mixture in the liquid form to transform into a gel. Mica can establish physical interactions between the silicate groups in the mica and rubber matrix. Increasing density and the viscosity of the latex phase with the addition of fillers could facilitate the gelling process. The addition of inert foreign particles into latex could improve the nucleation ability of the macromolecules (Lin *et al.*, 2016). These factors may influence the reduction of gelling time with the incorporation of PMW. Short gelling time has a competitive advantage in industrial applications in terms of increased productivity.

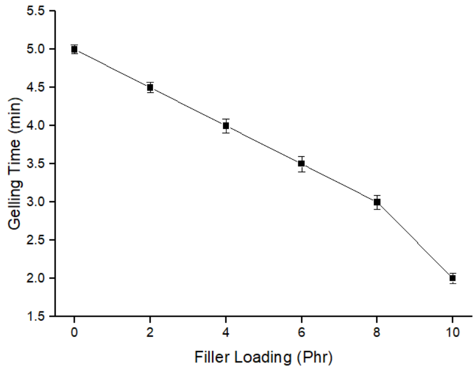

Fig. 3. The effect of PMW loading on gelling time of NRLFs

Fourier transform infrared spectroscopy (FTIR)

Figure 4 shows the composite spectrum of all the samples. Peaks that could be seen in the spectrum are listed in Table 4.The broad peak at 3380 cm^{-1} could be due to the presence of moisture and -OH groups presence in the waste mica. The peaks related to silica (995 cm^{-1}) have deepened with the increase in filler loading. The presence of characteristic peaks of natural rubber (834, 1375, 1452, and 1660 cm^{-1}) in all the samples confirmed that the bonds of natural rubber were not affected by the addition of waste mica.

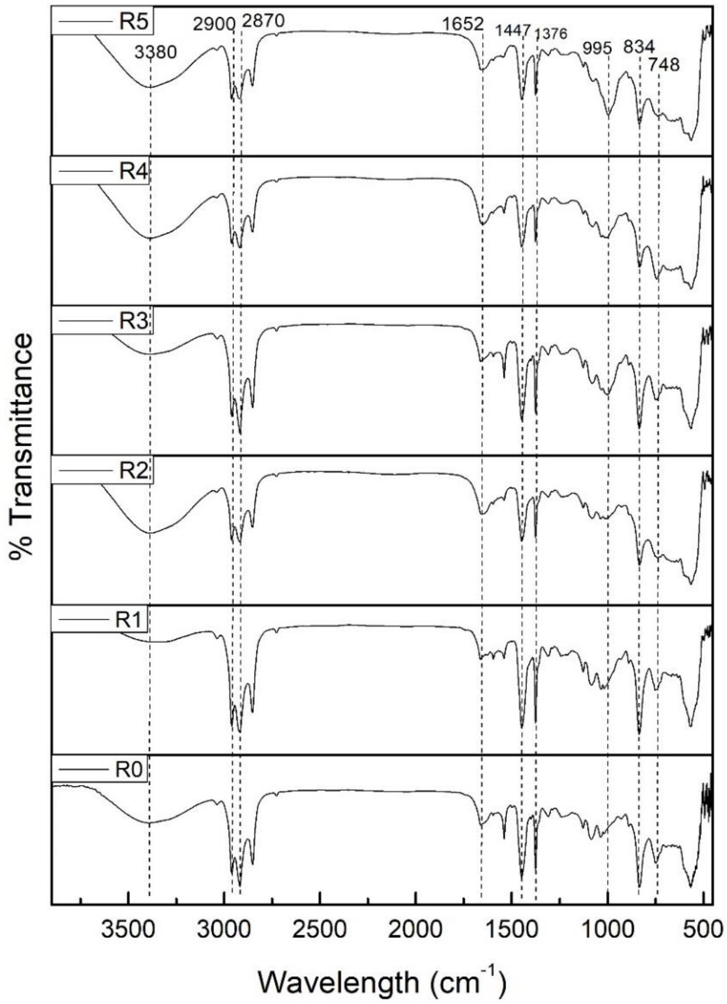

Fig. 4. FTIR spectra of PMW filled NRLF samples

Table 4. *FTIR data for PMW filled NRLF* (Beran, 2002; Suethao *et al*., 2021)

Frequency (cm^{-1})	Description
3380	-OH stretching vibration
2900	stretching vibration of the -C-H bonds in the methyl group of natural rubber
2870	Stretching vibration of -C-H bonds in methylene group
1652	stretching vibration of -C = C bonds natural rubber
1447	Bending vibration of -C-H bond

Frequency (cm^{-1})	Description
1376	Scissoring vibration of $–CH_3$ group
995	Si-O vibration
834	out-of-plane bending vibration of -C-H bonds

Conclusions

This study intended to determine the use of creamed natural rubber latex and processed waste mica for the manufacture of foam rubber with improved properties. The overall results showed that the density and hardness of the natural rubber latex foams could be improved while reducing the gelling time by the addition of processed mica waste powder. Further, FTIR results indicated that the bonds of natural rubber were not affected by the addition of processed mica waste powder. In conclusion, this study revealed that processed waste mica powder could be used to manufacture greener foam rubber products at the cottage level.

Acknowledgment

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Effect of seed quantity on growth performance of rubber seedling plants and quality of planting material

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Abstract

High-quality rubber seeds ensure high seedling performance and successful production of planting materials in the nursery management. An experiment was conducted at Moneragala Sub Station of RRISL in 2020 to investigate the performance of seedling plants raised from different seed quantities to determine the growth and bud-grafting success. Treatments were setup as two times of seed quantity taken and harvested in three rounds (T1-control), three times seed quantity taken and harvested in two rounds (T2), four and five times of seed quantities harvested in one round (T3 and T4). Seed beds of each treatment were arranged according to Randomized Complete Block Design (RCBD) with five replications. Germinated seeds were transferred to the rootstock nursery as soon as the tip of the radical has forced its way through the seed coat. Once the establishment was completed, the growth of seedling plants was evaluated under nursery condition. The seedling plants which were raised from four and five times of seed quantity have significantly increased stem diameter when compared with the control treatment (T1). It was also revealed that dead plant percentage of seedlings raised from control (T1) treatment was high when compared with T3 and T4 treatments. Increasing the number of fresh seeds to four to five times of the required quantity gives more opportunities to select early germinators with high vigor. Therefore, plants that were raised by T3 and T4 treatments have shown a significantly higher bud grafting success (about 80%) as compared to that of T1 and T2 treatments. The overall results revealed that a higher productivity can be achieved with one-time harvested seedlings from four to five times of required seed quantities. However, the seed availability and cost effectiveness of producing planting materials should also be considered in application of suggested method.

Key words: *bud grafting, germination, growth of rootstock, seeds, seedling, stem diameter*

Introduction

The rubber industry plays an important role in the economy of Sri Lanka. The current extent under rubber cultivation is 126,685 ha as per the latest statistics (Anon, 2018). In order to maintain the present rubber extent in the country, about 3.3 per cent of rubber extent should be replanted annually (Seneviratne and Wijesekara, 2017). However, there is a great potential for the expansion of rubber plantations in the country. The annual planting material requirement for new and replanting programs is about 2.5-3 million and plants are being produced in large scale rubber nurseries all over the country.

The annual total seed requirement of the country for establishment of rubber nurseries is around 12 million for the smooth functioning of rubber nurseries rubber nurseries. But, it has been reported that only 25% of the seeds sown in the germination bed produces vigorous root stocks (Seneviratne, 1997). Rubber seeds are collected from rubber fields with the onset of seed fall. There are two nursery seasons in the country corresponding with two seed fall seasons *viz.* January to February in the Intermediate Zone and July to August in the Wet Zone. High quality, vigorous seeds are important for seedling plant development in order to ensure fast growth, disease tolerance and high yield of the rubber tree (Rosli and Akmal, 2019). Rubber seeds are recalcitrant. The loss of viability on storage results in the production of hydrocyanic acid (HCN). Germination of the rubber seed is hypogeal and germination commences within 7 to 10 days under tropical wet climates (Priyadarshan, 2011). Young budded plants are produced by maintaining root stock nurseries for three to four months and bud grafting with authentic bud patches at the bud grafting stage as recommended by RRISL. After the bud grafting, quality planting materials with two whorls of leaf are produced within another four to five-months period. Therefore, the total nursery period for producing young budded plants is about nine months. The quality of planting material cannot be guaranteed only by the external appearance of the plant or the size of the plant. Nursery inspection reports have shown that 20 - 30 percent of planting materials produced in the nursery are young budded plants and remaining 70-80 per cent of rootstock plants cannot be bud-grafted, within three to four months due to the poor and uneven growth. Further, nursery inspection reports have depicted that despite all the requirements, the rootstock plants are grafted continuously for whole nursery period due to poor and uneven growth of seedling plants. This condition paves way for release of only 40 - 50 per cent of the total number of plants in the nursery thus increasing the cost of production. Likewise, the production of quality planting material mainly depends on the availability of quality seeds and thereby producing quality rootstocks nurseries. High quality seeds guarantee better performance of seedlings, increase the efficiency and successful production of planting materials in the nursery. Therefore, the present study was conducted to investigate the performance of seedling plants raised from different seed quantities in order to enhance the growth, bud-grafting success and productivity of planting material production in Sri Lanka.

Materials and Methods

The study area was located in Moneragala (IL1c). The experiment was carried out at a rubber nursery in an undulated flat land in Moneragala Sub Station of RRISL in 2020. Fresh rubber seeds of clone RRIC 121 were collected at the major seed fall during February, 2020. Germination beds were prepared and seeds were sown as per the treatments given in Table 1. Seeds beds of each treatment were arranged according to Randomized Complete Block Design (RCBD) with five replications.

Germinated seeds were transplanted to polybags of rootstock nursery as soon as the tip of the radical has forced its way out through the seed coat, according to rounds given in Table 2. Germination was started on 17th day after sowing. In T1 seed block, germinated seeds were harvested every other day for three rounds as per the RRISL recommendation (Control) which is maximum four rounds. The late germinators were discarded as they did not produce vigorous plants. The rootstock nursery was established by using black polythene bags (300-gauge, size 7"x 18"). They were arranged in single rows according to randomized complete block design (RCBD) with five replications. Each replication consisted of 80 plants per treatment.

According to Table 2, full requirement (100%) of germinated seeds were taken from T3 and T4 treatments 17th day of sowing in one round. The percentage of germinated seeds harvested from T1 and T2 treatments were 70.5% and 92.8% respectively at the first round. Accordingly, treatment structure was as follows:

T1- two times of seed quantity taken and harvested in three rounds (Control)
T2- three times of seed quantity taken and harvested in two rounds
T3- four times of seed quantity taken and harvested in one round
T4- five times of seed quantity taken and harvested in one round

Seedlings were bud grafted after reaching 6-7 mm stem diameter at 1 cm above the soil surface. Plants were bud grafted using clone RRISL 2001.

Table 1. *Treatments and seed quantity*

Treatments	Seed quantity	No. of seeds	Weight of seeds
T1 (control)	Two times of required seedling plants	800	3.2 kg
T2	Three times of required seedling plants	1200	4.6 kg
T3	Four times of required seedling plants	1600	6.3 kg
T4	Five times of required seedling plants	2000	8.2 kg

Table 2. *Percentage of germinated seeds harvested in each round*

Treatment	Seed quantity	Rounds	Percentage of seeds taken after each day of germination		
			17th day	19th day	21st day
T1 (control)	Two times	3	70.5	17.5	3.8
T2	Three times	2	92.8	7.2	-
T3	Four times	1	100	-	-
T4	Five times	1	100	-	-

Measurements

Growth of seedling plants was assessed by measuring the plant stem diameter (at 1cm above soil surface), diameter increment, leaf chlorophyll content, dead plant percentage, dry weight of shoots and roots and Shoot: root ratio. Plant stem diameter; dead plant percentage and leaf chlorophyll content (SPAD unit, from a chlorophyll meter) were measured at monthly intervals commencing from two months after planting. Three leaves were taken to measure chlorophyll unit by averaging all leaflets of leaf samples. Dry weights of seedling plants were taken four months after transplanting to the rootstock nursery. For this purpose, five seedlings from each treatment were uprooted at bud grafting stage and oven dried separately at 80 ^{o}C for 48 hours. In order to estimate shoot: root ratio weights of shoot and roots were separately recorded. Bud grafting success was measured after 21 days of the grafting by observing the successes bud patches.

Statistical analysis

Statistical analysis was done by the analysis of variance followed by a mean separation procedure, using Duncan's Multiple Range Test (DMRT), at a probability level of 0.05. SAS statistical software package – version 9.0 (SAS Inc., USA) was used to analyze data.

Results

Plant stem diameter, diameter increment, dead plant percentage, dry matter content and bud grafting success were assessed in order to evaluate the growth performance of rubber seedling plants under nursery conditions in Moneragala District. The variation of stem diameter of seedling plants under different seeds quantities exhibited a significant variation ($p<0.05$) among treatments (Table 3). The highest stem diameter was recorded in T3 and T4 *i.e.;* four and five times of seed quantity and transferred germinated seeds in one round. Girth increment of seedling plants at four months after planting were calculated by subtracting from initial girth and recorded in Table 3. Girth increment which is referred to as the growth expansion of stem diameter showed a significant increment in T3 and T4. As shown in Table 3, the growth performance of plants that were germinated from two times of seed quantities and taken seeds in three rounds as per the current recommendation (T1) has shown the lowest stem diameter, diameter increment and the highest dead plant percentage when compared with other treatments. There are no marked differences in chlorophyll content of leaves in all treatments. Plants which are raised from T3 and T4 seeds have shown minimum dead plant percentages and higher reachable bud-grafting percentage achieved when compared T1 and T2 seedling plants (Table 3).

Dry matter contents *i.e.;* dry weights of shoot and roots, total dry matter and shoot: root ratio of different treatments are listed in Table 4. The plants raised under T4 *i.e* five-times of required seeds have exhibited a higher total dry weight, shoot and root growth. As depicted in Table 4, total dry matter content and shoot:root ratio of plants varied among treatments.

A similar trend also observed for bud grafting success (Table 5). Plants which were raised by T4 and T3 treatments have shown significantly higher bud grafting success which is about 80% when compared with T1 and T2 treatment plants ($\leq$ 70%) (Table 5).

Table 3. *Effect of seed quantity on dry weight of shoots and roots of rubber seedlings, four months after transplanting into poly bags*

Treatments	Stem diameter at the initial stage (mm)	Stem diameter at the bud grafting stage (mm)	Diameter increment (mm)	Leaf chlorophyll content (SPAD value)	Dead plant %	Budded plants % $\geq$ 6 mm
T1	4.4 ± 0.05^{b}	5.8 ± 0.08^{b}	1.4 ± 0.05^{b}	40.35 ± 2.54^{a}	17.25^{a}	47^{c}
T2	4.2 ± 0.06^{b}	5.7 ± 0.08^{b}	1.5 ± 0.05^{ab}	40.80 ± 1.79^{a}	26.00^{a}	44^{c}
T3	4.9 ± 0.04^{a}	6.7 ± 0.06^{a}	1.7 ± 0.05^{a}	41.38 ± 1.83^{a}	1.25^{b}	71^{b}
T4	5.1 ± 0.04^{a}	6.9 ± 0.06^{a}	1.8 ± 0.04^{a}	42.98 ± 1.90^{a}	0.00^{b}	78^{a}

Table 4. *Dry matter content and Shoot:Root ratio*

Treatment	**Dry weight of shoot (g)**	**Dry weight of root (g)**	**Total dry weight**	**Shoot:Root Ratio**
T1	12.6 ± 2.04	4.3 ± 0.65	16.9	2.93:1
T2	13.1 ± 3.19	4.8 ± 0.97	17.9	2.73:1
T3	18.7 ± 3.21	6.3 ± 1.52	25.0	2.97:1
T4	18.6 ± 2.73	6.9 ± 0.77	25.5	2.70:1

Table 5. *Bud grafting success*

Treatment	No. of plants grafted	Success plants	Success rate (%)
T1	188	128	68
T2	176	123	70
T3	284	225	79
T4	312	256	82

Discussion

In nursery management, producing high-quality planting material at nursery level is a mandatory requirement. Bud grafts of seedling stocks with strong root system markedly influence on the growth of scion (Priyadarshan, 2011). The main objective of this study was to investigate the performance of seedling plants raised from different seed quantities with a view to enhance the quality and quantity of planting material production in Sri Lanka. In the current RRISL recommendation, "germinated seeds should be harvested every other day, and for a maximum of four rounds. Only *ca.* 50% of the seeds will germinate within this period and all the late germinates should be discarded as they will not grow into vigorous plants" (Seneviratne and Nakandala 2021). The results of the present experiment have shown that the growth attributes of T1 treatment have not performed well when compared with the T3 and T4 (Table 3). Increasing the quantity of fresh seeds in four to five times of required seedling plants gives more chance to harvest early germinators with high vigor. Those have shown increment of stem diameter and other growth attributes at four months after transplanting. As depicted in Table 3. Growth of T4 plants which were harvested from five times of seed quantity have shown enhanced performance on stem diameter, chlorophyll content and dead plant percentages when compared the other treatments. This might be due to the harvest of early germinators at the first instance of emergence with high metabolic activity in high-quality seeds which probably provide readily available energy for the emergence and seedling growth (Duand, 2008). The results showed that the higher the quantity of seeds sown for four and five led to harvest high-quality vigorous seeds at once, have an ability to produce evenly grown rootstock with less variation (Table 3).

The variation of dry matter content of stock plants (Table 4) revealed that there were marked difference in dry matter accumulation in T3 and T4 treatments when compared with T1 and T2. Therefore it is revealed that the plants raised by T4 and T3 seed quantities reached bud grafting stage earlier than the other two treatments (Table 5). In bud grafting also it was recorded that more than 70% of seedling plants under T3 and T4 treatments could be bud grafted at four months after transplanting whilst T1 and T2 have shown less than 45% of bud

grafting. This lead to a higher bud grafting success in T4 and T3 *i.e* more than 80% success (Table 5).
Finally, cost of planting materiel production was calculated and tabulated in Table 6. In this experiment, the cost per budded-plant was mainly determined by the number of success plants produced and cost of seed quantity used for producing young budding plants.

Table 6. *Cost of production of planting material*

Treatment	Seed quantity used (kg)	Cost of seeds used at a rate of Rs.60 per kg (Rs.)	Total cost of production (Rs.)	Number of success plant produced	Cost of production per plant (Rs.)
T1 – two times	3.2 kg	192.00	25,408.00	128	198.50
T2 – three times	4.6 kg	272.00	25,708.00	123	209.00
T3 – four times	6.3 kg	378.00	24,890.00	225	110.62
T4 – five times	8.2 kg	492.00	24,872.00	256	97.15

Conclusions

In conclusion, it is revealed that the growth performance of seedling or the stock plants raised from different seed quantities from four and five times seeds and harvested in one round significantly increased the growth attributes of seedling plants along with bud grafted plants. Results confirmed that rootstock plants which were raised by four and five times of seed quantity have resulted in a higher rate of bud-grafting success which will remarkably increase the profit of young budding nurseries. However, it is important to consider the availability of rubber seeds in a particular season and cost effectiveness of producing planting materials before selecting a suitable quantity of seed stock.

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A comparison of symptom-development by different isolates of *Phellinus noxius*: the causal agent of brown root disease of rubber

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Abstract
Brown root disease caused by the pathogen Phellinus noxius is an emerging disease condition in the Sri Lankan rubber industry. The possibility of the development of variant pathogen isolates with more pathogenic forms can be considered as one of the factors influencing the increased frequency of its occurrence in the country during the recent past especially in certain parts of the country. The study was conducted to evaluate the variability in symptom development ability of 24 Sri Lankan isolates of Phellinus noxius. A pot trial was carried out by artificially inoculating three months-old rubber seedlings with an inoculated mixture of rice bran and saw dust. Forty seedlings were inoculated with each pathogen isolate, and another forty seedlings were kept as controls without inoculation. Starting after two weeks of inoculation, ten destructive samplings were carried out at two weeks intervals to observe the pathogenicity levels of the different isolates. Based on the below-ground signs and symptoms, a pathogenicity score was given to each uprooted plant. Then those ranks were subjected to Kruskal–Wallis analysis and subsequently to the Wilcoxon rank-sum test. A variation of pathogenicity was observed among the 24 Phellinus noxius isolates. As all the isolates showed a stabilized pathogenicity value at three and half months of the inoculation, a cluster analysis was performed for the mean score values of pathogenicity rank of different isolates at three and half months and the developed dendrogram showed that the test isolates were separated into two main clusters at the similarity level 0.8. It denotes that the studied pathogen population consists of variability and these results can be applied at the development of management strategies.

Key words: brown root disease, dendrogram, rubber, symptom development

Introduction

Brown root disease caused by *Phellinus noxius* is one of the important root pathogens of rubber plantations in Sri Lanka (Silva *et al.,* 2013, 2017 and 2019). It is distributed in tropical and sub-tropical regions in Asia (including Southern Japan, Mainland China, Hong

Kong, Taiwan and Malaysia), Central America, Africa and Oceania (Larsen *et al.* 1990; CABI/EPPO, 1997; Chang *et al.* 1998; Ann *et al.*, 2002). Brown root disease has a very wide host range including economically important plantation and other crop species such as, *Camellia sinensis* (tea), *Coffea spp.* (coffee), *Artocarpus altilis* (breadfruit), *Cinnamomum spp*. (cinnamon), *Theobroma cacao* (cocoa), *Cocos nucifera* (coconut), *Garcinia mangostana* (mangosteen), *Citrus sp*. (citrus), *Mangifera indica* (mango), *Artocarpus heterophyllus* (jack), *Tectona grandis* (teak) and *Swietenia mahogoni* (mahogany). *Phellinus noxius* spreads by root contact and persists in roots and stumps of infected plants for more than 10 years after the death of the host (Chang 1996). The economic impact of *P. noxius* is highly variable and a loss of up to 60% can be caused in some other rubber-growing countries (Nandris *et al.*, 1987). Though the brown root disease has been reported in Sri Lankan rubber during the early phase, and has been stated probably the most common root disease of the rubber tree in the country at that time (Petch, 1911 and 1921), until the recent past its significance has not been well recognized.

The increased frequency of its occurrence in the country during the recent past have to be discussed especially in certain parts of the country. The factors influencing may include the expansion of the cultivation to non-traditional areas in dry and intermediate parts of the country and the possibility of the pathogen to be mutated into more virulent forms. Considering the diversity of soi1 and climatic conditions in which the pathogen develops, and the large number of tree species they attack, it is necessary to have an understanding whether there is any variation in symptom development ability (pathogenicity) within the population of the fungus. Ultimately, this heterogeneity in the aggressiveness of the parasite would be helpful in the development of management strategies against the disease. Therefore, this study was carried out with the objective of reviewing the variability in pathogenicity among the Sri Lankan isolates of the *P. noxius* in order to facilitate the development of effective management strategies.

Materials and Methods

Collection of disease samples

Twenty four number of *P. noxius* isolates available in the Department of Plant Pathology and Microbiology, Rubber Research Institute of Sri Lanka, (collected from mid-2013 to mid-2016) were used for the study (Table 1). These isolates represented different agro-ecological regions of the country.

Table 1. *Description of the isolates in the isolate collection*

Name of the isolate	Host	Location	GPS locate	Agro-ecological Zone
1	*Hevea brasiliensis*	Galigamuwa, Sri Lanka	7° 14' 12.7104" N 80° 18' 33.714" E	WL2b
2	*Hevea brasiliensis*	Matugama, Sri Lanka	6° 31' 40.1124" N 80° 5' 39.1272" E	WL1a
3	*Hevea brasiliensis*	Agalawatta, Sri Lanka	6° 31' 48.432" N 80° 9' 24.7932" E	WL1a
4	*Hevea brasiliensis*	Galigamuwa, Sri Lanka	7° 14' 7.3968" N 80° 18' 28.1556" E	WL2b
5	*Hevea brasiliensis*	Moneragala, Sri Lanka	6° 50' 46.1004" N 81° 19' 29.4924" E	IL1c
6	*Hevea brasiliensis*	Galagedara, Sri Lanka	7° 22' 18.6564" N 80° 30' 37.854" E	IL1a
7	*Hevea brasiliensis*	Moneragala, Sri Lanka	6°53' 30.663 "N 81°18' 31.948"E	IL1c
8	*Hevea brasiliensis*	Badalkumbura, Sri Lanka	6°55’1.165"N 81°13'31.246"E	IM2b
9	*Hevea brasiliensis*	Kithulgala, Sri Lanka	6° 59' 40.0992" N 80° 24' 43.1064" E	WM1a
10	*Hevea brasiliensis*	Kithulgala, Sri Lanka	6° 59' 43.7784" N 80° 24' 40.6332" E	WM1a
11	*Hevea brasiliensis*	Dehiowita, Sri Lanka	6° 57' 55.9548" N 80° 15' 59.0364" E	WL1a
12	*Hevea brasiliensis*	Agalawatta, Sri Lanka	6° 31' 53.2092" N 80° 9' 19.8504" E	IL1c
13	*Hevea brasiliensis*	Deraniyagala, Sri Lanka	6° 55' 45.9048" N 80° 20' 21.498" E	WL1a
14	*Hevea brasiliensis*	Haldummulla, Sri Lanka	6° 45' 33.5556" N 80° 52' 40.4544" E	IM2a
15	*Hevea brasiliensis*	Hopton, Sri Lanka	6°59' 31.56"N 81°11'55.68"E	IL1c
16	*Hevea brasiliensis*	Lunugala, Sri Lanka	7°01'60.00"N 81°11'60.00" E	IM2b
17	*Hevea brasiliensis*	Moneragala, Sri Lanka	6° 51' 49.9104" N 81° 20' 43.6164" E	IL1c
AH 1	*Cereya arborea*	Warakapola, Sri Lanka	7°08'22.8"N 80°14'04.2"E	WL2b
AH 2	*Gmelina arborea*	Badalkumbura, Sri Lanka	6°55’1.165"N 81°13'31.246"E	IM2b
AH 3	*Bridelia retusa*	Bulathkohupitiya, Sri Lanka	7°05' 27.838"N 80°20' 9.449"E	WL1a

Name of the isolate	Host	Location	GPS locate	Agro-ecological Zone
AH 4	*Mangifera indica*	Moneragala, Sri Lanka	6°53' 30.663 "N 81°18' 31.948"E	IL1c
AH 5	*Artocarpus heterophyllus*	Gampaha, Sri Lanka	7°06 2.652 "N 79°59'42.359"E	WL3
AH 6	*Tectona grandis*	Hopton, Sri Lanka	6°59' 31.56"N 81°11'55.68"E	IL1c
AH 7	*Cinnamomum zeylanicum*	Polgahawela, Sri Lanka	7°20' 26.967"N 80°16' 41.978"E	IL1a

Preparation of P. noxius inoculum

For the artificial inoculation, the method described by Bartz in 2007 was used with modifications. A medium comprising of rice bran and saw dust (1:2 w/w) with 15% (w/w) moisture was used as the carrier medium. The prepared medium was autoclaved for 45 minutes at 121ºC in polythene bags Two agar blocks of 30 cm^2 from the advancing margin of each test fungal culture grown on MEA was transferred aseptically into each bag of autoclaved medium and incubated for 12 weeks at RT (28 ± 2 ºC) under dark conditions.

Inoculation of rubber seedlings

Three-month-old rubber seedlings raised under controlled greenhouse conditions at RRISL were used for the study. Polybags (30 cm x 30 cm) were filled with unsterilized soil collected from rubber rhizosphere and four seedlings were planted in each bag. The inoculation was carried out by incorporating 100 g of inoculated medium (with respective fungal isolate) into the potting medium in a way to ensure contact with the collar region of each seedling. The completely randomized block design was adopted in the experiment. Forty seedlings were inoculated with each isolate, and another 40 seedlings without inoculation were kept as the control. Soil moisture level was checked every two days using a neutron moisture gauge and was kept constant.

Assessment on the pathogenicity level

Starting after two weeks of inoculation, ten destructive samplings were done (each time four seedlings inoculated with each isolate) at two weeks intervals to observe the pathogenicity levels of different pathogen isolates against rubber seedlings. Based on the signs and symptoms, a score was assigned for the foliar symptoms as; 0 (no infection), 1 (mycelial crust without root decay), 2 (mycelial crust with root decay) and 3 (plant death). For each uprooted plant a score was assigned for the root and collar signs and symptoms as; 0 (no infection), 1 (mycelial crust without root decay), 2 (mycelial crust with root decay) and 3 (plant death).

Statistical analysis

The pathogenicity levels recorded as ranks were subjected to Kruskal–Wallis analysis and subsequently to the

Wilcoxon rank-sum test, as the scores obtained for the different isolates were significant. Spearman's rank correlation coefficient was calculated to assess whether a correlation exists among the two sets of pathogenity ranks: foliar and roots. A cluster analysis was performed for the mean score values of pathogenicity ranks and dendrograms were developed for the Mean Score Values of Pathogenicity rank for both foliar and root symptoms.

Results and Discussion

The spearman's rank correlation coefficient of the two sets of pathogenicity ranks: foliar and roots showed a correlation (Correlation 0.820, adjusted for ties 0.787 at the probability < 0.001). The mean score values of the pathogenicity rank assigned for foliar and collar symptoms among the 24 *Phellinus noxius* isolates are shown in Tables 1 and 2, respectively.

Table 1. *The mean score values of the pathogenicity rank assigned for foliar symptoms*

Isolate	Mean score values of the pathogenicity rank (foliar) at different incubation durations*									
	0.5 Months	1 Months	1.5 Months	2 Months	2.5 Months	3 Months	3.5 Months	4 Months	4.5 Months	5 Months
1	47	45.25	33	34.75	25.25	43.5	42.5	42.5	42.5	42.5
2	47	33	33	24.125	25.25	18.5	18	18	18	18
3	59	57.5	44.5	43.5	62	64.5	63.5	63.5	63.5	63.5
4	47	45.25	51.25	64.75	62	54	53	53	53	53
5	47	57.5	44.5	45.375	33.875	33	32	32	32	32
6	47	71.3	44.5	45.375	53.375	64.5	63.5	63.5	63.5	63.5
7	47	33	33	24.125	25.25	18.5	18	18	18	18
8	47	57.5	44.5	34.75	33.875	43.5	53	53	53	53
9	71	57.5	69.5	73.5	88.25	89.25	89	89	89	89
10	47	57.5	56	56	52.25	43.5	42.5	42.5	42.5	42.5
11	47	45.25	44.5	45.375	33.875	33	32	32	32	32
12	47	57.5	56	64.75	62	54	53	53	53	53
13	47	57.5	56	45.375	52.25	54	53	53	53	53
14	47	33	44.5	34.75	25.25	25.75	25	25	25	25
15	47	45.25	44.5	45.375	52.25	43.5	42.5	42.5	42.5	42.5
16	47	57.5	62.75	73.5	65.375	69.25	68.5	68.5	68.5	68.5
17	47	45.25	44.5	34.75	33.875	33	32	32	32	32
AH1	47	45.25	56	56	62	64.5	63.5	63.5	63.5	63.5
AH2	47	57.5	67.5	73.5	71.75	79.75	79	79	79	79
AH3	47	57.5	44.5	54.125	62	54	53	53	53	53

Isolate	**Mean score values of the pathogenicity rank (foliar) at different incubation durations***									
	0.5 Months	**1 Months**	**1.5 Months**	**2 Months**	**2.5 Months**	**3 Months**	**3.5 Months**	**4 Months**	**4.5 Months**	**5 Months**
AH4	47	33	33	34.75	25.25	18.5	18	18	18	18
AH5	47	45.25	44.5	45.375	42.5	54	53	53	53	53
AH6	47	45.25	44.5	45.375	52.25	54	53	53	53	53
AH7	47	69.75	67.5	64.75	62	54	63.5	63.5	63.5	63.5

*****Note that the critical difference is 4.56 to compare the values within the columns

Table 2. *The mean score values of the pathogenicity rank assigned for root symptoms*

Isolate	**Mean score values of the pathogenicity rank (root) at different incubation durations**									
	0.5 Months	**1 Months**	**1.5 Months**	**2 Months**	**2.5 Months**	**3 Months**	**3.5 Months**	**4 Months**	**4.5 Months**	**5 Months**
1	48.5	44.5	48.5	50	44.75	59.875	57.75	57.75	57.75	57.75
2	48.5	44.5	36.5	38	33.125	21.75	20	20	20	20
3	48.5	44.5	60.5	50	51.5	50.125	48.25	48.25	48.25	48.25
4	48.5	56.875	60.5	50	56.375	51	48.5	48.5	48.5	48.5
5	48.5	44.5	48.5	38	33.125	31.5	39	39	39	39
6	48.5	61	48.5	50	44.75	51	48.5	48.5	48.5	48.5
7	48.5	44.5	36.5	26	21.5	21.75	20	20	20	20
8	48.5	56.875	48.5	50	44.75	51	48.5	48.5	48.5	48.5
9	48.5	69.25	60.5	74	81.5	91	90.5	90.5	90.5	90.5
10	48.5	44.5	48.5	50	44.75	50.125	48.25	48.25	48.25	48.25
11	48.5	44.5	36.5	38	44.75	31.5	29.5	29.5	29.5	29.5
12	48.5	56.875	48.5	50	56.375	68.75	67	67	67	67
13	48.5	44.5	36.5	50	44.75	41.25	48.5	48.5	48.5	48.5
14	48.5	44.5	36.5	38	44.75	31.5	29.5	29.5	29.5	29.5
15	48.5	44.5	48.5	38	33.125	31.5	29.5	29.5	29.5	29.5
16	48.5	69.25	60.5	50	56.375	59.875	57.75	57.75	57.75	57.75
17	48.5	44.5	36.5	38	44.75	31.5	29.5	29.5	29.5	29.5
AH1	48.5	56.875	48.5	62	68	68.75	76.25	76.25	76.25	76.25
AH2	48.5	56.875	60.5	74	68	68.75	67	67	67	67
AH3	48.5	44.5	60.5	50	44.75	50.125	48.25	48.25	48.25	48.25
AH4	48.5	44.5	36.5	38	33.125	31.5	29.5	29.5	29.5	29.5

	Mean score values of the pathogenicity rank (root) at different incubation durations*									
	0.5 Months	**1 Months**	**1.5 Months**	**2 Months**	**2.5 Months**	**3 Months**	**3.5 Months**	**4 Months**	**4.5 Months**	**5 Months**
AH5	48.5	44.5	48.5	50	44.75	41.25	48.5	48.5	48.5	48.5
AH6	48.5	56.875	48.5	50	56.375	59.875	67	67	67	67
AH7	48.5	44.5	60.5	62	68	68.75	67	67	67	67

***** Note that the critical difference is 4.56 to compare the values within the columns

According to the results, no isolate has shown either foliar or root symptoms at 2 weeks of inoculation and all the isolates have initiated a stabilized pathogenicity value at three and half months of inoculation.

As a stabilized pathogenicity value has been initiated for all the isolates at three and half months of inoculation, cluster analysis was performed for the mean score values of pathogenicity rank that time duration and the dendrograms were developed for the Mean Score Values of Pathogenicity rank for both foliar and root symptoms (Figs. 1 & 2).

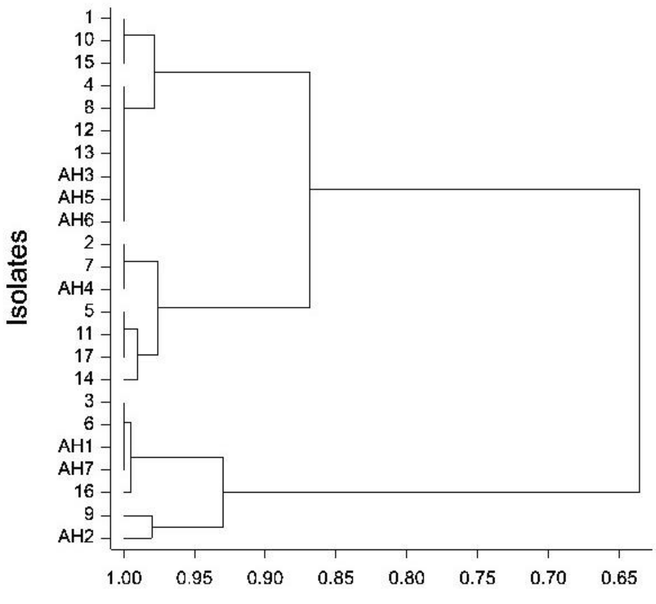

Fig. 1. Dendrogram for the Mean Score Values of Pathogenicity rank at 3.5 months of inoculation (Foliar)

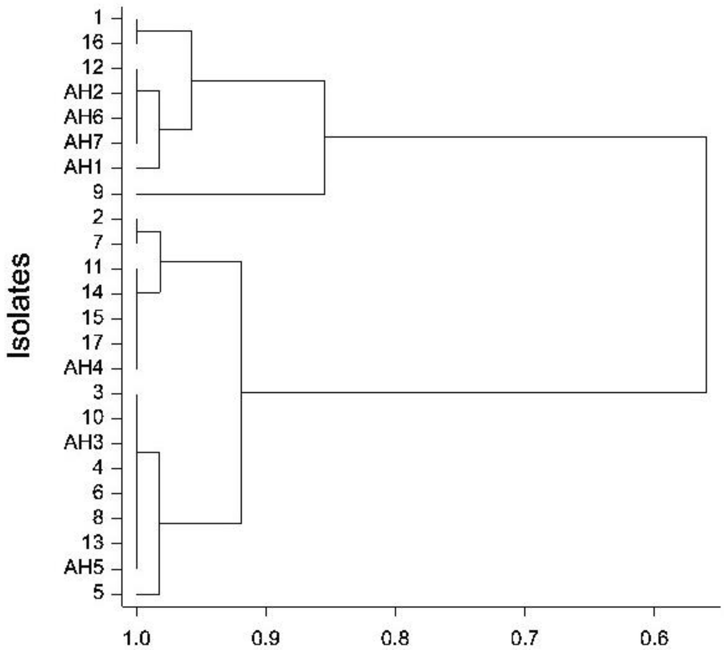

Fig. 2. Dendrogram for the Mean Score Values of Pathogenicity rank at 3.5 months of inoculation (Root)

According to the dendrograms for the Mean Score Values of pathogenicity rank for both foliar and root symptoms, it could be observed that the test isolates were separated into two main clusters at the similarity level 0.8. Isolate 9 which has been collected from Kithulgala, Sri Lanka (WM1a) was the most virulent, while the isolate 7 which has been collected from Moneragala, Sri Lanka (IL1c) was the least pathogenic.

In both foliar and root pathogenicity development, the isolates 16, (from rubber from Lunugala, Sri Lanka-IM2b) AH1 (from *Cereya arborea* from Warakapola, Sri Lanka-WL2b) and AH2 (from *Gmelina arborea* from Badalkumbura, Sri Lanka - IM2b) have grouped with Isolate 9 in the cluster and they can be considered as more virulent isolates.

Similar to this study, in a study carried out by Nandris *et al.* in 1987 on the variability in pathogenicity among several *P. noxius* isolates using segments of rubber tree branches, root penetration has occurred even with the least virulent strains used. Therefore, they have assumed that the differences in pathogenicity would be revealed mainly during tap root colonization. On this point, the speed of development of root necrosis toward the collar seemed to play an important role in pathogenesis. Ectotrophic development of *P. noxius* on plant roots has been proven by Nandris in 1985, and Garrett (1970) has established the “ectotrophic infection habit” as the more rapidly a parasite progresses into the tap root, the less time the plant has to react. It appears that in this experiment, contact with the roots is asynchronous and accordingly the initial moment of infection had fluctuate as a result of the biology of the fungus which does not possess a mycelial structure comparable to rhizomorphs of *R. lignosus. P. noxius* contacts the roots by means of a crusty mycelial sleeve which has a slower rate of development and Nandris *et al.* in 1987 suggest that this fact may involve an underestimation of the pathogenic potential of this fungus. Moreover, they state that the failure to make contact with the host may be the weak point in the success of artificial inoculation with *P. noxius*.

In the study carried out by Nandris *et al.* in 1987, the mortality rate has declined from the third month on, suggesting a reduction in fungal activity, while pathogenicity ranks: both foliar and root has been stabilized at 3 had half months of the inoculation. This decline has been described in previous work with rubber seedlings artificially infected by *Rigidoporus lignosus* (Nicole *et al.*, 1983) and with Eutcalyptus infected by Armillaria (Leach, 1937) using two hypotheses: a decrease of the fungal activity due to the exhaustion of trophic reserves in the woody sticks of the inoculum (Geiger *et al.*, 1986 b) and a delay of the colonization of the roots by the fungus induced by the development of host resistance (Geiger *et al.*, 1986a; Nicole *et al.*, 1986) and has been confirmed by epidemiological observations in rubber plantation (Nandris, 1985).

When the pathogenicity of the different isolates of *P. noxius* is concerned, the varying levels of pathogenicity, demonstrate an avenue to correlate it with the enzyme production capabilities of different strains. However, Nichol *et al.* 1985 states that the attempts to correlate pathogenicity with the capacity of different strains to degrade plant polymers in vitro had not furnished positive results. Nandris *et al.* in 1987 and Nichole *et al.* 1983 state that, the heterogeneity in pathogenicity among isolates demands testing of many isolates when a control method is developed.

Moreover, they state that, this fact must be taken into account particularly in the case of resistance breeding.

In this study, to distinguish differences in virulence among isolates, it was attempted to approach natural conditions and consequently the inoculum was placed close to the tap root instead of inserting it. The good association between the development of foliar symptoms and the damage to roots belowground in this study can be considered as a great advantage in future similar studies as it is generally difficult, costly and time consuming to excavate roots for observation of symptoms. In some other studies as well, foliar inspection was often relied upon identifying infected trees in the field (Nandris *et al.* 1987, Ann *et al.* 2002).

From a practical perspective, the heterogeneity in pathogenicity observed among isolates demands many isolates to be tested when control methods are developed *i.e.* at the screening of fungicides, they have to be screened against a set of fungal isolates representing the different clusters developed by the above dendrograms.

Conclusions

A variation of pathogenicity was observed among the *Phellinus noxius* isolates and the set of test isolates separated into two main clusters at the similarity level 0.8. Moreover, this heterogeneity in the pathogenicity of the pathogen population has to be considered in the development of management strategies.

Acknowledgement

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Evaluation of suitability of sesame oil as an alternative for aromatic processing oil in natural rubber composites

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Abstract

Polycyclic aromatic oils, high in aromatic content are used in tyre compounds as processing aids and these have been found to be carcinogenic. Therefore, it is necessary to find processing aids consisting of a low content of aromatics which would help to overcome the problem associated with the use of petroleum-based aromatic oils.

The main aim of this research was to develop carbon black filled natural rubber (NR) composites using environmentally friendly sesame oil as the processing aid. Initially sesame oil was characterized using Fourier Transform Infra-Red analysis. Thereafter, a series of NR based tyre tread compounds was prepared by varying the sesame oil loading from 3-9 phr at 2 phr intervals. Cure characteristics, physico-mechanical and swelling properties of these composites were evaluated and compared with those of the composite prepared with the aromatic processing oil, Dutrex-R (control). Dispersibility of carbon black in all the NR composites was assessed.

Viscosity, processing safety and cure rate of the composite produced with 5 phr sesame oil were higher compared to the control and indicated that the oil behaves as a co-activator in rubber compounds. Hardness, modulus at 100% elongation and abrasion volume loss of the vulcanizates prepared with more than 5 phr sesame oil were lower, whereas tensile strength, elongation at break and resilience were higher than those of the control. Tear strength and compression set of the vulcanizates prepared with 5 phr sesame oil were comparable to those of the control. Further, the former vulcanizate showed a higher and lower swelling indices in toluene and water, respectively compared to the control. Furthermore, the vulcanizates prepared with sesame oil showed better ageing resistance in comparison to the control. Hence, sesame oil could be a suitable alternative for Dutrex-R in tyre tread compounds at 5 phr level.

Key words: cure characteristics, physico-mechanical properties, polycyclic aromatic oils, sesame oil, swelling index, thermal ageing

Introduction

Petroleum-based aromatic oils, widely used in the tyre industry as processing aids have a greater aromatic content than petroleum-based naphthenic and paraffinic oils. Higher aromatic content indicates the presence of polycyclic groups in the oils. Aromatic oils have aliphatic hydrocarbon surface groups as aromatic substituent. Paraffinic and naphthenic oils have aliphatic hydrocarbon as short chain compound or substituent and all the natural oils including sesame oil have aliphatic carboxylic acid ester, alkyl long-chain and long chain aliphatic carbonyl compound surface groups. These aromatic oils containing polycyclic aromatic hydrocarbons have been found to release carcinogenic compounds to the environment (Dasgupta *et al.,* 2007). Hence, there is a growing interest for the search of processing aids low in aromatic content namely natural oils as alternatives for polycyclic aromatic (PCA) oils.

The focus nowadays in the rubber industry is towards identifying eco-friendly materials such as plant-based materials to substitute the harmful petroleum oils. As a result, markets for plant-based sustainable and biodegradable oil materials are growing and use of these oils is gaining popularity. If these oils can be used to replace petroleum based carcinogenic processing oils in natural rubber composites, it would help in the reduction of generation of carcinogenic compounds to the environment safeguarding the lives of human beings.

Sesame oil contains considerable amounts of linoleic, oleic, stearic, and palmitic acids. Some natural oils including sesame oil show flash and fire points higher than 200℃, whereas these points are higher than 160℃ in the case of petroleum oils. Flash and fire points are one of the important criteria for determining the processing safety, whilst handling the rubber compound during mixing, calendaring, extrusion, etc. Higher flash and fire points of oils always indicate good processing safety. High flash and fire points of natural oils may be due to the presence of carbonyl groups, alkaloids groups, etc. Such groups are absent in the case of petroleum-based oils, where the major groups are long chain alkyl type (Dasgupta *et al.,* 2007).

Early work reported that some petroleum oils show higher aniline point values, whereas natural oils including sesame oil show lower values. Aniline point indicates the presence of aromatic rings in the oils. As all the natural oils show very low aniline points, the compatibility of these oils with the general-purpose polymers like NR, styrene-butadiene rubber (SBR), and polybutadiene rubber (BR), was found to be better (Dasgupta *et al.*, 2007).

Studies have been conducted in the past using plant-based vegetable oils as processing aids in rubber composites. Palm oil, soybean oil and rapeseed oil are the globally important vegetable oils because of their high worldwide production and reasonable cost for large-scale industrial applications (Zhang *et al.*, 2017). Soybean oil, palm oil and sunflower oil were found to be better alternative processing aids than petroleum based aromatic oils. In addition, soybean oil was found to behave as a co-activator in carbon black filled NR composites (Jayewardhana *et al.*, 2009). Some of these vegetable oils were modified in the past with the aim of improving the processing behavior and properties of rubber composites. In one of these studies, effect of epoxidized vegetable oils as processing aids and activators in carbon black filled NR composites have been evaluated (Chandrasekera *et al.*, 2011). In another study, the plasticizing effect of epoxidized palm oil (EPMO) was compared with that of virgin palm oil and petroleum-based aromatic oil (AO) in carbon black (CB) filled SBR composites. At 3 phr loading of processing oil, the tensile strength of an EPMO-plasticized SBR/CB composite was comparable to that of an AO-plasticized SBR/CB composite (Lee and Song, 2019). Kumarjyoti *et al.* (2021) have reviewed the advancements in the application of renewable vegetable oils instead of non-renewable petroleum-based oils as processing aids for manufacture of commercially suitable sustainable rubber products. However, effect of sesame oil on physico-mechanical properties of NR composites has not been reported in literature. Hence, this research was conducted to assess the suitability of sesame oil as an alternative for petroleum-based aromatic processing oil, Dutrex R in carbon black filled NR composites in relation to physico-mechanical properties.

Experimental

Materials

Ribbed Smoked Sheet (RSS) rubber was provided by the Dartonfield Estate, Agalawatta. Organic virgin sesame oil was purchased from Coconut Miracle Ltd, Sri Lanka. Dutrex-R and CBS (N-cyclohexyl benzthiazyl sulphenamide) was supplied by Samson Compounds (Pvt.) Ltd., Galle. The other compounding ingredients namely carbon black, zinc oxide, stearic acid, IPPD (N-isopropyl–N’–phenyl–p-phenylenediamine), sulphur and toluene were purchased from Glorchem Enterprises, Colombo, Sri Lanka.

Methods

Initially, Fourier Transform Infra-Red (FTIR) analysis was conducted on virgin sesame oil and Dutrex-R and the two spectra were compared. Thereafter, five NR composites were prepared with the aid of a laboratory two-roll mill according to the tyre tread formulation given in Table 1. The composites were designated according to the content of the processing aid (Table 2). The mixing cycle employed in the preparation of these composites is given in Table 3.

Table 1. *Tyre tread formulation used in the preparation of NR composites*

Compounding Ingredient	Quantity (phr)
RSS	100
ZnO	5
Stearic acid	2
Carbon black (N330)	50
Processing oil (Dutrex-R/Sesame oil)	5/3, 5, 7 or 9
IPPD	1.5
CBS	1.5
Sulphur	2.5

phr = parts per hundred parts of rubber

Table 2. *Amount of processing oil used in the preparation of NR composites*

Compound No.	Name of processing aid	Amount (phr)
T0	Dutrex R (Control)	5
T1	Sesame oil	3
T2	Sesame oil	5
T3	Sesame oil	7
T4	Sesame oil	9

Table 3. *Mixing cycle used in the preparation of NR composites*

Compounding ingredient	Total mixing time (minutes)
Added RSS	0
Added ZnO + stearic acid	3
Added IPPD	4
Added ½ (HAF-N330 + Processing Oil)	5
Added ½ (HAF-N330 + Processing Oil)	6
Added CBS	7
Added sulphur	8
Dumped	9

Dispersibility of carbon black in the NR composites was analyzed using a dispergrader (Future Foundation, India). Cure characteristics, physico-mechanical properties, ageing resistance and swelling properties of the composites were determined as given below.

Determination of cure characteristics of NR composites

Cure characteristics namely, minimum torque (M_L), maximum torque (M_H), scorch time (t_{s2}), optimum cure time (t_{90}), cure rate index (CRI) and delta cure (M_H-M_L) of the five NR composites were obtained from the rheographs of MonTech D-RPA 3000, Germany according to ISO 6502-3 Part 3 at 150 ^{o}C.

Preparation of vulcanised test pieces

The five NR composites were placed in test piece moulds and pressed between the platens of a hydraulic hot press (Shiran Rubber Industries, Sri Lanka). The composites were cured at 150 ^{o}C temperature and applied pressure of 0.25-0.35 MPa according to respective optimum cure times obtained from the rheographs. After curing, the test pieces were removed from the moulds and immediately cooled under tap water to prevent further curing. The test pieces were conditioned at room temperature for 16 hours before carrying out testing.

Measurement of physico-mechanical properties of NR vulcanisates

An Instron tensile testing machine was used to measure the tensile properties of the rubber vulcanisates in accordance with ISO 37: 2017 at room temperature (27±2 ^{o}C) at a grip separation rate of 500 mm/min. Tear strength of the vulcanisates was measured using angle (Die B) test pieces with the aid of the same machine as per ISO 34-1: 2022. Hardness of the vulcanisates was measured by a "Digi Test" hardness tester for hardness in the IRHD N-scale as per ISO 48: 2018. Resilience of the vulcanisates was measured by a Wallace Lupke pendulum in accordance with ISO 4662: 2017. Abrasion volume loss of the vulcanisates was determined using a DIN abrasion tester in accordance with DIN 53516. Compression set of the vulcanisates was determined using a compression set apparatus (Wallace Instruments, UK) according to ISO 815-1: 2019**.** The test-pieces were compressed for 72 hours at room temperature. In addition, equilibrium swelling measurements were conducted and percentage swelling in toluene as well as in water was determined.

Determination of thermal ageing resistance of NR vulcanisates

Tensile and tear strengths were evaluated after ageing. Ageing was carried out in an air circulating oven at 100 ^{o}C (Sanyo Gallenkamp, UK) for 22 h according to ISO 188: 2011.

ONE WAY-ANOVA statistical analysis using Minitab 17 was employed to measure the impact of different sesame oil quantities on each of the above-mentioned properties at 0.05 significance level. Mean comparison was done using Tukey's test at 95% confidence level for each of the properties and identified the best treatment in comparison to the control.

Results and Discussion

FTIR spectra of oils

The peaks shown in the highlighted area of Figure 1 is due to the presence of polycyclic aromatic hydrocarbons. The two peaks observed for sesame oil at 693.18 and 720.89 cm^{-1} arise from the presence of 1% of monosubstituted aromatic groups such as phenols (Dasgupta *et al.*, 2007; Hossam *et al*., 2022), whilst the peaks observed at 728.72, 748.11, 810.51 and 855.49 cm^{-1} for the aromatic oil Dutrex-R correspond to monosubstituted aromatic, ortho disubstituted aromatic, para disubstituted aromatic and meta disubstituted aromatic, respectively. According to Dasgupta and co-workers (2007), aromatic content of petroleum based aromatic oil, low PCA oil, power oil TDAE_A and power oil TDAE_B are 36, 18, 30 and 29, respectively and that of the natural oil, sesame oil is 1 %. Hence, Figure 1 confirms that the aromatic content of sesame oil is low compared to that of petroleum-based aromatic oil, Dutrex-R.

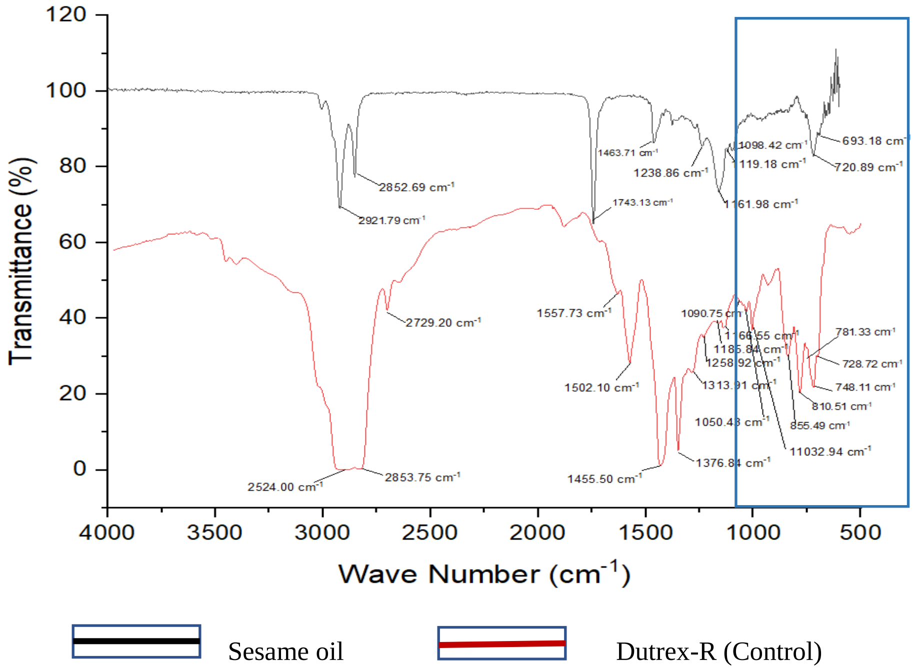

Fig. 1. FTIR spectra of sesame oil and Dutrex-R

Carbon black dispersion analysis
The filler dispersion images of the five NR vulcanisates are shown in Figure 2. The results are tabulated in Table 4.

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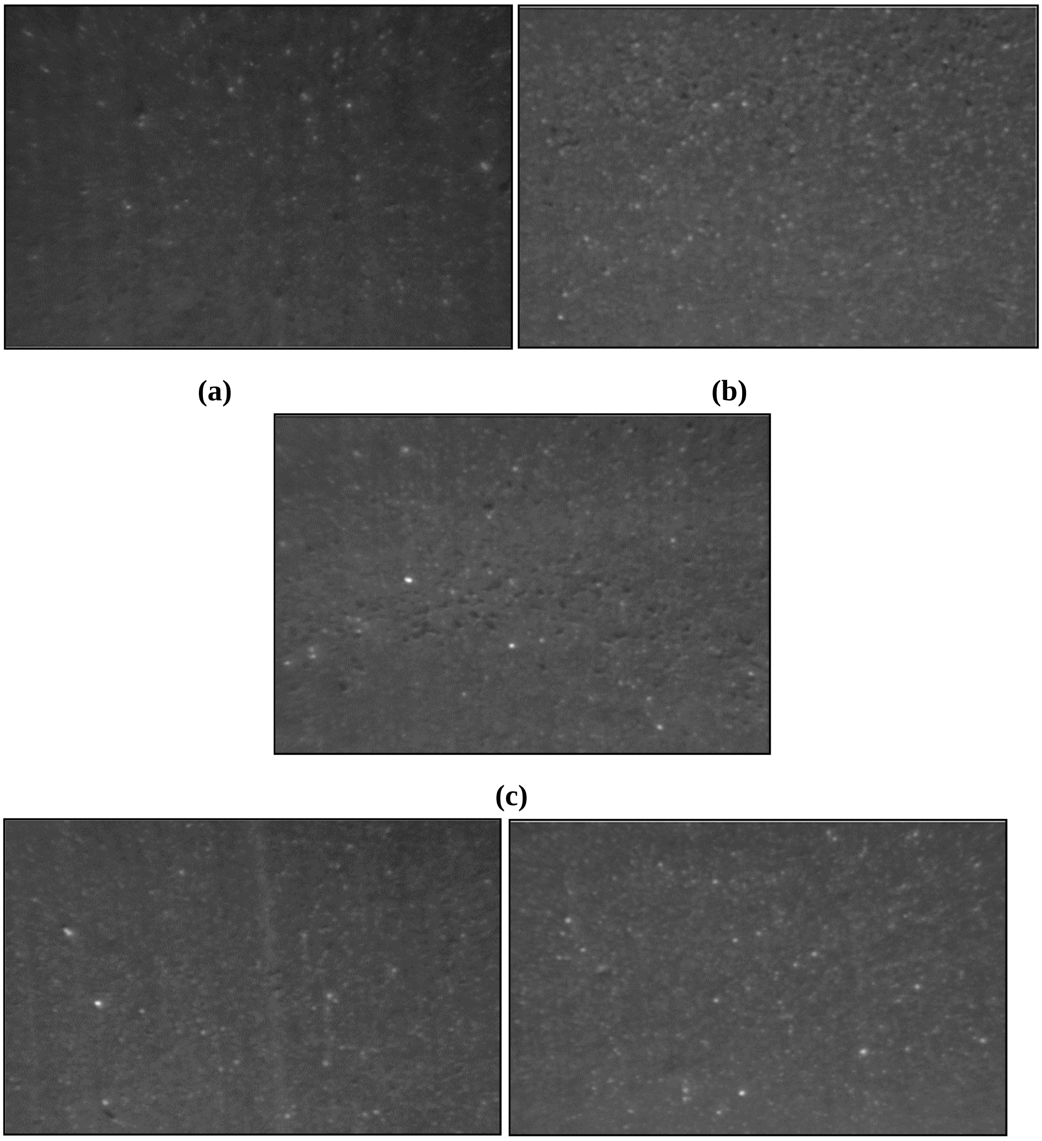
Table 4. *Filler dispersion results of NR vulcanisates*

Compound No.	Dispersion rating	Maximum size of agglomerates (Sq Pixel)
T0 (control)	9	5
T1	9	65
T2	9	24
T3	8	55
T4	9	63



(a) (b)

(c)

(d) (e)

Fig. 2. Filler dispersion images of carbon black filled NR vulcanisates produced with Dutrex-R–5 phr **(a)** and sesame oil–3 phr **(b),** 5 phr **(c),** 7 phr **(d)** and 9 phr **(e)**

The results of dispersion rating indicate that carbon black is well dispersed in the NR matrix of all five vulcanisates. Further, dispersion rating of the sesame oil incorporated vulcanisates are almost the same as that of the control.

However, maximum size of carbon black agglomerates present in the vulcanisates produced with sesame oil is very much higher than that of the control.

Cure characteristics

The cure characteristics of the NR composites are given in Table 5.

The lower minimum torque shown by the composites prepared with Dutrex-R (control) compared to that of the composites produced with sesame oil can be attributed to reduction in viscosity due to ease of dispersion of ingredients in NR (Abbas and Ong, 2019). Maximum torque and hence state of crosslinking of composites prepared with aromatic oil is higher than that of the composites prepared with sesame oil and could be mainly attributed to the presence of sulphur in aromatic oil. Additionally, sesame oil contains ester groups and these can cause hydrolysis at curing temperature in the basic medium and release free acid groups which would retard curing reducing the state of crosslinking. Further, maximum torque decreases with the increase of sesame oil loading. This is probably due to the increase in the amount of aliphatic carboxylic acid ester and long chain aliphatic carbonyl groups (Dasgupta *et al.*, 2007) which may restrict formation of crosslinks.

Most of the composites produced with sesame oil show a higher scorch time in comparison to the control. This is attributed to higher flash and fire points of sesame oil in comparison to petroleum-based oils due to the presence of carbonyl and alkaloid groups (Dasgupta *et al.*, 2007). 0.5-4 % sulphur present in petroleum oils may be another reason for the lower scorch time of the control (Dasgupta *et al.*, 2007). 90% cure time of the composite produced with 5 phr sesame oil is markedly lower than that of the control and agrees with the results of the study conducted by Dasgupta and co-workers. As expected, the trend in the variation of CRI is opposite to that of cure time.

Table 5. *Cure characteristics of the NR composites*

Processing aid	**Scorch time (min)**	**90% Cure time (min)**	**Cure rate index (min^{-1})**	**Maximum torque (d Nm)**	**Minimum torque (d Nm)**	**Delta cure (d Nm)**
Dutrex -R (5 phr) (control)	1.88	3.92	49.02	20.57	2.22	18.35
Sesame oil (3 Phr)	1.91	3.82	52.36	18.98	2.73	16.25
Sesame oil (5 Phr)	2.00	3.31	76.34	16.02	2.94	13.08
Sesame oil (7 Phr)	1.76	3.06	76.92	15.41	3.02	12.39
Sesame oil (9 Phr)	2.15	3.43	78.13	14.94	3.03	11.91

The trend in the variation of delta cure is similar to that of maximum torque. The results of delta cure indicate that crosslink density is higher in the composite prepared with Dutrex-R compared to the composites prepared with sesame oil.

Physico-mechanical properties

Hardness of the control is markedly higher than that of the vulcanisate prepared with 5 phr sesame oil (Fig. 3) and is in agreement with the results of modulus at 100% elongation (Fig. 4) and can be attributed to higher crosslink density (Pechurai *et al.,* 2015). Hardness decreases with the increase of sesame oil loading due to the decrease in crosslink density and softening effect of oil at higher loadings. As expected, variation of tensile strength (Fig. 5) is similar to that of elongation at break (Fig. 6). Elongation at break of the control is lowest and it could be due to the highest hardness achieved by better dispersibility of filler (Dasgupta *et al.*, 2007).

Resilience is higher (Fig. 7), hence heat build-up is lower and abrasion volume loss is also lower (Fig. 8) in the composites produced with sesame oil compared to the control. Lower abrasion volume loss of the former vulcanisates is advantageous in tyre treads and could be attributed to the presence of larger carbon black agglomerates as evident from carbon black dispersion analysis. Higher % swelling in toluene (Fig. 9) shown by the composites produced with sesame oil is due to lower crosslink density. In contrast, these composites show lower values for % swelling in water (Fig. 10) which is an added advantage for tyre treads.

Compression set (Fig. 11) and tear strength (Fig. 12) of the vulcanizates prepared with 5 phr sesame oil are comparable to those of the control.

The alphabetical letters A, B, C and D provide information on the source of the overall difference that was detected and detailed information on which groups differ from one another.

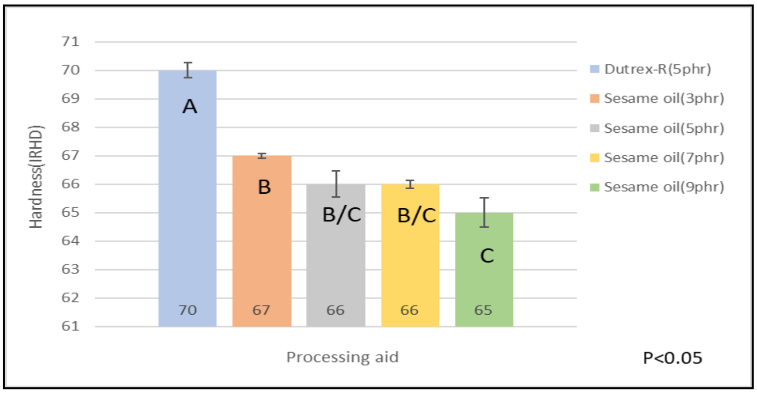


Fig 3. Variation of hardness of the NR vulcanisates

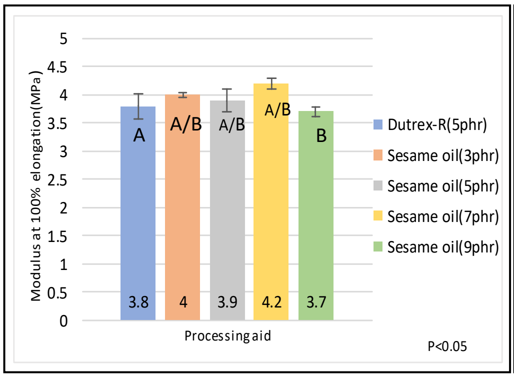


Fig. 4. Variation of modulus at 100% elongation of the NR vulcanisates

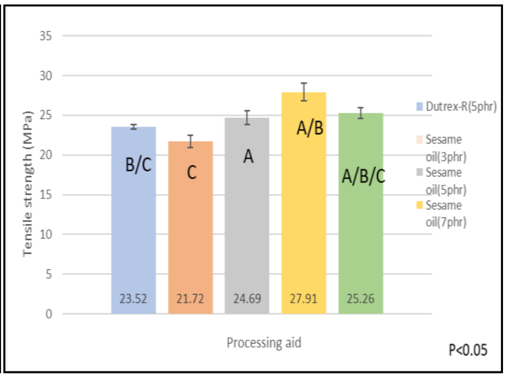


Fig. 5. Variation of tensile strength of the NR vulcanisates

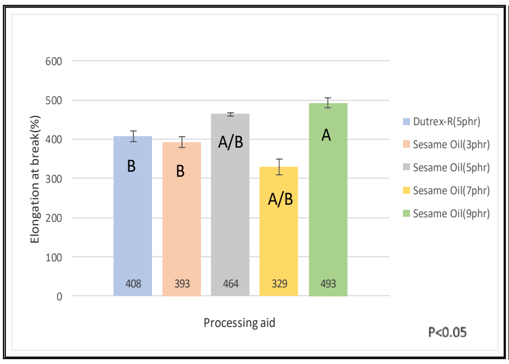


Fig. 6. Variation of elongation at break of the NR vulcanisates

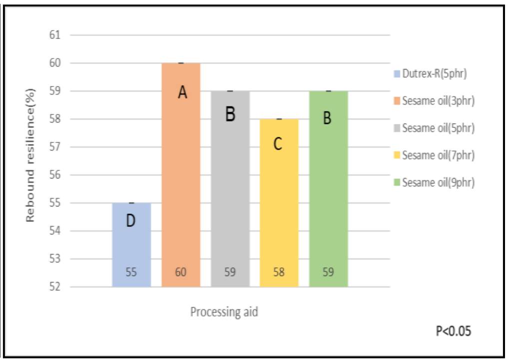


Fig. 7. Variation of resilience of the NR vulcanisates

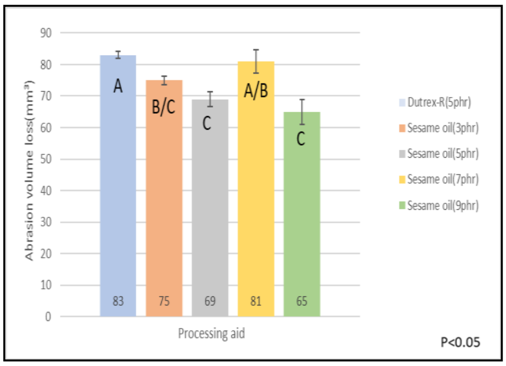


Fig. 8. Variation of abrasion volume loss of the NR vulcanisates

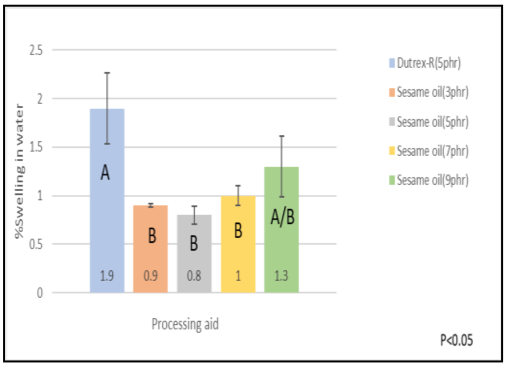


Fig. 9. Variation of % swelling in water of the NR vulcanisates

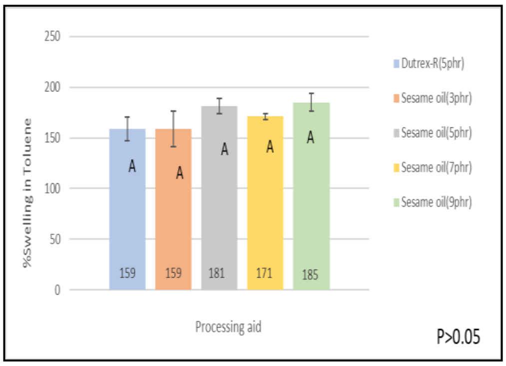


Fig. 10. Variation of % swelling in toluene of the NR vulcanisates

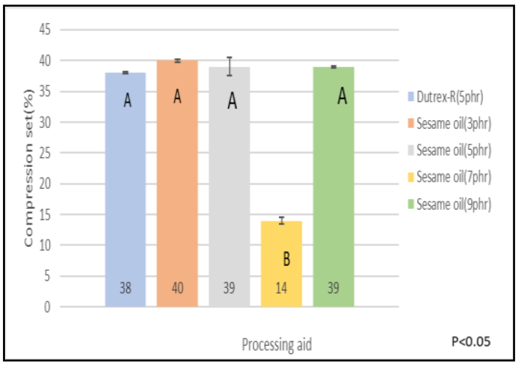


Fig. 11. Variation of compression set of the NR vulcanisates

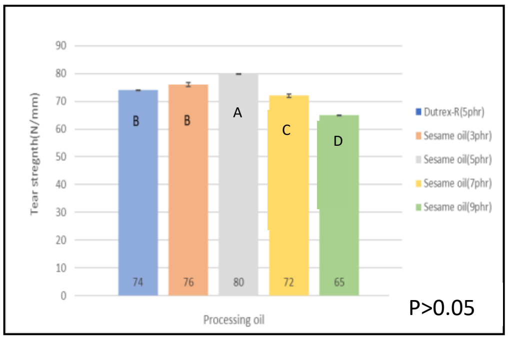


Fig. 12. Variation of tear strength of the NR vulcanisates

Resistance to thermal ageing

The vulcanisates prepared with sesame oil show better resistance to thermal oxidation compared to the control in regard to modulus at 300% elongation, tear strength and comparable with the other ageing properties of the control (Table 6). This could be attributed to the presence of natural antioxidants in sesame oil (Lucy and Hwang, 2005).

Table 6. *Percentage retention of mechanical properties after ageing*

Property	Dutrex-R (5 phr)	Sesame oil (3 phr)	Sesame oil (5 phr)	Sesame oil (7 phr)	Sesame oil (9 phr)
%Retention of tensile strength	82±4.80AB	104±12.14 AB	63±9.99B	85±19.03AB	86±5.38AB
%Retention of tear strength	68±11.76B	78±23.85AB	88±4.11AB	81±14.54AB	113±16.87A
%Retention of modulus at 100% elongation	147±25.41A	147±20.12A	133±8.88AB	111±10.49B	113±9.54B
%Retention of modulus at 300% elongation	91±14.35B	131±9.82A	109±20.68AB	111±5.76AB	108±3.22AB
%Retention of elongation at break	67±9.36A	85±12.07A	63±13.23A	83±18.63A	85±4.60A

Values in each column represent the mean of replicate ± SD (Standard deviation)
The means followed by the same letter within each row are significantly different at $p< 0.05$, except in the case of % retention of elongation at break.

According to Tukey's mean comparison, it was identified that for physico-mechanical properties, each of the sesame oil quantity shares the same grouping frequency when compared with the control. However, 5 phr was selected as the most suitable treatment since the control was also prepared with 5 phr Dutrex-R. Further, the former vulcanisate showed a lower swelling index in water (0.8 ± 0.16%) compared to the control (1.9 ± 0.63%). Furthermore, the former vulcanisate showed higher retention of tear strength after ageing (88 ± 4.11%) in comparison to the control (68 ± 11.76%). There is a statistically significant difference ($p < 0.05$) between each of the treatments, when tested in regard to physico-mechanical properties.

Conclusion

Sesame oil incorporated NR composites have shown an enhancement in most of the properties in comparison to the control NR composite prepared with Dutrex-R aromatic processing oil. Out of the NR composites produced with sesame oil, the composite produced with 5 phr sesame oil could be a suitable alternative for the composite produced with the same amount of Dutrex-R in tyre tread compounds.

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Annual soil loss assessment of smallholder rubber growing lands in the Kalutara District, Sri Lanka using the RUSLE model in GIS

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Abstract

Soil loss resulting from various land management practices in traditional rubber-growing areas of Sri Lanka has been a major issue of concern and one of the factors responsible for declining rubber land productivity. There is no or limited information on the spatial variability of soil loss from rubber lands in Sri Lanka's traditional rubber growing areas. This constraint has had a significant impact on the effective management of soil conservation in rubber-growing lands. This study focuses on assessing the soil loss from the smallholder rubber-growing lands in the Kalutara District using remotely sensed satellite image-based Digital Elevation Model (DEM), rainfall grid data, and prepared soil maps with ground-level surveys by Natural Resource Management Centre (NRMC) Sri Lanka. The factors including rainfall, topography, land area and the crop-specific coefficient for the rubber-growing lands in the study area were analyzed using the Revised Universal Soil Loss Equation (RUSLE) and Geographic Information System (GIS). The study revealed that about 30% of smallholder rubber-growing lands fall under the risk to severe risk categories of soil loss while about 60% of rubber lands are under the low-risk category. About 8,500 ha of smallholder rubber lands can be categorized as risk to severe risk for soil loss whilst about 15,000 ha are under the low-risk category for soil loss. The findings of this study are useful in the implementation of an effective soil conservation management plan and has the potential in applying this methodological approach in other areas of Sri Lanka for various crops.

Key words: Geographic Information System, Kalutara District, Revised Universal Soil Loss Equation, smallholder rubber-growing lands

Introduction

Soil erosion is a universal phenomenon that results in the loss of nutrient-rich surface soil, increased run-off from the more impenetrable subsoil, and decreased water availability to plants (Ganasri and Ramesh, 2015). Soil erosion by water has become a global concern in recent decades since the remarkable decline in the natural resources to population ratio (Terranova *et al.*, 2009) and affects global food security (Pimentel *et al.*, 1995; Lal, 2001). Many countries around the world are affected by accelerated soil erosion in varying conditions and developing countries suffer the most because their farming populations are unable to replace lost soils and nutrients (Erenstein, 1999) and the economic impact of the loss of nutrients is significant (Tamene and Vlek, 2006). Furthermore, soils are more vulnerable to erosion due to a variety of factors, including inappropriate agricultural practices, deforestation, overgrazing, forest fires, and construction activities.

The biophysical environment influences soil erosion which includes soil, climate, terrain, ground cover, and interactions between them (Ganasri and Ramesh, 2015). Besides biophysical environment factors, several land use management factors affect soil loss including the type of crop and tillage practices (Panagos *et al.* 2015). Whilst traditional agriculture is widely regarded as one of the primary causes of soil erosion, agroforestry practices are becoming increasingly valued for soil conservation (Béliveau *et al.*, 2017) and Young (1991) reported that tree canopy in agroforestry has the potential to control runoff and soil erosion.

It was reported that the conversion of tropical forest lands to plantations such as rubber (*Hevea brasiliensis* Mull. Arg.) monoculture and rubber-based agroforestry induces run-off and sediment yield Zhu *et al.* (2018). At present, rubber type called "*Amazonian rubber*", is mainly cultivated in South and South-East Asian countries. Smallholder farmers contribute to approximately 80% of global rubber production. In Sri Lanka, for example, the majority of rubber is grown on smallholders' lands, which account for approximately 71% of the total land extent (89, 588 ha) (MPISL, 2020). More specifically, such farmers seem to have inadequate infrastructure to protect plantation soil from degradation. Rubber can be grown in most parts of Sri Lanka under varying agroecological conditions. The ideal temperature for rubber cultivation is between 25 and 28 degrees Celsius, with an annual rainfall of more than 2000 mm. More rain, on the other hand, may have an adverse impact on tapping days. The optimum sunshine condition is 2100 hours per year and the suitable mean annual relative humidity should be less than 80% (Anon., 2021).

The forest canopy does not always protect the surface soil from rain-splash erosion according to Calder (2001) and this is contrary to the common belief of protecting soil erosion from the forest canopy. Indirect rainfall is reported as having higher kinetic energy than direct rainfall since water intercepted by the canopy flows along leaves and produces larger droplets that eventually strike the ground (Nanko *et al.*, 2008; Geißler *et al*., 2012). Rubber is a tree crop that has vast potential to cultivate in agroforestry and varying geographical regions including hilly areas. Absence or limited studies (Liu *et al*., 2017; Zhu *et al.*, 2018) have focused on analyzing rainfall-induced soil erosion in rubber plantations under different physiographic conditions. Identification of areas with a higher probability of soil loss induced by rainfall and quantification of relevant probable nutrient loss in such areas is vital in sustainable rubber land management.

The main topographic factors influencing soil erosion are slope, length, aspect, and shape. These factors contribute to rainfall run-off based on their varying degrees (Ganasiri and Ramesh, 2015). Significant efforts have been made to develop models of soil erosion quantification (Nearing *et al*., 2005). The most widely applied empirical model for soil loss estimation is the Universal Soil Loss Equation (USLE) which is suitable for estimating soil loss in cropland and gently sloping topography. The USLE has been extensively used in studies for the estimation of soil loss with its revised version which is named Revised Universal Soil Loss Equation (RUSLE) (Lee and Lee, 2006; Remortel *et al*., 2001). RUSLE has more advantages compared to the USLE in estimating the loss of soils (Renard, 1997) and is more flexible to model soil loss compared to USLE (Wischmeier and Smith, 1965). Geographic Information System (GIS) coupled with topographic features provides a user-friendly tool to analyze soil loss using soil loss equations and RUSLE with GIS can provide soil loss on a cell-by-cell basis (Shinde *et al.*, 2010). This approach is more beneficial when attempting to model soil loss over a large space. To address these research gaps, this study, therefore, aims to model the probability of occurrence and the quantity of soil loss in the smallholder rubber lands and subsequent possible nutrient loss.

Methods

Description of the study area and data

The study was conducted in the Kalutara district of Sri Lanka, where traditional rubber-growing lands are located in the Low Country Wet Zone. The study area lies between $79^{0}\ 88^{'}$ to $80^{0}\ 38^{'}$ Eastern longitudes and $6^{0}\ 32^{'}$ to $6^{0}\ 82^{'}$ Northern latitudes (Fig. 1). Rubber can be found in 26,564 ha of land in the Kalutara District. These lands belong to WL1a and WL1b agroecological regions. The regions of WL1a receive an expected annual rainfall (ERF) of 3200 mm or higher with a 75% probability while WL1b receives 2200 mm or higher. Both groups have major soil groups of Red Yellow Podzolic (RYP) and Low Humic Gley soils, while the terrain condition is undulating, hilly, and rolling. Table 1 gives the types and sources of data for the study.

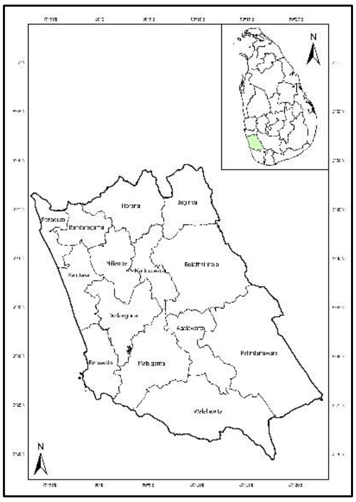

Fig. 1. Map of the study area, Kalutara District, and its Divisional Secretariat Divisions (DSD)

Table 1. *Data description*

Data type	Description	Sources of data collection
Digital Elevation Model (DEM)	100 m resolution grid Data	Genesis (Pvt) Ltd. Sri Lanka
Soil data	The great soil group map	Natural Resource Management Centre of Sri Lanka (Mapa & Somasiri, 1999)
	Soil properties for the Kalutara District	
Rainfall data	2.5m resolution grid data	www.worldclim.com
Rubber land area	Land use classification map of Kalutara District	Land Use Policy Planning Department (LUPPD) Sri Lanka
Crop factor	The effect of crop management practice on the rate of soil erosion	Munasinghe *et al*. (2001), Prasannakumar *et al*. (2012), Senanayake *et al*. (2013)
Soil Erodibility factor	The effect of the specific supporting practices of cultivation for soil erosion from up-slope to down-slope	Munasinghe *et al*. 2001, Prasannakumar *et al*. 2012, Senanayake *et al*. 2013

Model building and conceptualization of variables

The revised universal soil loss model

For this investigation, the revised universal soil loss equation (RUSLE) was used (Renard, 1997). The average annual soil loss was calculated using the RUSLE soil loss equation in the study area and the soil erosion risk map for the study area was mapped using Arc GIS pro version. According to Renard (1997), the RUSLE model simulates the effects of rainfall, topography, soil, and land use on rill and sheet soil erosion induced by rainwater and surface runoff. RUSLE can be mod

eled according to Eq. 1.

$$A = LS * R * K * C * P \qquad \text{(Eq. 1)}$$

Where,

A is the soil loss per unit area per year (t ha^{-1} yr^{-1}), *LS* is the slope length and steepness factor (dimensionless), R is the rainfall erosivity factor (MJ mm h^{-1} ha^{-1} yr^{-1}), *K* is the soil erodibility factor (t ha h MJ^{-1} mm^{-1}, *C* is the cover and management factor (dimensionless and it varies from 0 to 1.5), and *P* is the conservation or control factor (dimensionless and it varies from 0 to 1).

Modelling slope length and steepness factor (LS)

LS is influenced by the combined effect of slope length (*L*), slope steepness (*S*), and slope morphology on rill, inter-rill erosion, and sediment production. As slope length (*L*) increases, so does total soil erosion loss per unit as a result of downslope runoff accumulation. When the slope steepness increases, the velocity and erosivity of runoff increase

(Wischmeier and Smith, 1978). According to Pradhan *et al.* (2012), Inter-rill erosion is caused by raindrop impact on the soil surface and is thought to be uniform along a slope. The (L) parameter expresses the ratio of rill erosion (caused by flow) to inter-rill erosion (caused by raindrop impact) to calculate soil loss concerning a standard plot length of 22.1 m. The slope steepness parameter (S) describes how the slope gradient affects erosion in comparison to the standard plot steepness of 5.16. The effect of slope steepness on soil erosion loss is greater than the effect of slope length. As a result (LS) is the predicted ratio of s Soil loss per unit area from a 22.1 m long 5.16% slope. The digital elevation model (DEM) was used to estimate slope length (*L*) and slope gradient (*S*) for the study area. The DEM was prepared in GIS and derived the slope map for the area of Kalutara District. Then the derived slope map of the area was used to develop the flow direction map and flow accumulation map of the area. The calculation of the slope length factor (*L*) is described in Eq. 2.

$$L = \left(\frac{ƛ}{22.1}\right)^m \qquad \text{(Eq. 2)}$$

Where *L* is the slope length factor, ƛ the Horizontal projected slope length (*m*), and *m* is the Slope length exponent. The exponent *m* is affected by the slope steepness in this equation. According to the study by Wischmeier & Smith (1978), the "m" value is equal to 0.5, 0.3, and 0.2 when the slope is ≥ 4.5%, 3-4.5%, and ≤ 1 %, respectively. The mathematical derivation of slope steepness can be done using the following equations (Eq. 3 and Eq. 4) developed by McCool *et al*. (1987).

If the slope is less than 9%,

$$S = 10\ \sin\alpha + 0.03 \qquad \text{(Eq. 3)}$$

and

If the slope is greater than 9%,

$$S = 16.8\ \sin\alpha - 0.5 \qquad \text{(Eq. 4)}$$

Where *S* is the slope steepness factor and the α is the slope angle in degrees. A raster calculator is available in the ArcGIS ver. 10.2 was employed to generate the *LS* factor using spatial layers of factors, *L* and *S*.

Modelling Rainfall erosivity factor (R)

Rainfall intensity is a primary cause of soil erosion. Factor *R* expresses the possibility of runoff due to the impact of raindrops. To model the *R* factor for the local conditions, it was adopted the modeling approach reported by Premalal (1986) and the equation (Eq. 5) can be expressed as follows.

$$R = \left(\frac{972.75+9.95*F}{100}\right) \qquad (5)$$

Where *R* is the rainfall erosivity factor (MJ mm ha^{-1} $h^{-1}Year^{-1}$) and *F* is the average annual rainfall amount in mm. The same model has been used to estimate the *R* factor by Wijesundara *et al*. (2018) and Fayas *et al.* (2019) to quantify the soil erosion for the Kirindioya River and Kelani River basins in Sri Lanka.

Conceptualising Soil Erodibility Factor (K)

Soil's inherent properties have a direct influence on withstanding soil erosion. Also, the variation of resistance ability to erosion determines by the soil's physical properties such as texture, structure, aggregate stability, and available soil surface material. Brady & Weil (2008) have defined the K factor as the rate of soil loss per unit of erosive energy created by the rainfall calculated under a standard condition by a plot of land consisting of clean bare soil with a slope of 9% and 22.6 m long. The *K* factor for the Sri Lankan soil has been estimated by Wijesekara and Samarakon (2001) based on the estimated values for the great soil groups developed by Joshua (1977). Table 2 gives the *K* factor values for rubber-growing lands in the Kalutara District.

Table 2. *K factor values for different great soil groups in the study area*

Great soil group	**Values of K factor**
Red Yellow Podsolic	0.22
Sandy Regosols	0.48
Alluvial Soils	0.31

The great soil group map of Sri Lanka was obtained from the Natural Resource Management Centre (NRMC) and a great soil group map for the rubber growing areas in the Kalutara District was developed employing ArcGIS software.

Conceptualisation of Cover Management Factor (C)

The cultivation of crops always contributes to disturbing soils, changing topography, changing flow directions, *etc.* Therefore, cover cropping is practiced in cropland including rubber lands to protect bare land areas from soil erosion. A contrasting effect of crop management practices on soil erosion can be observed and factor *C* has been introduced to show this impact on soil erosion. Renard (1997) has reported the possibility of using the *C* factor for conservation plans. Land use classification maps published by the Survey Department of Sri Lanka were obtained to select the rubber-growing lands in the Kalutara District and the relevant C factor for the rubber-growing lands was estimated. Based on the study of Fayas *et al.* (2019), the *C* factor value for the rubber crop was assigned as 0.44. and spatial variability of the *C* factor was mapped using ArcGIS.

Conceptualisation of Support and Conservation Practice Factor (P)

The soil loss that occurred due to a particular crop-supporting practice in up-slope to down-slope cultivation is defined as the support and conservation practice factor (P). The *P* factor considers the capability of minimizing the eroding potential of rainfall and surface runoff. As the *P* factor values were assigned according to the required management practice for the study area, conservative measures of rubber plantations were considered. The *P* factor values for the different land use practices in Sri Lanka have been reported in the literature (Munasinghe *et al*., 2001; Prasannakumar *et al.*, 2012; Senanayake *et al*., 2013; Wijesundara *et al*., 2018; Fayas *et al*., 2019). Considering the previous literature on *P* factor values, the *P* factor was assigned as 0.35 for the rubber-growing lands. The spatial variability of the p-factor values for the rubber-growing lands was mapped using ArcGIS.

Development of soil erosion severity map

All the prepared spatial data layers of *LS*, *R*, *K*, *C*, and *P* factors were projected based on the Kandawala Sri Lanka grid system and 100 m spatial resolution in the Kalutara District. The *RUSLE* equation ($A= LS*R*K*C*P$) was estimated using the raster calculator available in Arc GIS and annual soil loss per hectare of land per year on the map was depicted. Derived annual soil loss was categorized as low risk (0-7 t ha^{-1} yr^{-1}), moderate risk (7 -15 t ha^{-1} yr^{-1}), high risk (15 -25 t ha^{-1} yr^{-1}), very high risk (25 - 45 t ha^{-1} yr^{-1}), severe risk (45 - 65 t ha^{-1} yr^{-1}), and very severe risk (more than 65 t ha^{-1} yr^{-1}).

Results and Discussion

Distribution of LS, R, and K factors

Figure 2 shows the spatial variability of the LS, R, and K variables. The LS factors range from zero to 97, and some locations like Bulathsinghala, Walallawita, and Palindanuwara have high LS factor values. Due to the higher likelihood of anticipated rainfall in the aforementioned places, the Rainfall erosivity (R) is similarly high there. The spatial variability of the *K* factor value depends on the variation of soil physical properties in the Kalutara District. The *K* factor value varies from zero to 48 in the District. Since this study is concerned only with rubber plantation there is no spatial variability for C and P factors.

Soil erosion severity map

The annual loss by soil erosion is depicted in Figure 3. While the highest annual soil loss was recorded as 617 t/ha/yr and it was reported close to the Tannahena East Grama Niladhari Division (GND) in Bulatsinghala Divisional Secretariat Division (DSD). The severity of potential risk for soil loss, rubber lands under each category, and percentage contribution to total rubber lands describe in Table 3. Sixty percent of the land area belongs to the "Low Risk" category while around 15% of the land is under the "Very Severe Risk" category of the area.

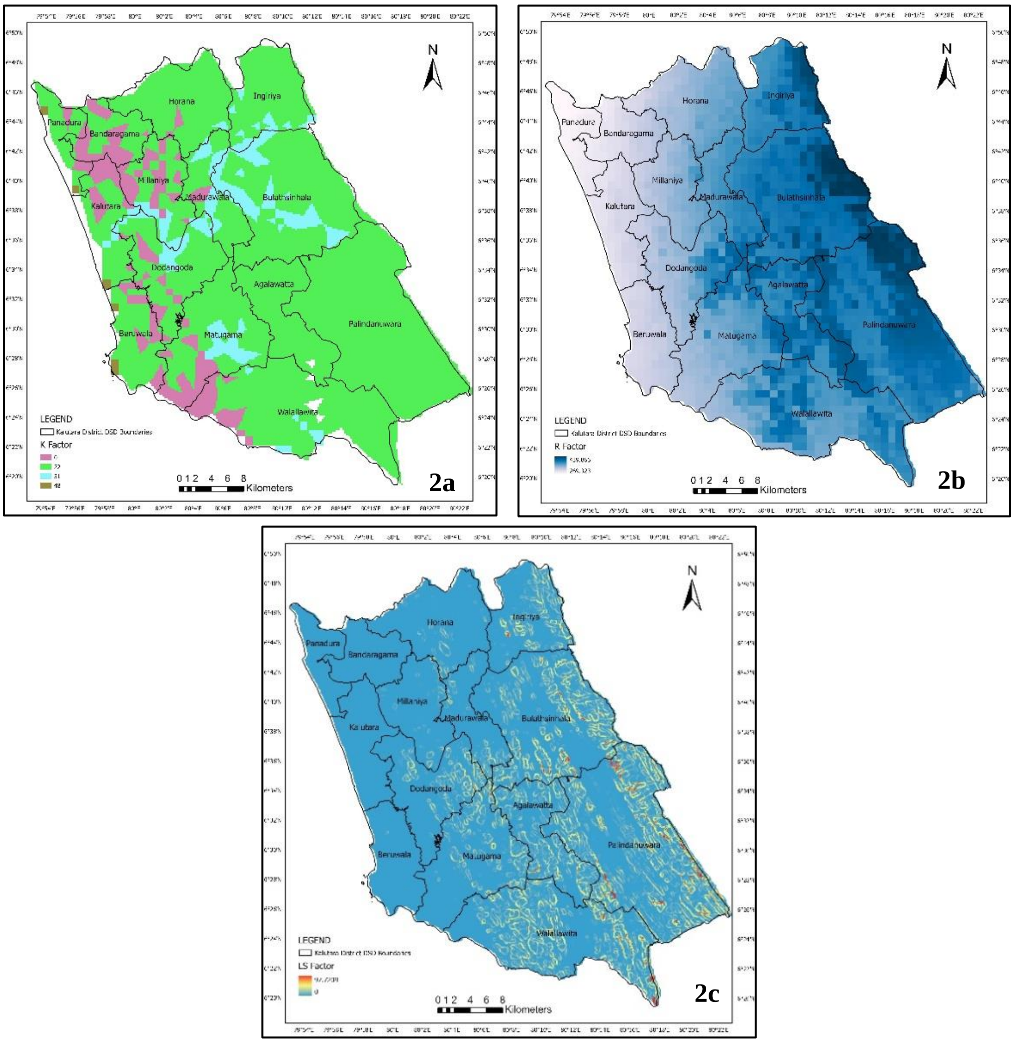

Fig. 2. Spatial variability of the **a.** *LS*, **b.** *R* and **c.** *K* factor

Table 3. *The annual soil loss from the rubber-growing lands in the Kalutara District*

Soil loss risk category	Area of soil loss (ha)	Percentage contribution to total rubber lands (%)
Low risk	15,738	60.0
Moderate risk	1,755	6.6
High risk	1,247	4.7
Very high risk	2,012	7.6
Severe risk	1,492	5.6
Very severe risk	4,064	15.5

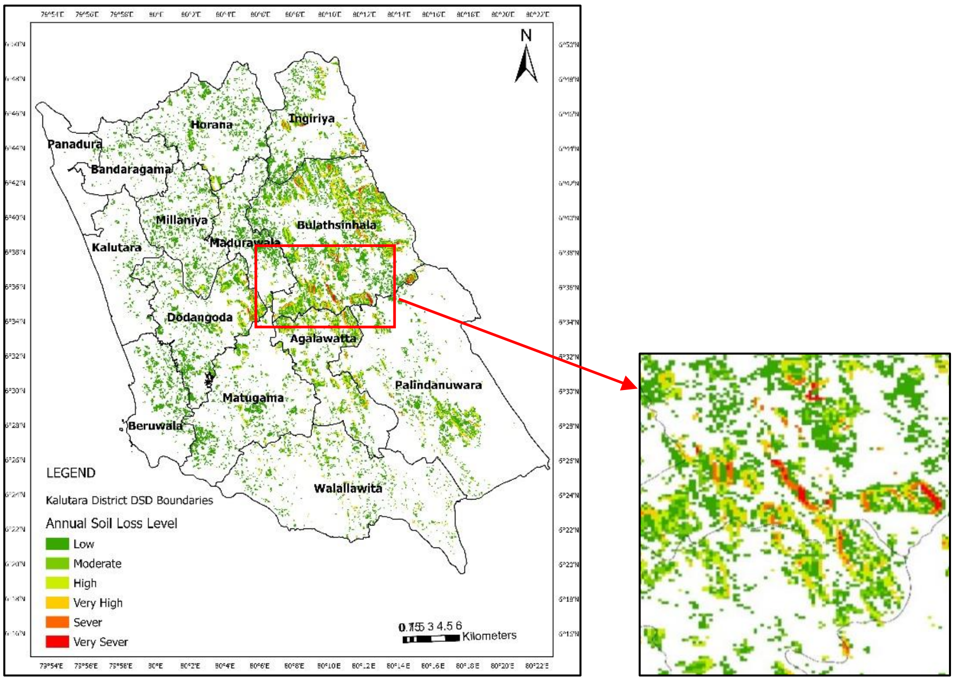

Fig. 3. The spatial variation in the annual loss of soil in the Kalutara District

Approximately 8,800 ha of rubber land (high risk to severe risk) requires immediate soil conservation measures. The spatial variability of the distribution of the risk of soil loss can be regarded as an indicator of the priority that soil conservationists and plantation managers must assign. The majority of these high-risk rubber lands are concentrated in specific areas of the Agalawatta and Bulathsinghala Divisional Secretariats within the Kalutara District, primarily due to the elevated rainfall erosivity observed in these regions.

Conclusions

According to the findings of this study, it is evident that approximately 30% of the rubber lands in the Kalutara District are at high to very high risk of soil erosion. The spatial distribution of soil erosion risk highlights the importance of implementing site-specific soil conservation measures that are proportionate to the potential erosion in each area. Additionally, a comprehensive best management plan can be developed to safeguard rubber-growing soils based on the identified risk levels, which can contribute to cost reduction in conservation efforts across farmlands.

Recommendations

To protect against soil loss and ensure sustainable rubber cultivation, it is crucial to consider the potential risk of erosion when expanding rubber into non-growing areas. Non-rubber areas adjacent to high-risk soil loss areas may be particularly susceptible to erosion and require special attention. While approximately 60% of the District's rubber-growing areas are classified as low-risk, conducting site-specific investigations before formulating a conservation management plan is essential.

Moreover, it is important to note that the accuracy of topographic layers used in this study is contingent on the satellite imagery utilized and its spatial resolution. To improve accuracy, it is recommended to employ the appropriate satellite images and analysis methods. Furthermore, the findings of this study can be enhanced with the acquisition of more accurate and timely data in the future.

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Identification and prioritization of the constraints of rubber farming in Moneragala District

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Abstract
Identification and prioritization of the constraints of rubber farming perceived by rubber smallholders in Moneragala district were the objectives of this study as rubber farming is still being expanded. There were 44 constraints identified by the focus group discussion with 48 Rubber Smallholders (RSs), who were selected from eight rubber-growing DS divisions based on a stratified sampling technique, prior to the questionnaire survey. Identified constraints were listed on the questionnaire. A pre-tested questionnaire survey, a focus group discussion, semi-structured interviews and field observations were used to collect data from 597 rubber smallholders who were selected from eight rubber-growing DS based on stratified sampling technique. The respondents were asked to assign a rank for all constraints. The 44 constraints perceived by rubber smallholders were categorized into following rubber farming activities; 1. Immature up-keeping, 2. Rubber tapping, 3. Manuaring of rubber farming, 4. Rubber processing, 5. Rubber marketing, 6. Extension service related to rubber farming and 7. Thurusaviya rubber societies. Among them, low quality of planting material, lack of knowledge of tapping, lack of knowledge of applying mature fertilizer unavailability of quality acid, low prices for every grade of RSS, lack of training programmes on rubber processing aspects and unsatisfactory input distribution were the highest prioritised constraints address the sustainability of rubber farming in Moneragala by the Henry Garrett Ranking Method. Development of an extension strategic plan in order to transfer the knowledge of the recommended rubber farming practices introduced by the Rubber Research Institute of Sri Lanka to rubber smallholders in Moneragala with the aim of enhancing rubber productivity, restructuring the rubber farming subsidies focused on Intermediate Zone rubber farming, improving the rubber marketing system and strengthening the Thurusaviya rubber societies were identified as strategies to overcome the identified perceived constraints of rubber farming in Moneragala.

Key words: constraints, non-traditional rubber farming areas

Introduction

The IL1c, IL2 and IM2b agro-ecological regions in Moneragala District (Moneragala) are used for Rubber Farming (RF) which are distributed among eight Divisional

Secretariat (DS) divisions (Wijesuriya *et al*., 2011). At present, the total extent of rubber smallholdings in Moneragala is about 5,087ha (9,415 holdings) and Moneragala is the fifth in position to grow rubber according to the land extent under rubber cultivation in Sri Lanka (MPI, 2019). Rubber Smallholders (RSs) have identified a wide range of constraints they perceived to affect their RF activities which fall into the aspects of immature up-keeping, mature up-keeping, tapping, Ribbed Sheet Rubber (RSS) manufacturing, marketing, extension and *Thurusaviya* Rubber Societies (TRSs) (Wijesuriya, *et al*., 2007, 2008, 2011 and 2012). The identification and prioritization of constraints of RF in Moneragala was important with regard to sustainability of RF and also in improving rubber productivity in the country as the process of expansion of RF into Moneragala is still being carried out. So that, identification and prioritization of the constraints of RF perceived by RSs in Moneragala were the objective of this study. Wijesuriya, *et al*., (2011) has studied the constraints in sustainable smallholder RF in Moneragala with participatory studies and has focused only on the constraints of adoption on technology. Wijesuriya, *et al*., (2007) has studied the constraints related to sustainability in the three major rubber growing districts. In both studies, it was not focused on the major areas of RF separately, as of immature up-keeping, mature up-keeping, tapping, RSS manufacturing, marketing, extension and TRSs.

Hence, the findings of this study would be useful for policy makers, researchers and extension personnel to formulate guidelines and also to organize work programmes more effectively to improve rubber productivity and sustainability of RF, as Moneragala is a non-traditional rubber growing locality with higher extent of area with newly-planted cultivars. The present study will have an impact on the level of livelihoods of RSs as well as on the sustainability of RF in Moneragala, while having a footprint on the country’s economic development.

Methodology

The study was conducted in Moneragala in Sri Lanka during 2019. The minimum total size of the sample was 597 RSs, representing 23% of the population at a 90% confidence interval using Raosoft web-based sampling calculator for which stratification was applied on the basis of geographical distribution of RSs in all rubber growing eight DS divisions in Moneragala (http:// www.raosoft.com/samplesize. html). Pre-tested questionnaire survey, semi structured interviews and field observations were used to collect data from the respondents. The questionnaire consists of questions from the three main domains and key general information of RSs, smallholdings, perceived constraints of smallholder RF and suggestions to solve the identified constraints. The perceived constraints of RF in Moneragala were evaluated at the ground level. There were 44 constraints identified by the focus group discussion with 48 RSs, who were selected from eight rubber growing DS divisions based on stratified sampling technique, prior to the questionnaire survey and the list was then administrated to RSs for response.

Identified constraints were listed on the questionnaire. The constraints were broadly divided into; 1. Immature up-keeping (14), 2. Rubber tapping (5), 3. Manuaring of RF (5), 4. Rubber processing (9), 5. Rubber marketing (4), 6. Extension service related to RF (5) and 7. TRSs (2). The respondents were asked to assign a rank for all constraints and the outcomes of such ranking have been converted into a score with the help of the following Eq. 1;

Percent position of each rank = 100 (R_{ij} - 0.5)/N_j……Eq. 1

Where;

R_{ij} = Rank given for the i^{th} variable by j^{th} respondents

N_j = Number of variables ranked by j^{th} respondents

Based on the results of the calculation of ranks using the formula mentioned above, Garrett values were determined using Garrett Ranking Conversion table. The Garrett values were then multiplied by the frequencies of the constraints in every rank. The mean score was used as the basis of the final ranking of the constraints (Rakesh *et al*., 2020; Manaros, *et al*., 2020). Suggestions were obtained from the Rubber Development Officers, officials of TRSs and RSs through questionnaire survey in order to remove and find solutions for the constraints.

Results and Discussion

Key information of smallholders

Male RSs were dominated, with male: female ratio of nearly 4:1. The age of RSs varied from 20 to 79 years. The majority (55%) of RSs belonged to the age category of 36-40 years. Nearly 10% of the respondents were above 60 years, while only 35% were found below 35 years. However, the young age (<35 years) category was not prominent in this study area, and it differs from a previous study carried out in Moneragala by Wijesuriya *et al*., 2008. The attraction of the younger generation must be directed to the smallholder rubber sector to ensure the sustainability of RF. None of the RSs has obtained higher education (diploma and degree level), and 1% of RSs had not attended a school. Further, only 3% of RSs had attended tertiary education level (GCE A/L). The majority of RSs (53%) have achieved more than ten years of RF experience with an average of 11.5 years.

Key information of rubber smallholdings

The summary of the characteristics of rubber smallholdings is presented in Table 1. The majority of the rubber smallholdings fall into the size of 1-1.5 acres (0.4-0.6ha). The clone RRIC 121 occupies 82% of the rubber smallholdings selected for the study. The prominent current harvesting panels were B0-1 and B0-2. The average harvesting stand was 478 trees/ha. The average number of harvesting days was reported as 123 per year and the average yield was 997 kg/ha/year.

Table 1. *The summary of the characteristics of rubber smallholdings*

Characteristics of rubber smallholdings	**% (N=597)**
Size of the holding (acres)	
<1	6
1-1.5	68
1.5-2	2
2.1-3	21
3.1-4	12
>4.1	1
Type of the clone	
RRIC 100	18
RRIC 121	82
Harvesting stand per ha. (no. of trees)	
Average	346
Range	(316-499)
Current harvesting panel	
B0-1	37
B0-2	46
B1-1	15
B1-2	2
Harvesting days/year	
Average	104
Range	(65-175)
Yield (dry basis) kg/ha/year	
Average	997
Range	(348-1102)

Constraints for immature up-keeping of rubber farming

The Table 2 revealed RF constraints for immature up-keeping of RF. Among those poor quality of planting material was the prominent constraint reported by RSs. The second and third constraints were the unavailability of planting material in the correct time and unavailability of plants for vacancy filling. The Rubber Development Department can play an important role for minimizing those three constraints. Because they have the authority to issue quality planting materials. The quality control process in rubber nurseries could be strengthened as one of the remedies to poor quality planting material. The recommended number of rubber trees is 512 ha^{-1} in immature smallholdings, which was found to have reduced to an average of 436 ha^{-1} and it ranged from 316 to 499. Lack of knowledge of applying fertilizer for immature rubber plants, unavailability of fertilizer for immature rubber plants in the correct time, unable to apply due to long drought period during the immature period and cost of fertilizer for immature rubber plants and manuaring were highlighted as manuaring constraints in the immature stage of RF. Immature plant death due to disease attack was mentioned as minor issue. Rubber plants per hectare when becoming tappable girth are positively related to low quality of planting material, unavailability of planting material in the correct time, un availability of plants for vacancy filling and immature plants death due to animal attack. Delay in the rubber subsidy and insufficient monetory value of rubber subsidy were also highlighted by RSs. The prominent reasons for the vacant areas in the fields are due to drought condition and *Wild boar/Porcupine* attacks. The most of RSs don't aware to identify the rubber diseases. RSs are needed to educate on the subsidy scheme to avoid any delays.

Constraints for rubber tapping

Table 3 shows the constraints for rubber tapping. Lack of knowledge and skill of tapping were major constraints, which are similar to traditional rubber growing areas as confirmed by Dissanayake *et al*., (2010). Comparatively, *Tapping Panel Dryness* (trees that do not produce latex) trees per acre were low (5/ac) with traditional rubber growing areas (traditional areas, *Tapping Panel Dryness* trees/ac= 12) (Dissanayake *et al*., 2010). The *Tapping Panel Dryness* trees were one of the reasons for the low number of trees tapping in a holding. Unavailability of modified tapping knives and marking plates were also highlighted by RSs. The unavailability of tappers was one of the lowest constraints in Moneragala, because the self-tapping system was more prominent (52%) in the area. Lack of knowledge and skill of tapping came up with possible causes such as lack of systematic training programmes accompanied with demonstrations and practical sessions. Farmers due to resource limitations (Mahaliyana-arachchi and Sivayoganathan, 1996) did not adopt management practices. Marking plates and modified tapping knifes should be distributed through TRSs.

Table 2. *Constraints for immature up-keeping of rubber farming*

Constraints	**Garrett mean score**	**Rank**
Low quality of planting material	73.18	1
Unavailability of planting material in correct time	72.75	2
Un availability of plants for vacancy filling	70.56	3
Plants death due to drought condition	69.88	4
Plants death due to animal attack (*Wild boar/Porcupine)*	68.53	5
Lack of knowledge of applying fertilizer for immature rubber plants	67.55	6

Constraints	**Garrett mean score**	**Rank**
Unavailability of fertilizer for immature rubber plants in correct time	65.22	7
Unable to apply due to long drought period during the immature period	63.25	8
Cost of immature fertilizer	62.24	9
Cost of manuaring for immature rubber plants	60.55	10
Long time period to reach the mature stage (>5 yrs)	59.88	11
Monitory value of rubber subsidy insufficient	58.24	12
Delay the rubber subsidy	50.33	13
Immature plants death due to disease attack	46.22	14

Table 3. *Constraints for rubber tapping*

Constraints	**Garrett mean score**	**Rank**
Lack of knowledge of tapping	72.75	1
Lack of skill of tapping	71.20	2
High number of *Tapping Panel Dryness* plants	69.18	3
Unavailability of marking plates and modified tapping knifes	60.56	4
Unavailability of tappers	58.53	5

Constraints for manuaring of mature stage of rubber

Table 4 revealed the constraints for manuaring of the mature stage of RF. Lack of knowledge of applying fertilizer for mature rubber trees and unavailability of fertilizer for mature rubber trees at the required time were the major constraints under the constraints of manuaring of mature stage RF. Commercial-level fertilizer suppliers mentioned (Semi–structured discussion with input suppliers) that demand for fertilizer for mature rubber trees was very low, therefore large quantities couldn't be ordered. Fertilizer should be applied when enough soil moister is available, therefore rainfall is very important (Samarappuli *et al.*, 2005). In some areas (*Bibila*, *Wellawaya* and *Buttala* DS divisions), it is unable to apply fertilizer for mature rubber trees due to long drought periods. The lowest prioritized issue was the cost of manuring, because of the subsidy of fertilizer for mature rubber trees given by the state.

Table 4. *Constraints for manuaring of mature stage of rubber farming*

Constraints	Garrett mean score	Rank
Lack of knowledge of applying fertilizer for mature rubber trees	73.75	1
Unavailability of fertilizer for mature rubber trees in the correct time	70.34	2
Cost of fertilizer for mature rubber trees	69.18	3
Unable to apply due to long drought periods during the mature period	60.56	4
Cost of manuring of fertilizer for mature rubber trees	54.67	5

Constraints for rubber ribbed smoke sheet manufacturing

Table 5 revealed that the constraints for rubber processing faced by RSs. RSs highlighted poor standards of acids in the absence of quality certification as the major issue. The cost of processing was high due to the high cost of acid. They also pointed out the scarcity of RSS manufacturing equipment and other inputs such as rollers, smokehouses and coagulation trays and the lack of credit and subsidy facilities to buy RSS manufacturing equipment. They requested to provide these through TRSs in a transparent way. Many (53%) of the RSs used group processing centres to produce RSS, where only a few RSs highlighted constraints in the group processing centres such as transparency and corruption. The average distance from processing centres (group and own) to the plantation is 4.8 km which affects the RSS manufacturing cost. The number of group processing centres in Moneragala was not sufficient to cater to the requirement of RSs. Increasing the group processing centres, supplying subsidy and loan facilities, increasing the loan and subsidy amount were proposed by officials of TRSs and Rubber Development Officers (RDOs), as solutions for the development of processing centres.

Table 5. *Constraints for RSS manufacturing*

Constraints	Garret mean score	Rank
Unavailability of quality acid	70.53	1
Cost of acid	68.53	2
Unavailability of smooth roll	67.21	3
Unavailability of diamond roll	63.44	4
Lack of subsidy/credit facilities to buy inputs/rollers	60.55	5
Lack of credit facilities to build smokehouse	60.34	6
Constraints in group processing centres	59.45	7
Unavailability of coagulating trays	58.46	8
Distance from plantation to processing place	58.35	9

Constraints in rubber marketing

Table 6 revealed that the constraints found in rubber marketing *in* Moneragala. Market constraints which exist are similar to that of traditional areas, like purchasing sheets in bulk and large margins kept by middlemen (Edirisinghe *et al*., 2005). However, low price for every grade of RSS was the major issue. Rubber prices between Colombo rubber auction and Moneragala have gaps comparing the traditional rubber growing areas. Most of rubber buying centres are situated in town areas and the average distance from farm gate to the market is 13.5km and significantly affects the COP of RSS. Rubber marketers mentioned that rubber sheets and field latex have to be transported to Colombo District, due to the unavailability of manufacturing centres in Moneragala. Therefore, their profit margins were also low. The most of *Thurusaviya* District coordinating officials indicated that rubber purchasing centres should be implemented through TRSs. Thus, the rubber product manufacturing sector should be developed as cottage level, medium and large industries to consume the rubber in the District itself. The cause for this high price of rubber, as mentioned by the *Thurusaviya* District co-ordinating officials, is due to the district level consumption.

Constraints related to the extension service of the rubber farming

Table 7 revealed the constraints related to the extension service of the RF. Lack of training programmes on RSS manufacturing and mature up-keeping were major constraints under the extension services. Although relevant authorities conducted the training programmes, it was not sufficient enough to fulfil the requirement and also RSs highlighted more extension needs in the RSS manufacturing aspects. The number of advisory visits to rubber smallholdings, processing centres/smoke houses and market places are comparatively low, due to the lesser number of RDOs (2,450 RSs/RDO) in *Moneragala* (Dissanayake, 2009; Wijesuriya *et al*., 2011). Poor knowledge on RF was identified as a result of poor extension and advisory services. One of the reasons for the non-adoption on RF technologies was that the technology generated by researchers and disseminated to RSs by extension workers was not accompanied by adequate and timely supply of farm inputs. Wijesuriya, *et al*., (2011) has highlighted that, low education level was a constraint in improving the awareness of rubber smallholders on recommended rubber farming technologies. Thus, low monthly income was also a bottleneck for adoption on recommended technologies. These constraints need to be considered thoroughly in drawing up appropriate action plans to make RF productive in Moneragala. Therefore, there is a great responsibility on the shoulders of all the institutions catering the smallholder rubber sector in devising appropriate management plans to help the RSs in these areas.

Constraints related to Thurusaviya rubber societies

The Table 8 shows the constraints related to TRSs which were highlighted by RSs. It was reported as unsatisfactory input distribution and trustworthiness of the officers of TRSs. Relevant officials (RDOs and *Thurusaviya*) should monitor the activities of societies to minimize the mal functions.

Table 6. *Constraints for rubber marketing*

Constraints	Garrett mean score	Rank
Low prices for every grade of RSS	73.18	1
Distance from farm gate to the market	72.21	2
Corruptions in latex weighing	70.75	3
Unavailability of a village level market places	65.56	4

Table 7. *Constraints of extension service related to the rubber farming*

Constraints	Garrett mean score	Rank
Lack of training programmes on rubber processing aspects	74.45	1
Lack of training programmes on mature stage rubber cultivation	72.21	2
Lack of advisory visits to mature stage rubber plantations	70.55	3
Lack of advisory visits to processing centers/smoke houses	68.66	4
Lack of advice in marketing	64.32	5

Table 8. *Constraints related with Thurusaviya rubber societies*

Constraints	Garrett mean score	Rank
Unsatisfactory input distribution	68.99	1
Trustworthiness of the society officers	67.55	2

Conclusion and recommendations

The 44 constraints perceived by rubber smallholders were identified into following rubber farming activities; 1. Immature up keeping (Low quality of planting material, unavailability of planting material at correct time, unavailability of plants for vacancy filling, plant death due to drought condition, plant death due to animal attack (wild boar/porcupine), lack of knowledge in applying fertilizer for immature rubber plants, unavailability of fertilizer for immature rubber plants in correct time, inability to apply due to long drought period during the immature period, cost of fertilizer for immature rubber plants, cost of manuaring for immature rubber plants, long time period to reach the mature stage (>5 yrs), insufficient monetary value of rubber subsidy and delay in rubber subsidy and immature plants death due to disease attack), 2. Rubber tapping (Lack of knowledge in tapping, lack of skill in tapping, high number of *Tapping Panel Dryness* plants, unavailability of marking plates and modified tapping knifes and unavailability of tappers), 3. Manuaring of rubber farming (Lack of knowledge in applying fertilizer for mature rubber trees, unavailability of fertilizer for mature rubber trees at correct time, cost of fertilizer for mature rubber trees, inability to apply due to long drought period during the mature period and cost of manuaring of fertilizer for mature rubber trees), 4. Rubber processing (Unavailability of quality acid, cost of acid, unavailability of smooth roll, unavailability of diamond roll, lack of subsidy/credit facilities to buy inputs/rollers, lack of credit facilities to build smokehouse, constraints in group processing centres, unavailability of coagulating trays and distance from plantation to processing place), 5. Rubber marketing (Low prices for every grade of RSS, distance from farm gate to the market, corruptions in latex weighing and unavailability of market places at village level), 6. Extension service related to rubber farming (Lack of training programmes on rubber processing aspects, lack of training programmes on mature stage rubber cultivation, lack of advisory visits to mature stage rubber plantations, lack of advisory visits to processing centres/smoke houses and lack of advisory service regarding marketing) and 7. *Thurusaviya* rubber societies (Unsatisfactory input distribution and trustworthiness of the society officers).

Among them, low quality of planting material, lack of knowledge of tapping, lack of knowledge of applying fertilizer for mature rubber trees, unavailability of quality acid, low prices for every grade of RSS, lack of training programmes on rubber processing aspects and unsatisfactory input distribution were the highest prioritised constraints address the sustainability of rubber farming in Moneragala. The strategies and recommendations for practical implications for overcoming the present constraints of rubber farming in Moneragala can be summarized as follows;

Strategy 1: Development of an extension strategic plan in order to transfer the knowledge of the recommended rubber farming practices introduced by Rubber Research Institute of Sri Lanka to rubber smallholders in Moneragala with the aim of enhancing rubber productivity.

Recommendations for implementation of strategy 1

- All multi-stakeholders of rubber industry should be involved in the development of the strategic plan
- The strategic plan is needed to be focused on the following; a) development of appropriate technology, b) transfer of developed technology, c) promotion of avenues for diffusion of technology and adoption on transferred technology, d) creation

of a suitable environment for implementation and e) development of research extension dialogues between researchers, extension personnel and rubber smallholders.

- The nature of training and extension programmes should be changed with regard to use of information and communication technologies.
- Awareness and training programmes on soil and moisture conservation, manuring, tapping panel marking, Brown root disease controlling, prevention of fire damages and animal attacks, the impact of droughts and wild animal attacks, tapping and rubber sheet manufacturing should be continuously organized for the sustainability of rubber farming.
- New recruitment of rubber development officers should be made with the provision of necessary travelling facilities (Motor bicycles and/or transport allowances, *etc.)*

Strategy 2: Restructuring the rubber farming subsidies focused on Intermediate Zone rubber farming.

Recommendations for implementation of strategy 2

- The criteria/indicators for subsidy should be revised in order to achieve sustainable development of rubber farming, based on the condition of the Intermediate Zone.
- The constraints of land ownership which prevail with *Swarnabhoomi* and *Jayabhoomi* deeds should be solved through relevant authorities.
- Rigorous monitoring is needed on the provision of subsidy to rubber smallholders.
- Increase subsidy of rollers and smoke houses.
- Rubber smallholders should be educated on the subsidy scheme of rubber farming to avoid any delays and misunderstandings with relevant institutions.
- The number of rubber development officers should be increased in order to establish an efficient distribution of rubber farming subsidies.

Strategy 3: Improvement of the rubber marketing system.

Recommendations for implementation of strategy 3

- Establishment and strengthening of the village-level marketing channels.
- Marketing system based on *Thurusaviya* societies can be formed to buy high-quality sheet rubber at the village level.
- Development of rubber grading system.
- Establishment of rubber sealing price.
- The rubber manufacturing industries should be developed in Moneragala.

- Development of rubber-based cottage industries at smallholder level.

Strategy 4: Strengthening the *Thurusaviya* rubber societies

Recommendations for implementation of strategy 4

- The management unit of *Thurusaviya* rubber society should take appropriate action to identify the needs of their members.
- According to the need identification, the strategic plan should be established in each *Thurusaviya* rubber society in collaboration with the relevant organizations, with maintaining good rapport with them.
- *Thurusaviya* rubber societies should be restructured as mix model of cooperative systems and commercial systems with business entity.
- *Thurusaviya* rubber societies can be upgraded as small-scale industries which are capable of manufacturing value-added rubber products (rubber bands, automotive accessories, *etc.*).
- The *Thurusaviya* rubber societies should be classified as low, moderate and high based on the viability and strength, through measurement of the involvement in the extension activities, welfare activities and record keeping, *etc*. and develop a strategic plan for each society by the relevant authorities.

Strategy 5: Addressing the constraints for immature up-keeping

Recommendations for implementation of strategy 5

- The availability of quality plants should be assured and that should be distributed through proper quality rubber plant certification
- Make rubber smallholders aware of quality plants
- Form smallholder quality plant selection clusters which consist of smallholders who are going to plant rubber, so that, these clusters can reject low-quality plants
- Introduction of guidance, monitoring and record keeping book for each smallholding. Criteria for reserving subsidies and immature up-keeping practices should be included in this book
- Subsidies should be released only after monitoring the field observation.

Strategy 6: Promotion of self-tapping

Recommendations for implementation of strategy 6

- *In-situ* Tapping skill development programmes should be conducted covering all smallholders/tappers in Moneragala at field level with post evaluation
- Adoption of self-tapping (Smallholders tap their own holdings) should be promoted
- Necessary equipment for annual tapping marking should be

distributed through the *Thurusaviya* rubber societies.

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Journal of the Rubber Research Institute of Sri Lanka
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1. Seneviratne, P., Flegman, A.W. and Wijesekera, G.A.S. (1995). The problem of surface sterilization of shoot materials of *Hevea. Journal of the Rubber Research Institute of Sri Lanka* **75**, 51-60.
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