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Livelihood capital improvements in the rubber growing community of the Eastern Province of Sri Lanka

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Abstract
Rubber cultivation in Sri Lanka has recently been expanded to the Eastern Province. With an initial observation on the positive effects of this process on the rural community in this region, the present study was conducted to either characterize or quantify the impacts of rubber cultivation on the rural community assessing the livelihood capital assets, i.e. Human, Physical, Natural, Financial and Social aspects. Padiyathalawa Divisional Secretaries area of the Eastern Province with a reasonable number of rubber lands under harvesting was selected for the study. All farmers having mature rubber fields (33) were assessed together with similar number of non-rubber farmers of the same village for comparison. Both types of farmers were in the range of 40-60 years of age and educated up to secondary level in the local school. All had no other occupation than farming and having an average of four members in a family and all had sufficient family labour for on-farm activities. With the additional income generated from rubber, a higher level of Financial capital was observed among rubber farmers. As a result, expenditure of rubber farmers was 40% higher than the rest and its pattern showed that rubber farmers spend more on children's education, family health and charity gaining a higher level of Human capital. Rubber cultivation has not so far influenced the Natural capital since all farmers had equal opportunities in accessing water sources and lands with fertile soils. Further, rubber associated development in Physical capital has made farmers to have basic infrastructure facilities for their houses, some luxury appliances for convenience, facilities to strengthen social connectivity and improvement in farming. With more social interactions, Social capital was found to be higher among rubber farmers. All these findings confirmed the suitability of rubber cultivation as a livelihood improvement strategy in rural development programmes in the Eastern province of Sri Lanka.

Key words: non traditional areas, rubber cultivation, social impact

Introduction

Rubber industry plays an imperative role in Sri Lankan economy by contributing 0.3% to the Gross Domestic Production (Anon, 2016a). To cater the future demand for raw rubber, the Rubber Industry Master Plan (RIMP) expects to widen the production base to yield over

175,000 MT per year by 2020 (Anon, 2015). However, records in 2016 show that the country had produced only 79,100 MT of raw rubber from existing 132,700 hectares of which 90% is concentrated in traditional Wet Zone (Anon, 2016b). Being closer to the metropolitan areas, lands in Wet Zone are highly subjected to fragmentation for settlements and other more lucrative economic ventures, threatening the existing cultivation and rubber cultivations planned for the future. Therefore as mentioned in RIMP, focus is given to cultivate rubber in non-traditional areas of the country, where ample arable land is available.

Being a war-torn area neglected for nearly three decades, Eastern province has been targeted for development programmes by the Government of Sri Lanka (GoSL). It comprises large extent of sparsely populated lands indicating the potential for establishing plantation crops like rubber. Population density in Eastern province is 176 persons/km^2 and 26% of agricultural lands in the country are in this region. Also, more women in the region are unemployed with an unemployment rate of 5.5% (Anon, 2016a). Farmers in these areas mainly depend on rain-fed subsistence farming and the majority are either below or hovering on the poverty line (Anon, 2011). Having high land per capita and labour force, GoSL has launched a high priority rubber planting programme in this region providing additional inputs with a target of 10,000 ha (Rodrigo and Iqbal, 2006). Rubber was firstly introduced to a village in Padiyathalawa Divisional Secretariat area of Ampara District in Eastern Province in 2003 and latex harvesting began in 2011.

Importance of assessing the impact of newly introduced cropping system on livelihood of a community has been well explained (Nath and Inoue, 2009; Rist *et al*., 2010; Scoones, 1998) and methodologies have been developed to assess such impacts through household assets (Ashley and Hussein, 2000; Scoones, 2009; Toillier *et al*., 2011). Accordingly, some studies have been conducted elsewhere to explore the impact of rubber cultivation on rural livelihood (Fu *et al*., 2009; Longpichai *et al*., 2012; Viswanathan and Shivakoti, 2006). They have confirmed that rubber cultivation can affect the household assets of rural livelihood in different perspectives depending on community characteristics. Enhancement of rural livelihood due to existing rubber cultivation has been documented in Sri Lankan context comparing with the scenarios of some other rubber growing countries (Nath *et al*., 2013). In addition, importance of cultivating rubber with some other crops and livestock as integrated farming systems to make farmers more profitable has been discussed (Munasinghe and Rodrigo, 2004; Rodrigo *et al.*, 2001; Somboonuske, 2001; Viswanathan and Shivakoti, 2008). Prospects of expanding rubber cultivation to non-traditional areas in South-East Asia have been investigated by Fox *et al.* (2011) and Fox and Castella (2013) both in socioeconomic and environmental terms. On the other hand, evaluation of the biodiversity and socio-economic risks of land conversion to rubber plantations has also been considered (Ahrends *et al.*, 2015). Further, importance of stakeholder perception on rubber cultivation programmes have also been emphasized (Fischer and Vasseur, 2002; Wigboldus *et al.*, 2017).

To date, 1,750 ha of rubber have been cultivated in Eastern Province with *ca.* 2,500 smallholders and 32 holdings (17 ha) have reached the stage of latex harvesting (Anon, 2017). Arrangements are in the way to provide especial subsidy programmes (about 33% higher monitory value over the usual programme) with international funding to promote rubber based farming systems in this region. In addition to the improvement of rural livelihood providing a continuous permanent income source, increasing the rubber production in the country and sustain the environment through enhancing the tree cover are also expected in this effort.

Initial studies conducted so far to explore the benefits of rubber cultivation in the Eastern province of Sri Lanka have given an indication of significant positive impact on rural livelihood (Rodrigo *et al*., 2009; Rodrigo *et al*., 2014). However detailed investigations are required to identify the contribution of rubber cultivation on wellbeing of the rural community in the Eastern province of Sri Lanka.

This study aimed to characterize and quantify the impact of rubber cultivation on the community in the Eastern province through the assessments on major livelihood assets in terms of Human, Physical, Natural, Financial and Social capital.

Methodology

The study was conducted in Padiyathalawa Divisional Secretariat area of Ampara District where rubber was initially introduced in the Eastern Province of Sri Lanka (IL2). Farmers having mature rubber (rubber fields with latex harvesting) were the main target group. As total number of farmers having mature rubber fields had been limited to 33, total population was selected for the study. For the purpose of comparison, 34 out of 107 fulltime farmers who had not cultivated rubber in the same village were selected on random basis.

The study was conducted during the period of January to August 2017. Initially, an awareness programme was conducted to make the relevant farmers aware of the objectives and general methodology of the intended study. Thereafter, interviewer administered questionnaire was conducted for data gathering**.** Thereafter, interviews with farmers were held using the local language (Sinhala) for gathering required information. Livelihood status of both rubber and non-rubber farmers was assessed in terms of Human, Physical, Social, Natural and Financial capital assets. In building up the Human capital, farmers' age, gender, education level, literacy, occupation and details of the family such as labour force, number of dependents and expenditure pattern of the household were considered. Prevalence of natural resource stocks such as water source and access to land and quality of the lands were considered as Natural capital assets. Under the Physical capital assets basic infrastructure of house (type of floor, wall, roof and sanitary facilities), convenience in dwelling (furniture and electrical appliances, electricity and water supply to house, energy source for cooking), connectivity with the society (telecommunication, access road and road vehicle) and improvement in farming (livestock, farm vehicles and farm equipment) were considered. Borrowing and lending power of money, involvement in religious activities and charity, participation and leadership in community activities, interaction with relations and friends were considered as Social capital assets. Financial capital assets were determined by household income and securities (safe keepings).

Both descriptive and quantitative methods were used to analyze the data. To assess the significance in comparing capital assets between rubber and non rubber farmers, t-tests were made. All analyses were performed using GENSTAT ver. 19 statistical package (VSN International, 2017).

Results

Importance of human capital of farmers

The majority of households were male-headed (94%) with an average family size of four including one dependent. The age of farmers varied between 26 to 78; however, 70% lied in the range of 40-60 years. Most of the farmers had secondary level education with that 80% are literate on both read and write ability. None of them had experience in doing other occupations except farming. All families were enriched with own family labour having an average of 18 working hours per day per family.

Total average annual household expenditure of a rubber growing family (LKR 81,717) was significantly higher ($t=-3.22$, $p<0.05$) than that of a non-rubber growing family (LKR 56,503). Among the components of expenditure, greater portions have been recorded in cultivating crops and food for household in both types of households. In percentage apportion, expenditure on food of both groups was more or less similar with 34% share to the total. However in absolute terms, rubber farmers have spent LKR 27,000 per annum for their food whilst that of non-rubber farmers was LKR 19,000. Rubber farmers have assigned significantly higher proportion (each 5%) of their expenditure for children's education ($t=-3.43$, $p<0.05$) and family health care ($t=-3.15$, $p<0.05$) than non-rubber farmers (Fig. 1).

Importance of natural capital of farmers

Natural capital assets such as prevalence of water source, access to land and quality of the land did not show significant difference among both farmer groups. All farmers have had safe water sources; wells for drinking water and water streams for their daily other needs. Lands were mostly uniform and enriched with soil properties. Irrespective of the farmer group, the average lands owned by a farmer was 2 ha and many of those lands are located within 1 km distance from the home. Non rubber farmers fully utilize their lands for subsistence farming whilst rubber farmers used only *ca*. 20% of that for the same (Fig. 2).

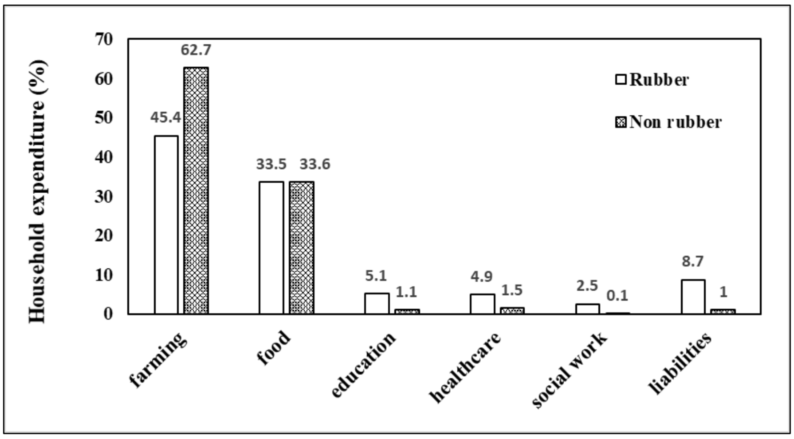

Fig. 1. Household expenditure pattern of farmers

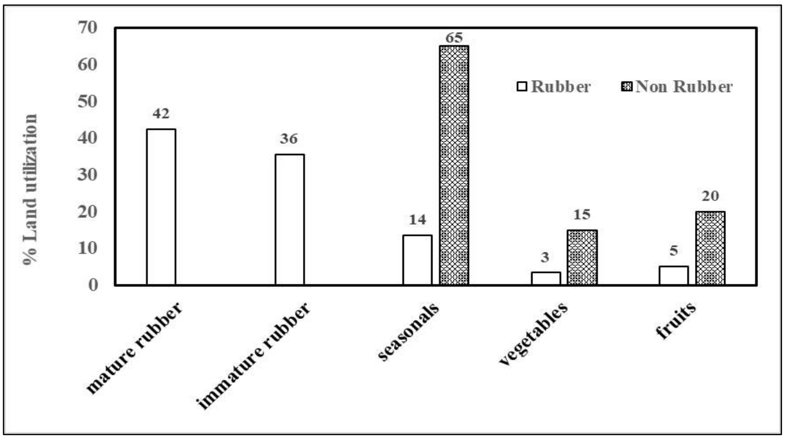

Fig. 2. Land distribution for different crops

Importance of financial capital of farmers

Total household income of a rubber farmer comprising both farm and off-farm earnings was significantly (t=-5.40, $p<0.05$) higher than that of non- rubber farmer. Annual income of a rubber cultivating household ranged from LKR 100,000 to LKR 555,000 with an average of LKR 280,000. Further, the income from rubber has accounted for 60% to the total. However, average income of a non-rubber household has limited to LKR 155,000 and varied within the range of LKR 71,000 to 300,000 (Fig. 3). Rubber farmers have inclined to save money with savings accounts at rural banks and an incident of enrolling in an insurance scheme was recorded by one farmer.

The average annual saving of a rubber farmer was LKR 12,000.

Importance of Physical capital of farmers

Having basic infrastructure in rubber growers' houses *i.e.* cement floor and wall, tile or asbestos roof was significantly higher than that of non-rubber growers. Also, convenience in dwelling such as having electricity and water supply to house, gas/electricity for cooking, luxury furniture and electrical appliances was significantly high among rubber growers. Further, they were significantly enriched with telecommunication facilities and gravel/concrete access roads facilitating connectivity with the society. In addition, rubber farmers have shown significant improvements in purchasing farm vehicles and farm machinery (Table 1 & Fig. 4).

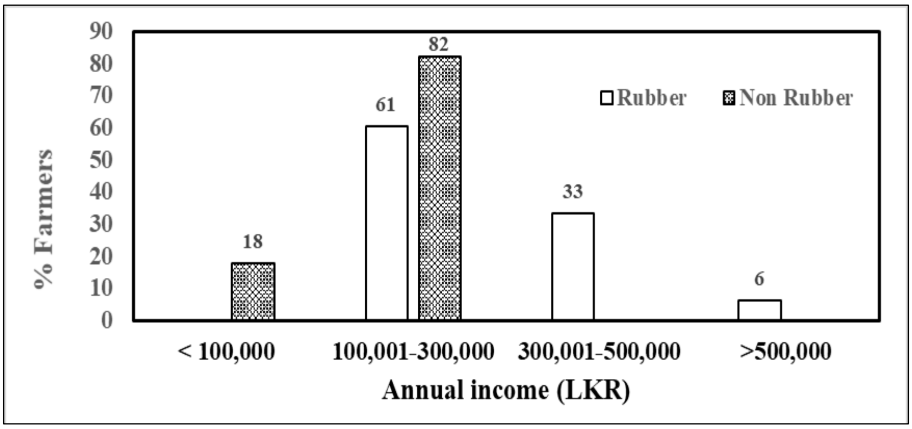

Fig. 3. Annual income distribution of households

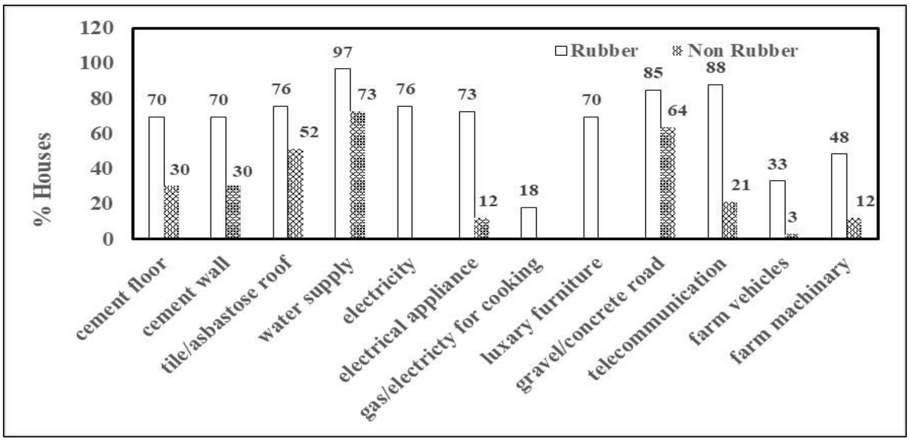

Fig. 4. Physical properties of farmer houses

Table 1. *Statistical significance in the impact of rubber cultivation on physical assets of rubber farmers*

Physical capital	Spearman rank correlation	t approximation	P>[t]
Basic infrastructure;			
Cement floor	0.403	3.55	<0.001
Cement wall	0.403	3.56	<0.001
Tile/Asbestos roof	0.266	2.23	0.029
Sanitary facilities	0.222	1.84	0.070
Convenience in dwelling;			
Water supply	0.356	3.07	0.003
Electricity	0.783	10.15	<0.001
Electrical appliances	0.618	6.34	<0.001
Gas/electricity for cooking	0.318	2.71	0.009
Furniture	0.734	8.71	<0.001
Connectivity with society;			
Gravel/concrete access road	0.260	2.17	0.033
Tele-communication	0.675	7.37	<0.001
Road vehicles	0.073	0.59	0.556
Improvement in farming;			
Farm vehicles	0.396	3.48	<0.001
Farm machinery	0.401	3.53	<0.001
Livestock	0.043	0.34	0.732

Importance of social capital of farmers

Rubber farmers have significantly high capacity over non rubber farmers in lending money to neighboring farmers in the village. Further, it was observed that interaction with relatives and friends and involvement in religious activities have increased significantly with the rubber cultivation. Also, they contributed significantly high amount for charity work and spent much time for community participation (Table 2 & Fig. 5).

Table 2. *Statistical significance in impact of rubber cultivation on social capital of rubber farmers*

	Spearman rank correlation	t approximation	P>[t]
Money lending capacity	0.672	7.32	<0.001
Money borrowing capacity	0.018	0.15	0.884
Visit relatives	0.390	3.41	0.001
Visit friends	0.408	4.23	<0.001
Visit religious places	0.465	0.600	<0.001
Community participation	0.034	2.58	0.012
Community leadership	0.205	1.69	0.095
Charity work	0.861	13.63	<0.001

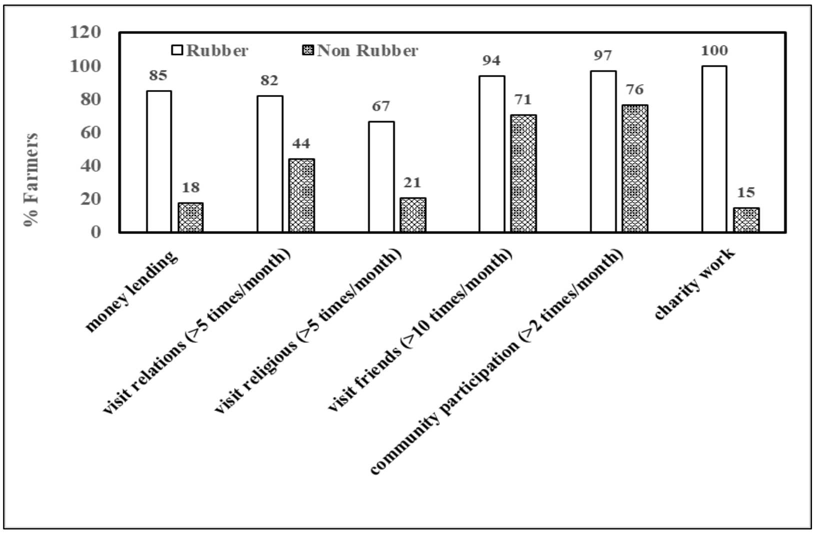

Fig. 5. Social capabilities of farmers

Discussion

In the promotion process of rubber cultivation in non-traditional areas, rain-fed farming systems are the focus in Sri Lanka and elsewhere (Fox *et al*., 2008; 2011; Fox and Castella, 2013). In such systems, farmers are usually engaged in subsistence agriculture which provides directly the most of dietary needs and then, the sale of additional produce facilitates to meet the other requirements. Uncertainty in weather pattern makes the rural life indecisive resulting in hidden poverty. For instance, 8% of farmers in the Eastern Province in Sri Lanka are considered to be poor hence receive the social benefits given to the poor by the government (*e.g.* Samurdhi payment). In addition to the rubber production, the promotion of rubber cultivation in such areas aims at providing a permanent income source to the poor for their livelihood improvements (Anon, 2015) which was the focal point in the present study.

A previous study conducted in the same village at the time of introducing rubber showed that farmers in the village were having more or less equal living standards (Rodrigo *et al*., 2009). Further, there were no records on any new introduction of income generating activities to the village. Therefore, it is very clear that the significant increase in Financial assets of farmers is due to the income from rubber. Similar financial improvements in farming communities have been observed in traditional rubber growing areas in Sri Lanka, India and Thailand (Nath *et al*., 2013; Viswanathan, 2008; Viswanathan and Shivakoti, 2006; 2008). As a result, the bargaining power has improved as shown by the changes in Human capital where rubber farmers were able to spend 40% more over the non-rubber farmers.

In existence, being an essential item, dietary needs are met first before spending on other necessities. With the increase in income level, the absolute amount spent for food has increased among rubber farmers, however proportion to the total was basically same between two categories of farmers. It shows that food habit of farmers has changed marginally with additional income from rubber, but still they are confined to a simple lifestyle. Sri Lanka is among the countries in the lower middle income category with the records on close to zero hunger (Anon, 2014) and this study provides evidence of achieving development goals.

Dealing with banks and insurance companies with some level of savings by rubber farmers indicates the changes in social dynamics of farmers towards sustainable and less risk future. Additional expenditure has been incurred on cultivation of crops which can be considered as a short- and medium-term investment. Moreover, in building up Human capital, more attention has been given for long-term investments for sustainable future such as own and family health care and more importantly, children's education. Sri Lanka has a fairly good free medical system (Rannan-Eliya *et al*., 2015); however in handing a large number of patients, such facilities seem inadequate to the level of satisfaction required by people. Time taken to meet a doctor and have it at convenient time, obtaining special care when necessary, distance travel and inadequate drug supply are reported as some of weaknesses in the free medical system. Therefore, if finances are available, people in Sri Lanka tend to go for private medical assistance. However, with poor income in subsistence farming under rain-fed systems, it seems more farmers have to forego even the health care to some extent and depend mainly on the government assisted free medical facilities. Also, despite the free education in Sri Lanka for children, the competition for exam success has resulted in seeking private tuition for difficult subjects. Additional finance given by rubber has opened the door for this facility bringing some hope to a brighter future for farmers' children.

Natural Assets are dominated by lands and then, water availability. Therefore, in short-term, improvements in this category cannot be expected since all farmers have a reasonable extent (*ca.* 2 ha) of lands and in general, individuals in the farming do not prefer to sell their lands others as everyone needs to depend on lands for subsistence. Any additional acquisition should be made from the Government lands. Though water is in scarce during dry periods, investing on water cannot easily be done at individual level as it requires community involvements. With only a few rubber growing farmers, such moves cannot be expected and it may be a reality only happens with a well organized rubber farming community.

Improvement in Physical assets such as upgrading the condition of the house to be more attractive, convenient (*e.g.* electricity, water supply, electric appliances and furniture) and stable (*e.g.* cement walls and floor, asbestos/tile roof) reflects the changes in living standards of farmers associated with rubber cultivation. These facts are consistent with the findings of Nath and Inoue (2009) and Nath *et al*. (2013). Although such facilities are essential components in today's context, the study reveals the level of substandard life of farmers in this region. The majority is living on farming under rain-fed agriculture and no guarantee is available to provide stable income for the peasant community. Instead of maintaining positive cash flow towards the Government for the development of the country, the Government has to pump money back as aids and reliefs to sustain the rural life in these areas. Therefore, promotion of rubber cultivation in these areas creates a win-win situation where the Government can develop the rubber industry by supporting the poor.

Long-term positive impact of rubber cultivation to the national economy will also be shown by the changes in Social Assets. Improvement in lending capability of money shows the rubber farmers' financial strength. More economic returns can be expected in long-term by investing those money. Enhancements in the interactions with relations and fellow villagers of rubber farmers, their participation in community activities and involvement in more charity works will also add an unseen social value to the rural economy in the socioeconomic context.

Findings of this study basically show the positive impacts of rubber cultivation on the economies at household, village and country levels whilst no negative impacts recorded. Therefore, it justifies the efforts and investments made to expand the rubber cultivation in the area for the enhancement of rural livelihood. In refining a production system for improved sustainability, the modern management tools such as material flow and material flow cost analyses and lifecycle assessment can be deployed. Such approaches have been adopted in raw rubber manufacturing (Duniwilla *et al*., 2017). No such studies have ever been conducted for rubber cultivation and hence proposed for future research.

Conclusions

Rubber cultivation in the Eastern province has been able to improve the Human capital of farmers showing significant increase in the expenditure on children's education and family health care. Increase in total household income resulted in an improvement of Financial capital with more rubber farmers in high income categories. Further, rubber associated development in Physical capital has made farmers to have basic infrastructure facilities for their houses, some luxury appliances for convenience, facilities to strengthen social connectivity and improvement in farming. Capacity of lending money, visiting relations and friends, attending to religious activities, participating community activities and charity work were higher in rubber farmers showing the improvement in Social capital. Therefore, the study confirmed the utility values of rubber cultivation in improving the overall livelihood of peasant community in the Eastern Province of Sri Lanka.

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Recent trends in disease occurrence in the non-traditional rubber-growing areas of Sri Lanka

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Abstract
As the rubber industry is being extended to non-traditional areas in Uva, Northern and Eastern provinces in Sri Lanka, it was important to extend the crop protection arm to those areas also. The disease profile recorded in those areas for a period of three years was studied. The symptomatology of the major diseases and the diversity of the Sri Lankan populations of the pathogens causing major diseases were also studied. Furthermore, the alternative hosts of the pathogens of the major diseases were also looked for. With the observations made, it could be concluded that, during the study period, brown root disease was the malady with the highest incidence in the non-traditional rubber-growing areas of Sri Lanka. Encrustation of sand and stones on the root surface could be identified as the characteristic diagnostic symptom of the disease. The different isolates of Phellinus noxius showed variations in colony morphology. With the contextual observations of the reported incidences, drier soil conditions, poor land preparation and association with the forest-associated tree species were suggested to be the major reasons for the higher incidence of brown root disease in the studied areas. White root disease was also recorded to a lesser extent. Corynespora leaf fall disease was found to be the foliar disease with the highest incidence. Cow pea (Vigna unguiculata) and soy bean (Glycine max) were recorded to be two alternative hosts of Corynespora-causing fungus.

Key words**:** disease profile, *Hevea brasiliensis,* non-traditional rubber-growing areas

Introduction

Due to the fact that there is no more land available in the traditional rubber-growing areas of Sri Lanka, the rubber industry is being extended to non-traditional rubber growing areas in Uva, Northern and Eastern provinces where land and labour are non-limiting factors. This was carried out during the first decade of the new millennium and most of these clearings are now in the immature phase or at the beginning of tapping. The newly established lands are mostly cleared natural forests and rubber is being the first plantation crop. As these non-traditional areas include parts of Low/Mid Country Intermediate and Dry Zones, the crop may face different agro-climatic conditions. Moreover, in those areas, the environmental factors such as the rain fall pattern, soil characteristics, and the natural flora and fauna are different from those of the traditional rubber-growing areas of Sri Lanka. The management practices adopted and the cropping systems are also dissimilar to that of wet zone. These altered conditions not only influence the crop growth and development, but also affect the host-pathogen interactions, it was expected that the natural balance between the crops and the pathogens may have been disturbed leading to novel disease outbreaks.

This study was carried out to find out the disease profile recorded in the non-traditional rubber-growing areas of Sri Lanka; to identify the symptomatology of the major diseases and to study the diversity of the Sri Lankan populations of the pathogens causing diseases with high prevalence; identification of the alternative hosts of the pathogens of the major diseases.

Materials and Methods

Surveying of the diseases

The reported disease incidences from non-traditional areas in Uva province to the Rubber Research Institute of Sri Lanka between the period from mid-2013 to mid-2016 was used as the sample of study. A structured questionnaire was used to collect the background information of each disease incidence.

Collection and maintenance of the pathogen isolates

Disease samples were collected from *H. brasiliensis* and other host species. Isolations were made on artificial media (Malt Extract Agar or Potato Dextrose Agar) from symptomatic roots/leaves/ bark portions after surface sterilization in 70% ethyl alcohol for 2 minutes. Pure cultures were obtained from hyphal tip isolations executed through microscopic observations. The cultures were maintained in the respective media at room temperature (RT, 28 ± 2 ºC). Four day old fungal cultures were used to study culture characteristics of inoculation. Description sheet of Commonwealth Mycological Institute (CMI) were used as a guide to identify the isolated fungi.

Studies on the diversity of the pathogens and symptomatology of the diseases

The isolates of the pathogens with highest incidence were used in the diversity study. They were grown on artificial media at RT in the dark for four days. Mycelial plugs of 9mm diameter were removed with a sterile cork borer from the leading edges of the fungal colonies, and one such plug was placed in the center of each 90 mm Petri dish containing the medium.

The coloration, fluffiness and the density of the cultures as the culture characteristics were recorded after four days of inoculation. Ranks from 0-5 were given for the brownish colouration developed in the culture, as the rank zero and five being the lowest and highest colourations of the cultures

respectively. The fluffiness was ranked from 1-4 as the rank one and four being the lowest and highest fluffiness respectively. The density was ranked from 1-3 as the rank one and three being the lowest and highest densities of the cultures respectively. Five replicates were used in all experiments.
The scores recorded based on the coloration, fluffiness and the density of the cultures for different isolates were analyzed employing Wilcoxon Rank Sum Test (WRST). Subsequently, the mean scores obtained through the WRST were used to group the isolates employing agglomerative hierarchical approach in cluster analysis as it is the most widely used method compared to divisive method (Rencher, 2002). The statistical software, Genstat ver.16 was used in the data analysis.
In the root diseases, the signs and the symptoms on the collar and the root systems were studied and in foliar disease incidences, the disease symptoms of the leaves were recorded.

Studies on the alternative hosts

In order to identify the possible alternative host species of the diseases-causing pathogens of rubber, the presence of live and dead non-rubber species in the vicinity of the diseased rubber trees were investigated. In each of the root disease incidences, the firstly-diseased rubber tree was traced and the root system of the tree was exposed as to find out the association of the roots of the neighboring trees with the respective tree. The signs and the symptoms of both the rubber tree as well as the associated tree were recorded.
In the case of foliar diseases, plants around the diseased rubber tree having foliar disease symptoms were selected to be tested for the existence of the pathogens.

Results and Discussions

Disease profile recorded in the non-traditional areas

As expected, the disease profile recorded was different from that of the traditional areas, hence the white root disease: which is recorded in the highest incidence in the traditional rubber-growing areas was reported in a lesser rate. The major disease problems which were reported in a higher occurrence are described below.

a) Brown root disease

In 39 of the maladies, the signs and symptoms shown by the trees resembled those of the brown root disease. When observed under the microscope, as per the CMI descriptions, all the isolates resembled the microscopic characters of the *Phellinus noxius*, the causative fungus of the brown root disease of rubber. All the cultures grown in the laboratory showed distinctive raised brown and white plaques (patches) and produced arthrospores, which are asexual spores formed by the division of special hyphal segments.
This was the highest percentage of the maladies in non-traditional rubber-growing areas and interestingly brown root disease is a condition which is less frequently reported from traditional

rubber growing areas. This disease is distributed in tropical and sub-tropical regions of Asia, Central America, Africa and Oceania (Larsen and Cobb-Poulle. 1990; CABI/EPPO, 1997; Chang and Yang 1998; Ann *et al.*, 2002). It was first recorded on *Hevea* in Ceylon in 1905 (Petch, 1911). Murray in year 1930 stated that, it is one of the commonest root diseases of *Hevea* in Ceylon (Murray, 1930). However, when the past few decades are concerned, the occurrence of brown root disease was controversial with the historical declaration. It was observed that the disease was less-frequently reported and the reported incidences were confined to limited areas during the latter part of the 20^{th} century.

Diversity of the population of Phellinus noxius

The different isolates of *Phellinus noxius* showed variations in colony morphology (Fig. 1).

The coloration, density and the fluffiness in the culture figure showed variations and visible clusters could be obtained with all three characters (Fig. 2).

Fig. 1. Variability in cultural morphology of *Phellinus noxius* (after 3 days of growth under dark conditions)

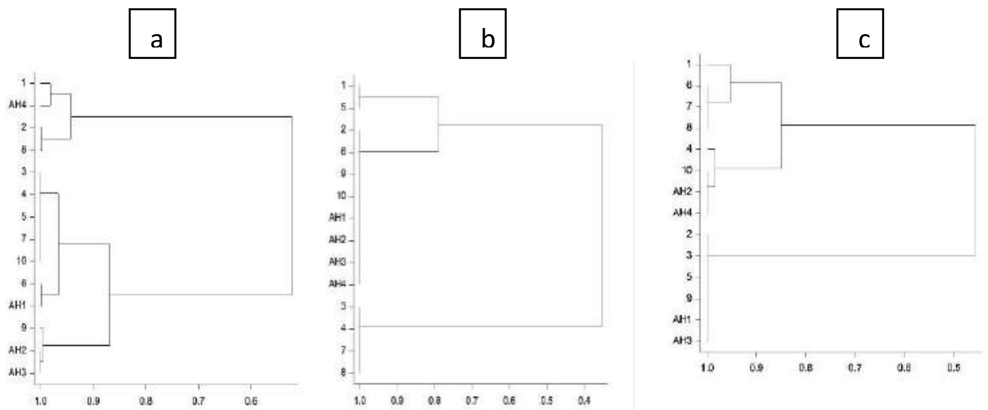

Fig. 2. Dendrograms showing the clustering of the isolates based on the **a**. colouration, **b.** density and **c.** fluffiness

According to the mean score values, isolates showed a variability in all three colony characters: colouration, density and the fluffiness. Two groups were prominent in clustograms obtained for the characters. However, the clusters formed based on the three colony characters did not show a clear similarity. Moreover, the *P. noxius* isolates obtained from the other species have not shown a significant genetic distance among the *P. noxius* isolates from rubber.

Signs and symptoms of the disease

The aboveground symptoms of brown root disease were more or less similar to those caused by white root disease as symptoms are caused by hindrance of uptake and transport of water and nutrients from the soil. Slow plant growth, yellowing and wilting of leaves, defoliation and branch dieback were the major above ground symptoms (Figs. 3a & 3b). However, time duration between the exhibition of the initial foliar symptoms and the death of the tree was much lesser than in the case of white root disease.

Roots infected with *P. noxius* initially exhibited a brown discoloration of the wood just beneath the bark (Fig. 3c). Tawny brown gummy rhizomorphs were firmly fixed to the outer bark surface with an encrustation of sand and stones on the root surface (Fig. 3d). This could be identified as the characteristic diagnostic symptom of the disease. The inner bark was covered with a white to brownish mycelial mat. The dead wood later become white, dry, and honey-combed (Fig. 3e). Occasionally, bracket like fructifications were observed on the basal trunks of diseased trees. The fructification was a dark brown hard bracket, dark grey on the underside. (Fig. 3f & 3g). In addition to these signs and symptoms, dryness of the trees which are in early tapping was another symptom which growers recognize a tree in diseased. In the early stage of the infection, application of management strategies are effective. According the reported incidences, the borer attack was also commonly observed as a secondary attack of the trees and which are beyond control.

Though the brown root disease shows a comparatively easy-to-diagnose signs and symptoms, the disease is not a very familiar disease to Sri Lankan rubber growers. It was noticed that the disease identification is lagging behind leading to further spread of the disease by accumulation of the inoculum in the plantations.

Higher incidence of brown root disease

The majority of reported brown root disease incidences in this study were from rubber plantations established after clearing native forests. Moreover, the disease was frequently reported from the smallholders, where rubber is planted after leaving woody debris of the prior stand: either forest, rubber or some other crop species (Fig. 4). In all incidences, stumps of forest or some other tree species left behind at the time of land preparation were observed in contact with the firstly diseased plant of the current disease patch.

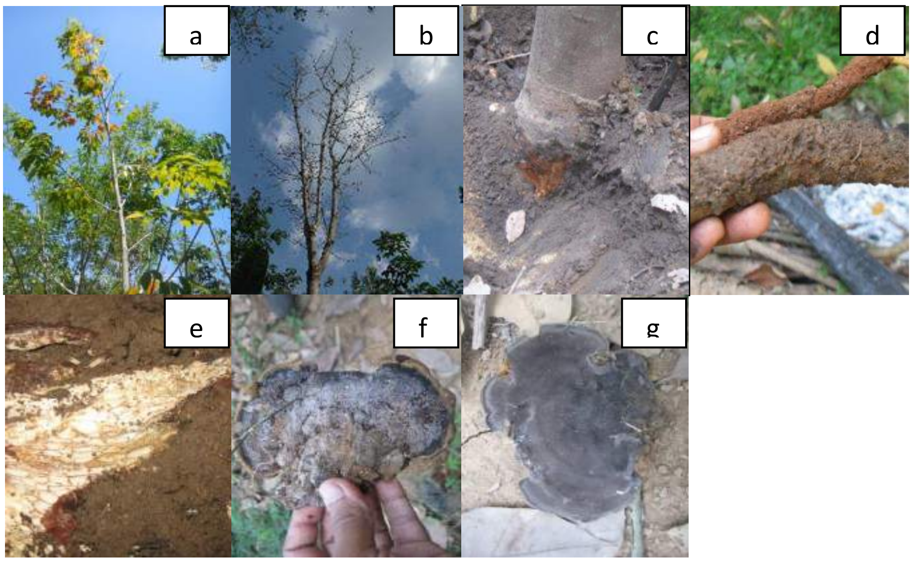

Fig. 3. Symptoms of the brown root disease of rubber plants **a)** yellowing and wilting of leaves – can not be seen; **b)** branch dieback; **c)** brown discoloration of the wood just beneath the bark; **d)** encrustation of sand and stones on the root surface; **e)** honey-combed wood; **f)** fruiting bodies (upper surface); **g)** fruiting bodies (lower surface)

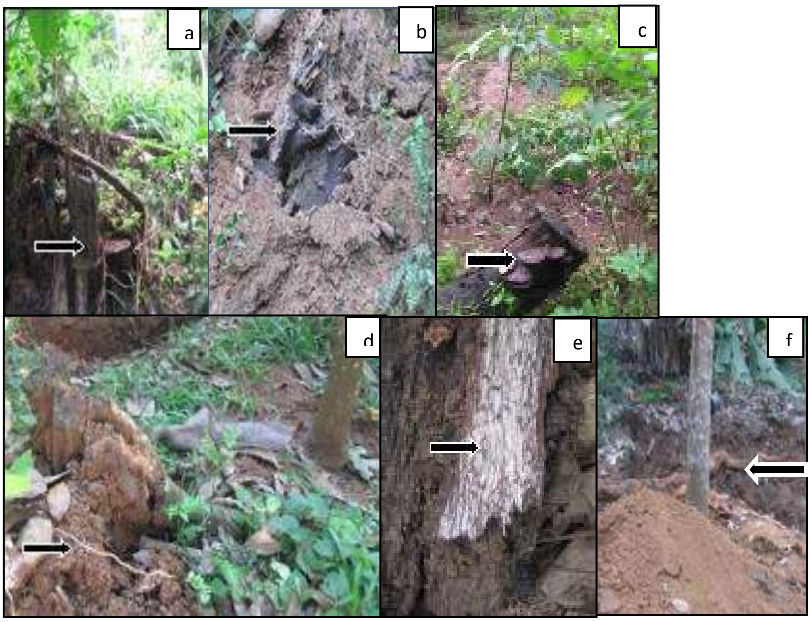

Fig. 4. Infected roots and stumps of forestry species: (**a, b, c, d**) fructifications on stumps (**e**) honey-comb appearance, (**f**) brown discoloration of the wood

As per the observations, the presence of un-removed root pieces of the native tree species can be identified as one of the major factors favorable for the development of the brown root disease in those areas. According to the past records in Sri Lanka also the brown root disease causing fungus has been of common occurrence in the earlier days of rubber plantings. When rubber was inter planted in cocoa and tea fields. The rubber trees later got infected from the dead stumps remained after the removal of cocoa and tea by simply cutting off the bushes (Advisory Circular of RRISL, 1954).

When E. J. Corner described *Fomes noxius* (currently *Phellinus noxius*) as a new species in 1932, and it was usually found in cleared or disturbed areas. Since, the beginning of the 20th century, many plantations of rubber, tea, cocoa, coffee, oil palm, and mahogany established on cleared forests sites had been infected or destroyed by *P. noxius* (Pegler *et al.*, 1968). It can be expected that the inoculum is present in native tropical forests of Sri Lanka and new infection centers may have initiated when roots of the newly planted trees come in contact with infected stumps or other woody debris of cleared native forest. Further spread from the initial infection centers is through root contacts and *P. noxius* can persist in the roots and stumps of infected plants for more than ten years after the death of the host (Chang, 1996).

During the surveys carried out by Chang, *Phellinus noxius* occurred more frequently in fields with sandy soils, probably because sandy soils drain better and are less likely to become submerged for significant length of time, even during high rainfall (Chang, 1996). On the other hand, clay soils drain poorly; therefore these soils are more likely to be submerged, a situation that is detrimental to the survival of *Phellinus noxius* (Chang, 1996). The non-traditional areas are in the intermediate zone of the country, and is obvious that the soils are drier and less likely to become submerged for significant length of time. Therefore, the probability of brown root disease incidence is higher in such areas.

b) White root disease

With the similar signs and the symptoms to those observed in the traditional rubber-growing areas, 10 of the maladies were diagnosed as white root disease with the support with the cultural characteristics of the pathogen, *Rigidoporus microporus*. The presence of the dry soil conditions in these areas can be identified as the major reason for the reduction of the white root disease.

c) Corynespora leaf fall

Corynespora leaf fall, caused by *Corynespora cassiicola* was present on rubber in 15 incidences. It was confirmed by signs and symptoms culture characteristics and microscopic observations.

Alternative hosts of the pathogens

a) Brown root disease

However, the pathogen isolates could be obtained only from four alternative species, as some of the roots were too decayed. They were *Careya arborea* ('kahata'), *Gmelina arborea* ('eth demata'), decayed *Mangifera indica* (mango) and *Artocarpus heterophyllus* (jack). These isolates showed variation in their cultural characteristics (Fig. 1). The studies on the pathogenicity and the cross infectivity of the isolates among the tree species from which they were isolated and rubber are in progress.

Brown root disease has a very wide host range including, most of the 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 mahagoni* (mahogany) (Chang 1996).

b) Corynespora leaf fall

As the above-mentioned cash crops are commonly intercropped with rubber in the study areas, the studies on the cross infectivity are in progress.

Conclusion

With the findings of the study, it can be concluded that, brown root disease was the malady with the highest incidence in the in non-traditional rubber-growing areas of Sri Lanka. Drier soil conditions, poor land preparation and association with the forest-associated tree species were the major reasons for higher incidence of this disease in the non-traditional rubber growing areas. The different isolates of *Phellinus noxius* showed variations in colony morphology. The coloration, density and the fluffiness in the culture figure showed variations and visible clusters could be obtained with all three characters. *Corynespora* leaf fall was found to be the foliar disease with the highest incidence. Cow pea *(Vigna unguiculata),* and Soy bean *(Glycine max)* were recorded to be two alternative hosts of *Corynespora cassiicola*. The importance of looking into the management of these maladies in non-traditional rubber-growing areas can be emphasized in order to have a sustainable rubber industry in the country.

Acknowledgement

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Moringa oleifera leaf extract as a biostimulant on growth and other physio-chemical attributes of rubber (*Hevea brasiliesnsis*) under drought and heat stress conditions

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Abstract

Drought and high temperature are the major impediments limiting growth of Hevea. We studied the efficacy of foliar applied Moringa (Moringa oleifera) leaf extract (MLE) as a biostimulant on the response of Hevea to sub-optimal climatic conditions. Rubber plants of clone RRISL 203 cultivated in the Intermediate Zone (IZ) and Dry Zone (DZ) were spray treated with water (mock treatment), MLE at 5, 10 and 15% concentrations for IZ and 3 and 5% for DZ. Physiological parameters viz. net photosynthesis (Pr), chlorophyll content (Cc), stomatal conductance (gs) and leaf water potential (Ψ) were recorded after three months from the commencement of treatments whilst girth measurements were recorded at three and twelve months after treatments in the IZ. Total phenolic content (TPC) and antioxidant activities, employing FRAP (ferric reducing assay power) and ABTS (2,2'-azino-bis-3-ethylbenzothiazoline-6-sulphonic acid) techniques, were estimated after three months from first spraying in the DZ. Significantly higher Pr, Cc and gs values were recorded from plants treated with MLE at all three concentrations as compared to control. Significantly higher TPC values (17.17 and 15.90 mg of gallic acid equivalent/ g of leaf sample), and FRAP values (14.79 and 14.70 mg of trolox equivalent/g of leaf sample) and ABTS values (70.26 and 59.43 mg of TE/g of leaf sample) were recorded in plants treated with MLE at both concentrations (3 and 5%) as compared to control (12.50 mg of GAE/g of leaf sample, 10.68 mg of TE/g of leaf sample and 49.96 mg of TE/g of leaf sample), respectively. A significantly higher girth (11.5 cm) was recorded in plants treated with MLE at 5% as compared to control (9.66 cm) after 12 months of treatments. Improved growth and physio-chemical attributes of rubber plants could be attributed to the beneficial effect of MLE as a biostimulant and therefore, exogenous application of MLE could effectively be utilized as an environmental friendly and inexpensive strategy for growth improvement in Hevea under sub-optimal climatic conditions.

***Key words*:** abiotic stress, growth, Moringa leaf extract, rubber

Introduction

Rubber has been grown traditionally in the Low and Mid Country Wet Zones covering the South–Western, Southern and Central parts of Sri Lanka. However, as the scope of further expansion of cultivation in traditional areas is being limited, there has been some effort to extend rubber plantation to non-traditional areas, such as Moneragala, Padiyathalawa, Ampara, Vavuniya, Hambanthota and Puttalam in the Intermediate and Dry Zones of the country (Rodrigo *et al.*, 2009, 2011 and 2014; Iqbal *et al.*, 2010). The mean annual rainfall in the Intermediate and Dry Zones are 1000-1500 mm and 1000 mm, respectively with four to seven month-long dry periods and one major monsoon rainy period (Lakmini *et al.*, 2006).

Crop growth and yields are negatively affected by sub-optimal water supply and high temperatures due to physical damages, physiological disruptions, and biochemical changes (Fahad *et al.*, 2017). Stress phenomena that occur simultaneously, such as drought and heat, have shown to be more detrimental to plant growth than each of these stresses individually (Perdomo *et al*., 2015). Plants which are exposed to stress, accumulate reactive oxygen species (ROS) like superoxide anion radical, hydroxyl radical, and hydrogen peroxide which are very lethal and cause extensive damage to protein, DNA and lipids and thereby affect normal cellular functioning (Foyer and Noctor, 2005). Redox homeostasis in plants during stressful conditions is maintained by enzymatic and non-enzymatic low molecular compounds, *i.e.* antioxidants, like ascorbic acid, reduced glutathione, α-tocopherol, carotenoids, phenolics, flavonoids, and proline (Gill and Tuteja, 2010).

Severe growth reduction and longer immaturity periods due to drought stress have been reported in rubber grown in non-traditional dry areas (Chandrashekar *et al.*, 1998; Sreelatha *et al.*, 2011). Under water stress conditions, very low stomatal conductance (Chandrashekar *et al*., 1998) and severe inhibition of photosynthesis and transpiration were reported in rubber (Krishna *et al*., 1991). Drought tolerance in plants is a complex phenomenon being controlled by a large number of minor genes and loci on chromosomes (Mohammadi *et al.*, 2005). The genetic improvements in combination with the proper cultural practices are considered important in managing the abiotic stresses in crop plants (Wahid *et al.*, 2007). Nevertheless, genetic variation in the existing *Hevea* germplasm being limited, drought tolerant rubber clones are yet to be produced in Sri Lanka through conventional breeding.

As an alternative to long-term breeding approach, priming (preconditioning) has been widely adopted as a short-term strategy to induce resistance to drought and heat stress in various crop plants (Savvides *et al.*, 2016). Exogenous application of growth regulators and osmoprotectants at different growth stages can play an important role in inducing resistance against drought and heat (Fahad *et al.*, 2017). Cost effective exogenous use of plant-based extracts (biostimulants) containing plant growth regulators, hormones and antioxidants have also been reported for the improvement of crop performance with higher economic returns (Bakhtavar *et al.,* 2015). Plant biostimulants contain substance(s) and/or microorganisms whose function when applied to plants or the rhizosphere is to stimulate natural processes to enhance nutrient uptake, nutrient efficiency, tolerance to abiotic stress, and crop quality (Van Oosten *et al.,* 2017).

In recent years, Moringa (*Moringa oleifera*) has gained enormous fame as having biostimulant potential (Bakhtavar *et al.,* 2015). Moringa is commonly known as 'drumstick' or 'horseradish' and grows in the tropical and subtropical regions of the world. Moringa leaves are well-known as a vegetable and are rich in vitamins, particularly A and C, iron, calcium, carotenes and phenolics (Foidl *et al*., 2001; Rady *et al.,* 2013; Yasmeen *et al*., 2013; Rady and Mohamed, 2015). Leaf extracts of Moringa show potential antioxidant properties (Siddhuraju and Becker, 2003). In addition, extracts of Moringa possess sufficient quantity of cytokinins (Rady *et al.,* 2013, Rady and Mohamed, 2015).

Exogenous MLE has shown to alleviate abiotic stresses *viz.,* drought, heat, salinity, and improve growth and physiological attributes in various crop plants such as Pear *(Pyrus communis),* Wheat, Maize, Quinona (*Chenopodium* spp.) and Sorghum (El-Hamied and El-Amary, 2015; Nawaz *et al.,* 2016; Pervez *et al.,* 2017; Maswada *et al.,* 2018; Rashid *et al.,* 2018; Ahmad *et al.,* 2016). In Sri Lanka, especially in the Intermediate and Dry Zones, Moringa is a predominant plant grown along fences and in some home gardens. Rubber x Moringa intercropping systems are being popularized in the North and East of Sri Lanka under a Special Capital Project No. 22-01.17 of the Rubber Research Institute of Sri Lanka. Therefore, Moringa leaves are readily available and can be collected free of cost or at a very low cost in the above areas at present.

Nayanakantha *et al.* (2018) demonstrated, for the first time, that exogenous MLE improved physiological parameters of *Hevea* in the Intermediate Zone. Nevertheless, growth and physio-chemical attributes of *Hevea* in response to MLE treatment under drought and heat stress conditions in both Intermediate and Dry Zones have not been reported. The current study, thus, aimed to investigate the effect of MLE as a biostimulant on growth and physio-chemical attributes of *Hevea* under sub-optimal climatic conditions.

Materials and Methods

Experiment in the Intermediate Zone (IZ)

A medium holder's rubber field, Nottinghill Private Estate in Mawathagama (IZ), of clone RRISL 203 (three months old) was selected for the study. Rainfall and the number of rainy days were recorded for a period of three months from the day of treatment imposition. Soil moisture content in the field was recorded using Theta Probe (ML3, Delta-T devices, UK) equipment. Day time temperature and relative humidity (RH) in the field were recorded on the same day of data collection using a pocket weather meter (Kestrel 3000 wind meter, USA). Fresh Moringa leaves (1 kg) were collected and crushed with two liters of water using a blender. The resultant juice extract was named as 50% solution, from which 5, 10 and 15%

solutions were made with appropriate dilutions. Plants were spray treated (primed) separately with aqueous Moringa leaf extract (MLE) at 5, 10 and 15% concentrations at monthly intervals for a period of six months from January to June in 2017. Control plants were devoid of priming treatments. In the mock treatment, plants were also sprayed with water at monthly intervals. There were three blocks and each block had 20 plants. Four plants were imposed with each treatment in each block, according to a randomized completed block design (RCBD), so that there were 12 plants for each treatment. Other agro management practices were done as recommended by RRISL.

Measurements of growth and physiological parameters

Girth was recorded before imposing the treatments and also at 3 and 12 months after the first spraying. Physiological parameters *viz.,* net photosynthesis (*Pr)* and stomatal conductance (g_s) on intact mature leaves were recorded using a portable photosynthesis system (LI-6400), LI-COR, U.S.A. A photosynthetic active radiation (PAR) of 1800 µmol m^{-2} $s^{-1}$was supplied by a light unit mounted on the top of leaf chamber. Two leaves were selected from each plant for each treatment and three plants were used for each treatment. Measurements were taken between priming treatments. For the mock treatment, plants were sprayed with water. There were three blocks and each block had 20 plants. Five plants were imposed with each treatment in each 09:00-11:00 hrs after three months from the first spraying. Leaf water potential (Ψ) was recorded using pressure chamber equipment (Model 1000, PMS Company, USA), after three months from first spraying. For each treatment, two plants were selected and one leaf was collected from each plant for recording water potential data. Chlorophyll content in intact mature leaves from three plants (2 leaves per plant) for each treatment was measured using a SPAD-502 plus Chlorophyll meter (Minolta Camera Co., Ltd., Japan).

Experiment in the Dry Zone (DZ)

One year after the first study at Mawathagama, a smallholder's rubber field of clone RRISL 203 (three months old) at Malayalapuram in Kilinochchi was selected for the second study. Soil moisture content in the field was recorded using Theta Probe equipment. Day time temperature and relative humidity (RH%) in the field were recorded on the same day of data collection using a pocket weather meter. Plants were spray treated with MLE at 3 and 5% concentrations at monthly intervals for a period of three months. A lower concentration of MLE (3%) was selected on the basis of the results obtained from the first study and subsequent studies were conducted under the glass house conditions at RRISL. Control plants were devoid of block according to a RCBD, so that there were 15 plants for each treatment. Other agro management practices were done as recommended by RRISL.

Antioxidant analysis

Three months after first spraying in the DZ, three plants from each treatment, representing each block, were selected and a leaf (from middle area of the stem) was collected from each plant so that three leaves were collected for each treatment. Cut ends of the petioles were wrapped with moistened cotton plugs, put into polythene bags, sealed, labeled and transported to the Herbal Technology Section, Industrial Technology Institute (ITI), Halbarawa Garden, Malambe, on the same day the samples were collected.

Leaf samples were subjected to various antioxidant assays. Free radical scavenging activity of leaf samples was determined by ABTS (2,2'-azino-bis-3-ethylbenzothiazoline -6-sulphonic acid) radical cation decolorization assay following the procedure of Re *et al.* (1999). The results were expressed as milligrams of Trolox equivalent (TE) per gram of leaf sample. FRAP (ferric reducing antioxidant power) assay was done following the procedure of Benzie and Strain (1996). The results were expressed as milligrams of TE per gram of leaf sample. The total phenolic contents (TPC) in leaf samples were determined spectrophotometrically according to Folin-Ciocalteu method (Singleton *et al.*, 1999) and the results were presented as milligrams of gallic acid equivalent (GAE) per gram of leaf sample. All the samples were analyzed in triplicates.

Data analysis

Significance of the observed treatment differences was tested by analysis of variance using proc ANOVA procedure of the SAS software package (version 9.1) and significant means were separated using the least significant difference (LSD).

Results and Discussion

Day time temperature and relative humidity (11:00-11:30 hrs) recorded at experimental sites in the IZ (for 2017) and in the DZ (for 2018) are shown in Figure 1. The amount of rainfall and the number of rainy days recorded for a period of four months from January-April 2017 for the IZ are shown in Figure 2. No rainy days were recorded during the study period (January-April 2018) in the DZ. The soil moisture content recorded in the IZ on 24th April 2017 and in the DZ on 21st April 2018 were 2.1% v/v and 2.0% v/v, respectively.

Results revealed that high temperature, low humidity and low soil moisture conditions prevailed in the experimental sites in both the zones. Therefore, it can be presumed that the plants had been subjected to abiotic stresses caused by drought and heat during the study period.

Physiological parameters

Under the above mentioned sub-optimal soil and weather conditions, significantly higher net photosynthetic rates were recorded in plants treated with MLE at all three concentrations (5, 10 and 15%) as compared to the control, three months after treatment. Nevertheless, no significant differences in photosynthetic rates between MLE treated and mock (water) treated plants were recorded (Table 1).

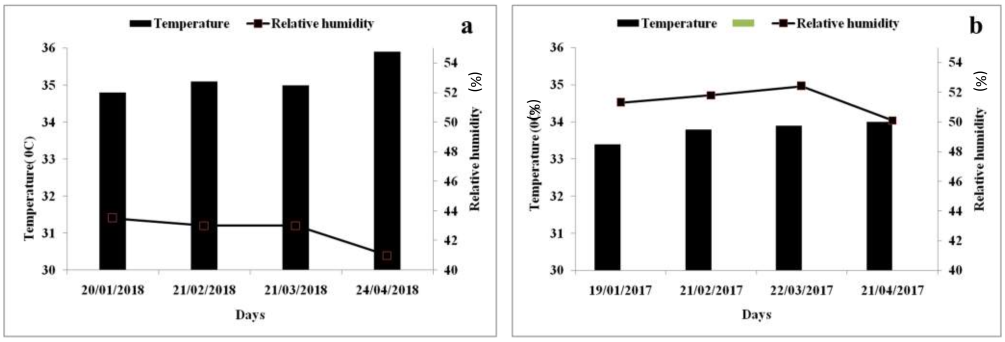

Fig. 1. Day time temperature and relative humidly recorded at the experimental site in the DZ on the same days of data collection from January to April 2018 (a) and in the IZ from January-April 2017 (b).

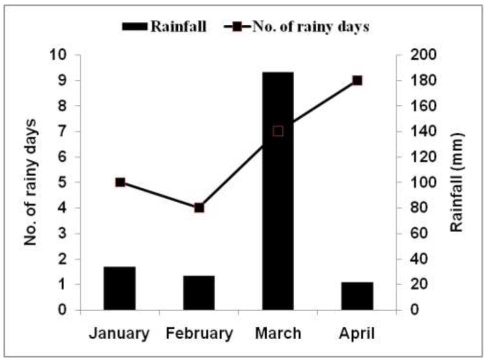

Fig. 2. Rainfall and the number of rainy days recorded at the experimental site in the IZ from January to April 2017

Significantly higher stomatal conductance values were recorded in plants treated at all levels of MLE as compared to the control. However, MLE at 10% had a significantly higher value as compared to both control and mock treatment (Table 1). But there were no significant differences in stomatal conductance values in plants treated with MLE at 5 or 15% as compared to mock treatment. Higher leaf water potential (more negative) values were recorded from plants treated with MLE, especially at 10 or 15%, as compared to control or mock treatment (Table 1).

Table 1. *Effect of MLE on physiological attributes of Hevea under sub-optimal climatic conditions in the IZ, three months after treatments imposition*

Treatment	Net photosynthetic rate (µmol m^{-2} s^{-1})	Stomatal conductance (mmol $m^{-2}s^{-1}$)	Chlorophyll content (SPAD value)	Leaf water potential (Ψ) (Mpa)
Control	14.00±2.01^{b}	0.185±0.02^{c}	51.66±0.17^{b}	-1.45±0.05
Water	16.00±0.70^{ab}	0.237±0.02^{bc}	52.53±0.49^{b}	-1.55±0.15
5% MLE	18.53±0.31^{a}	0.297±0.02^{ab}	55.83±1.05^{a}	-1.95±0.05
10% MLE	19.33±0.33^{a}	0.300±0.02^{a}	56.10±1.51^{a}	-2.15±0.05
15% MLE	19.53±0.86^{a}	0.327±0.03^{ab}	58.36±0.67^{a}	-2.25±0.05
LSD$_{0.5}$	3.641	0.791	2.777	

Data presented are the means ± SEs. Values followed by the same letter in a column are not significantly different at p<0.05.

One of the key physiological phenomena affected by the drought and heat stress in plants is photosynthesis. It is mainly affected due to reduced leaf expansion, improper functioning of the photosynthetic machinery and leaf senescence (Fahad *et al.,* 2017). Stomatal closure under drought reduces the CO_2 availability which makes plant more susceptible to photo damage. The reduced moisture availability induces negative changes in photosynthetic pigments, damages the photosynthetic machinery and impairs the performance of important enzymes causing considerable losses in plant growth and yield (Lawlor and Cornic, 2002).

Rubber tree regulates the stomatal apertures to avoid excessive loss of water and stomatal closure occurred to maintain the water potential above a critical threshold, thus protecting against xylem cavitation (Kunjet *et al.,* 2013). Under drought stress, the water deficit causes a decrease in the leaf water potential and stomatal conductance which leads to a reduction of transpiration in the rubber trees (Kunjith *et al.,* 2013). Very low stomatal conductance (Chandrashekar *et al.,* 1998) and severe inhibition of photosynthesis and transpiration (Krishna *et al.,* 1991) have already been reported for *Hevea* under drought stress.

In the present study, improved physiological parameters *viz.* photosynthesis and stomatal conductance in plants treated with MLE as compared to control under sub-optimal climatic conditions could be directly attributed to the beneficial effect of MLE as a rich source of antioxidants such as phenolics, ascorbate, carotenoids (lutein, alpha-carotene, beta-carotene and xanthin), vitamins like (A, B, C), different essential minerals (K, Ca, Fe), proteins and zeatin which can increase the efficiency of PSII (Foidle *et al.,* 2001). Exogenous application of MLE has been shown to improve photosynthesis and stomatal conductance in Quinoa (*Chenopodium* spp.) (Rashid *et al.,* 2018), Maize (Bakhtavar *et al.,* 2015) and rocket (*Eruca vesicaria* sub sp. *sativa*) (Abdalla, 2015) under abiotic stress conditions. Nevertheless, treatment of rubber plants with water alone also improved photosynthesis in par with MLE treatments, suggesting the beneficial effect of foliar spraying of water on growth of rubber under sub-optimal climatic conditions. Higher water potential (more negative values) due to MLE treatment could be attributed to the accumulation of more osmolytes in *Hevea.* Accumulation of osmolytes, such as proline, glycine betaine, soluble proteins and soluble sugars, is a strategy to overcome osmotic stress provoked by drought (Ahmad *et al.,* 2016).

The leaf chlorophyll content increased significantly in rubber plants treated with MLE at all three concentrations (5, 10 and 15%) as compared to control and mock treatment after 3 months of treatment imposition (Table 1). Drought and heat stress trigger metabolic changes especially by excess ethylene production leading to early senescence and chlorophyll degradation. Thus, maintenance of stay green character is very important and considered as best indicator of thermo tolerance (Rashid *et al.,* 2018). Yasmeen *et al*. (2013)

demonstrated that exogenous MLE significantly increased the chlorophyll content in leaves of salt stressed wheat plants. Ali *et al.* (2011) reported that treatment of maize plants with MLE could increase the leaf chlorophyll contents through activation of cytokinin dependent isopentenyl transferase (ipt) biosynthesis thus avoiding premature senescence of leaves. In the present study, increased chlorophyll content in rubber plants treated with MLE could be attributed to the presence of cytokinin, such as zeatin in MLE extract. Besides zeatin, MLE contains high nutritional potentialities of several macro elements such as Mg (Yameogo *et al.,* 2011), a constituent of chlorophyll, which would account for the increase in chlorophyll content in rubber plants.

Antioxidant analysis

MLE at both concentrations (3 & 5%) significantly increased the TPC and FRCP in leaf samples as compared to control and the mock treatment in the DZ (Table 2). Nevertheless, a significantly higher ABTS value was recorded from plants treated with MLE at 5% as compared to control and other treatments. Further, significantly higher ABTS values were recorded from plants treated with MLE at 3% or water as compared to control.

To overcome oxidative damage under stressed conditions, plants develop an antioxidant defense system consisting of various antioxidant enzymes and nonenzymatic antioxidants *e.g.,* proline, tocopherols, glycine betaine, total soluble sugars, total free amino acids, phenolic compounds, ascorbic acid, and carotenoids (Mittler, 2002). This antioxidant system maintains ROS at a less toxic level by converting them into water and oxygen. Therefore, increased accumulation of non enzymatic antioxidants in MLE treated rubber plants under sub-optimal climatic conditions could be directly attributed to the beneficial effect of MLE as a biostimulant containing a rich source of antioxidants, hormones and essential macro and micro nutrients (Foidl *et al.,* 2001; Siddhuraju and Becker, 2003; Rady and Mohamed, 2015).

The ROS-scavenging systems play an essential role in maintaining redox homoeostasis. Activities of antioxidant enzymes; (superoxide dismutase (SOD), peroxidase, catalase (CAT) and glutathione reductase (GR)) and concentrations of antioxidant molecules (glutathione and ascorbate) are the most predominant functions in plants (Zhang *et al.,* 2018). The antioxidant elevation in rubber leaves in the present study could also be due to the stimulatory effect of MLE on activation of genes responsible for the above enzymes which scavenge free radicals.

TPC, FRAP and ABTS techniques have been employed for estimation of antioxidant activities in latex of *Hevea* (Siriwong *et al.,* 2018). MLE application has also been reported to increase leaf antioxidant contents and ameliorate the negative effects exerted due to drought and heat stresses in wheat and Quinoa plants (Nawaz *et al.,* 2016; Rashid *et al.,* 2018).

Growth parameters

A significantly higher girth was recorded in plants treated with MLE at 15% concentration as compared to control after three months from the first spraying (Table 3). However, there was no significant difference in plants treated with MLE at all three concentrations as compared to mock treatment after 3 months from the first spraying. Nevertheless, after 12 months from the first spraying, a significantly higher girth value was recorded in plants treated with MLE at 5% as compared to control and mock treatment. Girth values in plants imposed with MLE at 10% and 15% were on par with those in control and mock treatment after 12 months of first spraying. This suggests that application of MLE at low concentration (5%) at monthly intervals over a long period is beneficial than applying higher concentrations of MLE for growth improvement in *Hevea.* Nevertheless, application of MLE at high concentrations (10% and 15%) on *Hevea* over a long period, including months with extreme weather conditions, might exert more stress so that the beneficial effect of MLE could not be obtained.

Under stress conditions plants utilize most of their resources for improvement in defence mechanisms rather than growth and development (Yasmeen *et al.,* 2013). Nevertheless, growth enhancement of rubber plants could be attributed to the beneficial effect of MLE as a biostimulant containing macro and micro nutrients, growth promoting hormones, amino acids and antioxidants (Yasmeen *et al*., 2013; Rady and Mohamed, 2015). Foliar spray of MLE has been shown to boost the growth of crop plants by increasing leaf area and photosynthetic rate as mineral composition of MLE makes it an excellent natural growth promoting substance (foliar nutrients) influencing physiological processes in a positive way (Yasmeen *et al*., 2013).

Table 2. *Effect of MLE on total phenolic contents and antioxidant activities of Hevea after three months of treatments imposition at monthly intervals in Kilinochchi*

Treatment	TPC (mg of GAE/g of leaf sample)	ABTS activity (mg of TE/g of leaf sample)	FRAP activity (mg of TE/g of leaf sample)
Control	12.50±0.11^{b}	49.96±0.08^{c}	10.68±0.14^{b}
Water	13.55±0.07^{b}	55.08±0.48^{b}	11.59±0.23^{b}
3% MLE	15.90±0.10^{a}	59.43±0.14^{b}	14.70±0.66^{a}
5% MLE	17.17±0.19^{a}	70.26±0.10^{a}	14.79±0.17^{a}
$LSD_{0.5}$	1.542	4.725	1.249

Data presented are the means ± SEs (n = 3), triplicate analysis from the pooled leaf samples for each treatment. Values followed by the same letter in a column are not significantly different at $p<0.05$

Table 3. *Effect of MLE on growth of Hevea before and after imposing treatments at monthly intervals for six months*

Treatment	Girth (cm) at Day 0	Girth (cm) after 3 months	Girth (cm) after 12 months
Control	4.54±0.11[a]	5.78±0.08[b]	9.66±0.14[b]
Water	4.44±0.07[a]	6.43±0.48[ab]	9.82±0.23[b]
5% MLE	4.27±0.10[a]	6.66±0.14[ab]	11.5±0.66[a]
10% MLE	4.54±0.19[a]	6.83±0.10[ab]	10.8±0.17[ab]
15% MLE	4.45±0.06[a]	7.00±0.31[a]	10.5±0.29[ab]
$LSD_{0.5}$	0.3205	1.051	1.249

Data presented are the means ± SEs (n = 15). Values followed by the same letter in a column are not significantly different at $p<0.05$

Among the plant growth regulators, zeatin, a naturally occurring form of cytokinins present in MLE, has a critical role in promoting cell division and modification in apical dominance in plants and thus enhancing growth of crop plants (Ahmad *et al.*, 2016). Spraying Sorghum plants with MLE at 3% increased growth parameters and yield (Ahmad *et al.*, 2016). Moreover, Abdalla (2015) reported that treatment of rocket (*Eruca vesicaria* subsp. *sativa*) plants with MLE at 2% increased the content of N, P and K in leaves.

Conclusion

Our study demonstrates, for the first time, that exogenous application of MLE is effective in improving physio-chemical attributes and growth of *Hevea* under sub-optimal climatic conditions, possibly by antioxidant elevation. Therefore, application of MLE, preferably 5%, may effectively be utilized as an inexpensive and environment friendly biostimulant for enhanced performance of *Hevea* under drought and heat stress conditions as an adaptation measure for climate change.

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Effectiveness of commercially available selected water-based and oil-based ethephon formulations as a yield stimulant of rubber (*Hevea brasiliensis*)

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Abstract

Rubber industry plays a major role in the economy of Sri Lanka. Two types of commercial ethephon mixtures i.e. water-based and oil-based are presently marketed in Sri Lanka to use as yield stimulant of rubber. Though the yield performance of these mixtures had been studied, no proper investigation has been made on effectiveness of these two types of commercial ethephon mixtures on factors affecting latex regeneration and flow of Hevea brasiliensis.

Mature rubber plantation with RRIC 121 genotype tapped on first virgin panel (BO-I) with S/2 d4 (half spiral once in four days) system was selected for the study. Yield related factors and latex physiological parameters of rubber trees stimulated with two types of commercial ethephon mixtures were determined on each tapping day during June - August, 2018.

Daily latex volume per tree, daily dry rubber yield per tree (g/t/t), latex thiol content, latex polyphenol content and plugging index showed a similar pattern of variation between the rubber trees stimulated with water-based and oil-based ethephon over the experimental period and the variations were not statistically significant. Oil-based ethephon stimulated rubber trees had a significantly higher latex dry rubber content (43.80±0.37, 42.69±0.47, 42.13±0.50%) than water-based ethephon stimulated trees (40.63±0.36, 39.39±0.42, 39.59±0.36%) over the three consecutive stimulation cycles. Inorganic phosphorus content in latex was found to be 21-23% higher in trees applied with water-based stimulant than oil-based stimulant over the period studied. Oil-based stimulation showed 7-11% increase in latex flow duration than water-based stimulation. Though some physiological parameters of latex have been improved in trees with application of oil-based ethephon, yielding capacity for a particular period was statistically comparable in trees applied with water-based and oil-based ethephon.

Key words: *Hevea*, low intensity harvesting, oil-based ethephon, rubber, water-based ethephon

Introduction

Rubber tree (*Hevea brasiliensis*) is a commercially cultivated plantation crop for industrial production of latex

(Verheye, 2010). Harvesting of latex is the costliest operation in rubber plantations which has led to higher cost of production (COP) (Rodrigo *et al.*, 2011). In addition, currently the plantations are facing difficulties such as fluctuation in rubber price, shortage of harvesters and high rate of bark consumption and these issues have made a significant impact on rubber plantation industry (Prasanna *et al.*, 2010; Rodrigo *et al.*, 2011). Reduction of tapping days due to rain interferences, lack of skilled harvesters, poor field conditions and improper infrastructure facilities have also affected the economic performance of rubber lands (Kudaligama *et al.*, 2012; Rodrigo *et al.*, 2011).

Tapping a half spiral of the tree, once in two days frequency (S/2 d2) is the traditional harvesting system of rubber in Sri Lanka (Kudaligama *et al.*, 2010). However, in order to mitigate the above mentioned issues prevailing in rubber plantation industry, mainly high COP and lack of skilled harvesters, low intensity harvesting (LIH) systems have been introduced. These systems allow trees to be tapped in a lesser frequency or lesser amount of bark consumption and ensure sustained production in rubber plantations (Njukeng *et al.*, 2011).

Ethephon is used as the yield stimulant along with the LIH systems in order to recover the yield loss due to the reduction of harvesting intensity (Gao *et al*., 2018). Ethephon is a kind of plant growth regulator that penetrates into the plant tissues and decomposes to produce ethylene that increases activities of anabolic physiological processes such as biosynthesis of rubber and related proteins (Tseng *et al.*, 2000; Coupe and Chrestin, 1989). Ethephon induces sucrose hydrolysis in tissues, thus the carbon supply for rubber biosynthesis through increased glycolysis (Tupy, 1985; Mesquita *et al*., 2006). Also, released ethylene inhibits latex coagulation and avoids blockings by making walls of laticiferous vessels rigid and thickened (Shi *et al.*, 2016). Furthermore, effect of ethephon on cell membrane permeability results in decrease of laticiferous vessel obstruction (Zhu and Zhang, 2009). As a result of delaying the plugging of latex vessels, the duration of latex flow is increased (Emuedo *et al.*, 2017; Gao *et al*., 2018). Thereby the yield per tapping is increased (Kudaligama *et al.*, 2013).

There are two types of commercial ethephon mixtures (*i.e.* water-based and oil-based) which are available for stimulation of rubber trees in Sri Lanka and both are imported in ready-mixed form. Though the yield performance of different low intensity harvesting systems with oil-based ethephon had been studied previously (Kudaligama *et al.*, 2013), factors affecting latex regeneration and flow with oil-based ethephon and water-based ethephon under Sri Lankan conditions has not been studied in detail. Therefore, this study was conducted with a view to investigate the effectiveness of water-based and oil-based ethephon on yield and factors affecting latex regeneration and flow of *Hevea brasiliensis* under Sri Lankan conditions.

Materials and Methods

Mature rubber field replanted with RRIC

121 *Hevea* genotype and tapped on first virgin panel (BO-1) with S/2 d4 (half spiral, once in four days) tapping system at Galewatte Division of Dartonfield Estate in Kalutara district was selected for the study. Two commercial ethephon mixtures, water-based and oil-based currently marketed in Sri Lanka were selected as the treatments. Randomized complete block design (RCBD) with three replicates was used and three sub-samples from each replicate were used for sampling. For each sub-sample ten trees with equal vigour had been randomly selected. As per the recommendation for S/2 d4 system, trees were stimulated monthly by applying 1.6 g of 2.5% ethephon per application per tree (Rodrigo *et al*., 2011). Important yield related factors such as daily latex volume per tree, dry rubber content of latex (Anon., 1984), daily dry rubber yield per tree (g/t/t), latex flow duration and plugging index (Milford *et al.*, 1969) were determined on each tapping day after stimulation with the two different types of ethephon during June - August, 2018.

Latex samples were collected to the vessels immersed in ice, avoiding latex dripped for the initial five minutes after tapping. Serum was extracted by coagulating 2.5 g of latex in 25 ml of 2.5% trichloro acetic acid (TCA) and used for testing latex physiological parameters.

Determination of sucrose content

Test samples were prepared by diluting 0.1 ml of latex serum with 0.4 ml of TCA. Sucrose content was determined using the anthrone method described by Scott and Melvin (1953). Absorbance of the samples were measured at 620 nm using a UV-VIS Spectrophotometer (SHIMADZU UV-1800). Sucrose content of the samples were determined using a calibration curve prepared with different sucrose concentrations ranging from 40-200 $\mu g ml^{-1}$.

Determination of inorganic phosphorus content

Test samples were prepared by diluting 0.4 ml of latex serum with 1.6 ml of TCA. Inorganic phosphorus content was determined using the method described by Taussky and Shorr (1953). Absorbance of the samples were measured at 740 nm using a UV-VIS Spectrophotometer (SHIMADZU UV-1800). Inorganic phosphorus content of the samples was determined using a calibration curve prepared with different potassium dihydrogen phosphate concentrations ranging from 10 - 50 $\mu g ml^{-1}$.

Determination of thiol content

Test samples were prepared by diluting 1.0 ml of latex serum with 1.0 ml of TCA. Thiol content was determined using the method described by Boyne & Ellman (1972). Absorbance of the samples was measured at 412 nm using a UV-VIS Spectrophotometer (SHIMADZU UV-1800). The concentration of thiol of the samples was determined using a calibration curve prepared with different glutathione (reduced) concentrations ranging from 1 - 5 $\mu g ml^{-1}$.

Determination of polyphenol content

Test samples were prepared by diluting 1.0 ml of latex serum with 1.0 ml of TCA. Modified Folin-Ciocalteus method was used to determine polyphenol contents of the samples (Turkmen *et al*., 2006). Absorbance of the samples were measured at 750 nm using a UV-VIS Spectrophotometer (SHIMADZU UV-1800). The concentration of polyphenols of the samples were determined using a calibration curve prepared with different gallic acid concentrations ranging from 5 - 25 μgml^{-1}.

Statistical analysis of data

Data were analyzed using SAS software. ANOVA was done for the variables followed by mean separation using Least Significant Difference (LSD) at the significance level of 0.05.

Results and Discussion

A similar variation of latex sucrose content could be observed in trees stimulated with both oil-based and water-based ethephon throughout the period tested (Fig. 1a). Generally, a decrease of latex sucrose content is observed under ethephon application as a result of the higher sucrose consumption in latex regeneration (Gohet *et al*., 2008). A significantly higher average sucrose content (p=0.027) was evident in trees stimulated with oil-based ethephon (4.94±0.31 mM) than that with water-based ethephon (4.08±0.23 mM) during the first stimulation cycle (Fig. 1a). However, average sucrose content of both formulations showed no significant difference over the remaining period. A higher content of sucrose in latex may indicate a good loading to the laticifers (Jacob *et al.*, 1989) which may positively effect on latex regeneration, ultimately the yield. Thus, higher latex sucrose content may indicate more sucrose recovery to the laticifers (Sainoi *et al*., 2017). Respectively, 1.41±0.22 mM and 2.08 ± 0.12 mM were observed in oil-based stimulated and water-based stimulated trees as the lowest latex sucrose contents whilst 9.21±0.62 mM and 7.42±0.19 mM were the highest during the period.

Inorganic phosphorus content of latex is directly correlated with the latex production of trees and an indicator of energetic level of metabolism of latex cells (Jacob *et al.*, 1989; Gohet *et al*., 2008). Pattern of variation of latex inorganic phosphorus content was similar with both types of ethephon (Fig. 1b). Over the three month period, water-based formulation showed a higher monthly average latex inorganic phosphorous contents (20.75±0.54 mM, 22.87±0.47 mM, 20.68±0.33 mM) compared to oil- based formulation (16.93±0.50 mM, 18.56±0.71 mM, 17.07±0.55 mM) with a statistical significance (p=0.000) (Fig. 1b). Highest and lowest inorganic phosphorous content in latex with water-based ethephon was 23.06±1.48 mM and 13.56±2.74 mM whilst it was 21.24±1.52 mM and 16.02±2.24 mM in oil-based ethephon, respectively. Significantly higher inorganic phosphorus content in rubber trees applied with water-based ethephon indicates a comparatively higher metabolic activation and energy consumption in latex regeneration with water-based ethephon.

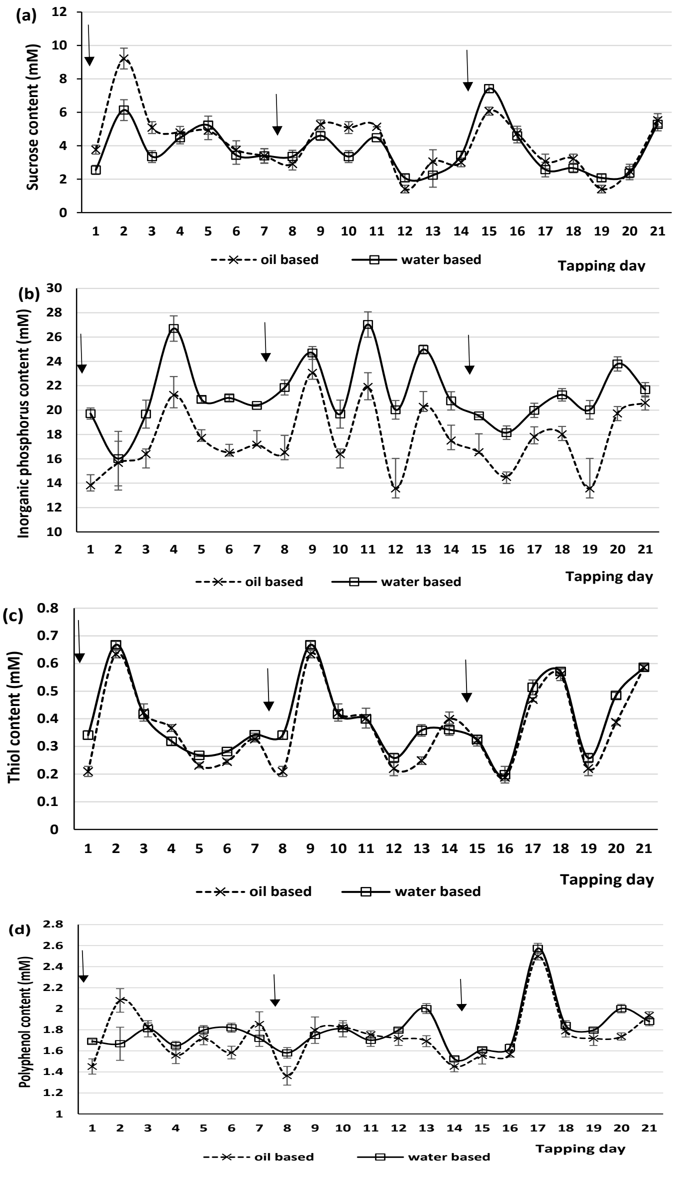

Fig. 1. Variation of latex (a) sucrose, (b) inorganic phosphorus, (c) thiol and (d) polyphenol content of rubber trees stimulated with different types of ethephon ('Arrow' mark indicates the day of stimulation)

Variations of thiol in water-based ethephon and oil-based ethephon treatments were more or less similar with no significant difference over the period investigated (Fig. 1c). Average values of latex thiol content of oil-based and water-based ethephon applied rubber trees were 0.35±0.02, 0.37±0.02, 0.39±0.02 mM and 0.37±0.02, 0.39±0.02, 0.42±0.02 mM over three stimulation cycles, respectively. In oil-based and water-based ethephon stimulated rubber trees, highest thiol content found was 0.63±0.01 mM and 0.67±0.01 mM. For oil-based and water-based ethephon treatments, the lowest thiol content was 0.19±0.01 mM and 0.20±0.03 mM, respectively. Latex thiol content has a direct relationship with latex production. It was reported that thiols act as a potential activator for key enzymes such as invertase and pyruvate kinase (Jacob *et al.*, 1989). Thiol also acts as an antioxidant that protects cells against damages caused by reactive oxygen species (De Costa *et al.*, 2006).

Over three stimulation cycles, latex polyphenol contents in rubber trees treated with oil-based ethephon and water-based ethephon varied in a similar pattern with time and the difference between treatments was not statistically significant (Fig. 1d). The highest and lowest latex polyphenol contents found in oil- based stimulated trees were 2.50±0.04 mM and 1.36±0.09 mM, respectively whilst it was 2.57±0.05 mM and 1.58±0.05 mM in trees applied with water-based ethephon over the period investigated. Higher phenols might be due to the reduced level of polyphenol oxidase enzyme which is a key enzyme in coagulation of latex (Coupe and Chrestin, 1989). On the other hand, higher polyphenol content in latex may result in latex discoloration in the presence of polyphenol oxidase enzyme (Yapa, 1976).

Plugging index of water-based ethephon and oil-based ethephon was statistically comparable. However, rubber trees stimulated with oil-based ethephon had a significantly higher latex flow duration than that of water-based ethephon in most of the tapping days ($p < 0.05$) (Fig. 2a and b).

With application of oil-based and water-based ethephon, minimum plugging index of trees were reported as 1.73±0.13 and 1.37 ± 0.07, respectively and it has been increased to the maximum values 3.27±0.23 and 3.44±0.28, respectively during the period investigated. Observed maximum and minimum flow durations were 176.7±1.8 min and 114±1.7 min in oil-based stimulated trees whilst 178.3±1.0 min and 126.3±1.4 min were in water-based stimulated trees, respectively (Fig. 2a and b).

Dry rubber content of latex was found to be significantly higher ($p <0.001$ in all stimulation cycles) in oil-based ethephon treated rubber trees than the water-based ethephon treated rubber trees over the period (Fig. 3a). Previous studies have also reported comparatively higher values of dry rubber content of latex with oil-based ethephon treated rubber trees (Kudaligama *et al.*, 2013). Over the period tested, oil-based and water-based ethephon stimulated trees reported 46.23±0.12% and 42.60±0.13% as the highest dry rubber content, respectively and reported lowest DRC values were 39.50±1.63% and 36.67±0.06%, respectively during the period (Fig. 3a).

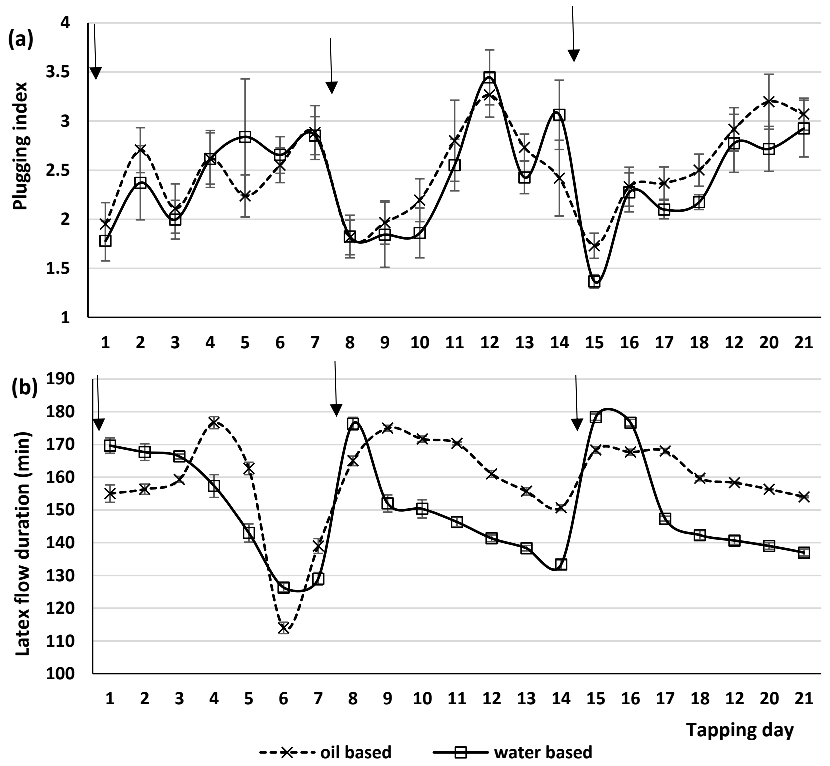

Fig. 2. Variation of (a) plugging index and (b) latex flow duration of rubber trees stimulated with oil- based and water- based ethephon formulations ('Arrow' mark indicates the day of stimulation)

Average DRC% for three stimulation cycles were 43.80±0.37, 42.69±0.47, 42.13±0.50 in oil-based ethephon stimulated trees whilst 40.63±0.36, 39.39±0.42, 39.59±0.36 in water-based ethephon stimulated rubber trees. Drop in DRC% was higher in water-based ethephon applied trees than in oil-based ethephon stimulated trees throughout the period.

Both latex volume per tree and dry rubber yield per tree per tapping (g/t/t) showed a similar pattern of variation with oil-based ethephon and water-based ethephon treatments with no statistical significance (Fig. 3b and c). During three consecutive stimulation cycles, average values of latex volume of a tree were 171.24±11.61 ml, 217.43±15.26 ml, 237.71±12.59 ml and 161.43±11.96 ml, 220.86±15.65ml, 239.33±12.14 ml with oil-based and water-based ethephon stimulated rubber trees, respectively. Respective average g/t/t values during the study were 92.15±4.99 g in oil-based ethephon stimulated rubber trees and 84.93±4.64 g in water-based ethephon stimulated rubber trees (Fig. 3b and c). Peak g/t/t of oil-based ethephon stimulated trees was reported as

144.85±8.01g and it was 133.37±16.19 g in water-based ethephon stimulated trees during the period.

Irrespective of the type of stimulant, the highest response for ethephon stimulant was observed on the very first tapping day (3rd day after stimulation) after stimulation and then gradually decreased with time towards the next ethephon application.

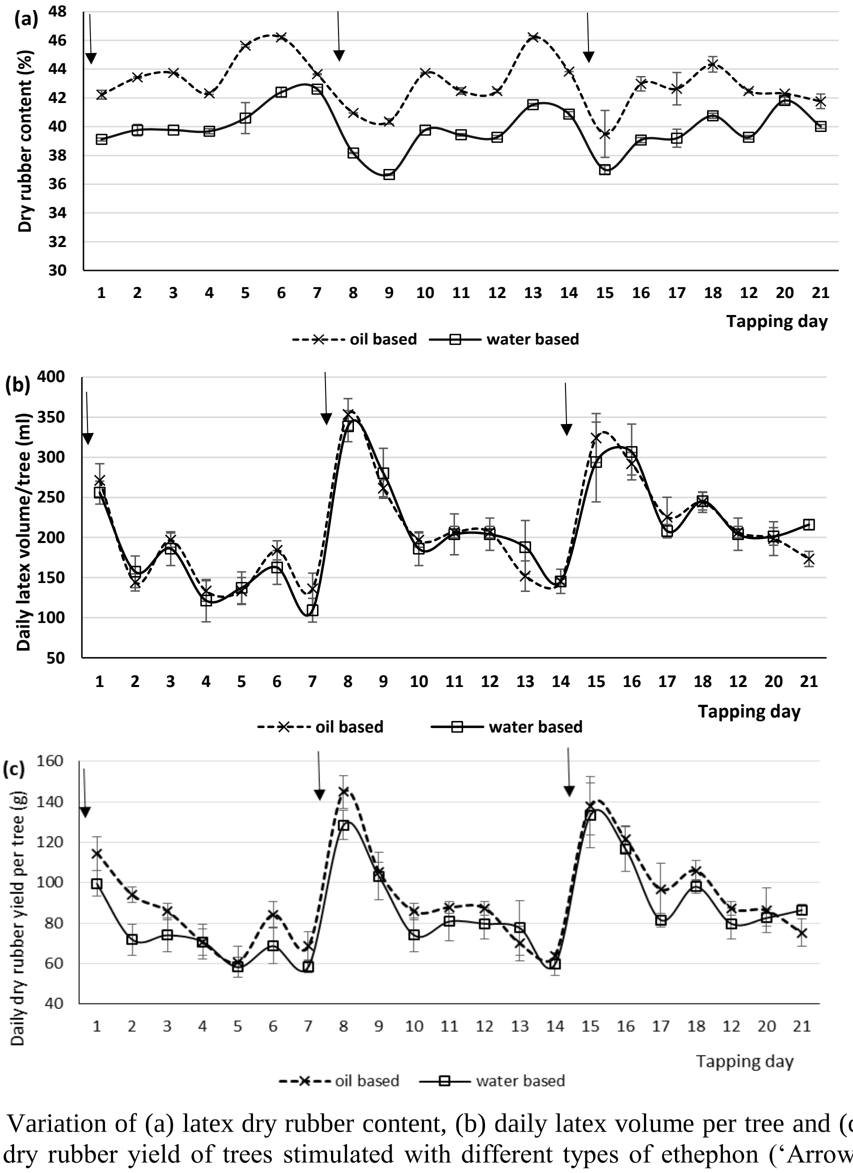

Fig. 3. Variation of (a) latex dry rubber content, (b) daily latex volume per tree and (c) daily dry rubber yield of trees stimulated with different types of ethephon ('Arrow' mark indicates the day of stimulation)

Conclusion

Physiological parameters of latex of rubber trees showed some variations between oil-based ethephon and water-based ethephon treatments. Though oil-based ethephon resulted a higher sucrose availability in laticifers on some tapping days, any positive effect on yield has not been observed. Higher inorganic phosphorous content in rubber trees stimulated with water-based ethephon indicates higher energy consumption in latex regeneration. As the yielding capacity of both ethephon types are similar, it can be presumed that oil-based ethephon is better performing as a long-term stimulant due to lesser requirement of energy consumption for latex production than the water-based ethephon. Extended latex flow duration by oil-based stimulation was more than that of water-based stimulation on most of the tapping days. This is an indication of the slow releasing effect of oil-based ethephon. Oil-based ethephon stimulated rubber trees resulted higher dry rubber content than the water-based stimulated rubber trees. However, yielding capacity did not vary significantly in trees applied with water-based and oil-based ethephon. Further studies are needed to investigate long term effects of these different ethephon formulations.

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Poverty alleviation through improvement in technical efficiency in the smallholder rubber sector: case study from Kegalle District of Sri Lanka

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Abstract

Growth and development of the agriculture sector play an important role in the alleviation of poverty. There is a long-lasting debate on whether improvement in efficiency levels leads to eradicate poverty. Further, some studies unveiled that farm and farmer characteristics have a significant influence on poverty. Hence, this study attempts to examine the relationship between technical efficiency and poverty and the effect of farmer's characteristics on poverty levels among the smallholder rubber farmers in Kegalle District.

Data were collected from 195 smallholder rubber farms in Kegalle district through a questionnaire survey. Cobb-Douglas Stochastic Frontier Analysis (SFA) was employed to determine the Technical Efficiency (TE) of the farmers and Poverty Gap Index (PGI) was calculated to measure the depth of poverty in the sample. Correlation analyses were conducted to analyze the relationship between poverty and technical efficiency. Generalized Linear Model (GLM) was employed to determine the farm and farmer characteristics affecting poverty.

The estimated mean technical efficiency of smallholder rubber farmers in Kegalle district was 63%, implying that the natural rubber production could be increased further by 37% through better use of existing resources and technology. Correlation analysis indicated that TE has a significant negative correlation (r=-0.147, P=0.04) with poverty, indicating that improving TE will help to alleviate poverty.

Results of GLM model indicated that years of education of the farmer and the farm size have a strong negative influence on poverty while family size and age of the farmer have a positive association with poverty. Hence, policymakers should give more consideration to these factors in poverty alleviation programmes.

***Key words*:** Cobb-Douglas Stochastic Frontier Analysis, correlation analysis, generalized linear model, poverty, smallholders, technical efficiency

Introduction

Natural Rubber (NR) is one of the major contributors to the Sri Lankan economy which generates an export revenue of more than US$ 1 billion according to the statistics. About 68% of NR is provided by the smallholder sector in Sri Lanka. Kegalle District has the highest NR land area followed by Ratnapura, Kalutara, Gampaha, and Colombo districts. The

NR production of the country has recorded as 82,000 tonnes in the year 2017, which has been in a slightly up and down movement (Anon, 2017a).

The NR production of the country remains as quite steady state during the last few years, yet considerably low with respect to the area under tapping. This is one of the major concerns in the Sri Lankan rubber sector. The overall productivity in the country is around 800 kg/ha/year, which is far behind the countries like Vietnam, India and Malaysia where the yields average around 1680, 1431 and 1400 kg/ha/year, respectively (Anon., 2016a; Anon., 2016b).

The low productivity may lead to loss of a considerable amount of potential income, which makes the smallholder rubber sector an uncompetitive venture (Kumarasinghe *et al*., 2012). Further low rubber prices and low productivity levels of rubber lands push small scale rubber farmers into poverty (Anon., 2016c). In attempting to enhance the productivity of existing lands, one crucial aspect is increasing efficiency which can be measured in terms of technical efficiency (Kumarasinghe *et al*., 2012). Technical efficiency can be defined as the ability of firms to produce the maximum possible output level from a given set of inputs and technology (Kumbhakar *et al*., 2015).

Socio-economic characteristics of households have a significant influence on the poverty status of the household. Age, farm size, farm experience, years spent in school, family size, gender and dependency ratio are the key socio-economic variables that should be critically considered in the poverty alleviation programmes (Umeh *et al.*, 2013; Omoregbee *et al*., 2013).

As most of the rural people depend on agriculture for their livelihood, farm productivity improvement through increasing technical efficiency is one of the major policy decisions taken to alleviate poverty. At a given level of inputs, a producer is said to be technically inefficient if he is unable to produce the maximum possible output level. Hence, improvement in technical efficiency will increase farm income and reduce poverty (Islam and Haider, 2018).

There is a longstanding discussion about the effect of technical efficiency and factor productivity on poverty alleviation. Many scholars show evidences in favour of an inverse relationship between efficiency and poverty, while some of the studies indicate that technical efficiency is not sufficient in poverty reduction or there is no significant relationship between technical efficiency and poverty (Gelaw, 2013; Asogwa *et al*., 2012; Islam and Haider, 2018).

There is little empirical evidence of the relationship between technical efficiency and poverty among the smallholder rubber farmers in Sri Lanka to guide agricultural policies that aimed towards alleviation of poverty among the rural farmers. Further, it is important to identify the farm and farmer characteristics of smallholder rubber farmers that affect poverty. Hence this study attempts to examine the relationship between technical efficiency and poverty among the smallholder rubber farmers and the smallholder rubber farm and farmer characteristics that affect the poverty in Kegalle District, which can be exploited as a basis for poverty alleviation strategy.

Methodology

Study area

The study area lies between 80° 20' E Longitudes and 7° 14' N Latitudes. Kegalle District was purposefully selected for the study as it is one of the major rubber growing areas in Sri Lanka where rubber market channels are well established. This district has an extent of 28,765 ha of rubber which is around 30% of the total rubber extent in Sri Lanka. The number of smallholdings in this area is about 24,309 with a total extent of 16,959 ha. (Anon, 2016b). Contribution to total poverty from the Kegalle District is 7.2% and the number of poor people in the District is 60,435 out of 869,000 total population. Hence, around 6% of the total population in Kegalle District is suffering from poverty. Further, the Head Count Index (HCI) and Poverty Gap Index (PGI) in Kegalle District are 7.1% and 1.1%, respectively (Anon., 2017b).

Sample selection and data collection

Randomly selected 195 smallholdings stratified according to the number of holdings in each Divisional Secretariat (DS) were used in the survey. The farmers were interviewed through a structured questionnaire to collect primary data.

Frontier analysis

The frontier production function methodology has been extensively used in production economics to estimate technical efficiency due to its strong theoretical background (Kumbhakar *et al*., 2015). The stochastic frontier approach was selected for this study, as this method allows for statistical noise (Bravo-Ureta *et al*., 2007). The Cobb-Douglas functional form was used to estimate the production function as it satisfies homogeneity condition and allow to estimate returns to scale and elasticity coefficients relatively easier (Coelli *et al*., 1998). The following Cobb-Douglas production function was used in the analysis.

$$\text{Ln } Y_i = \beta 0 + \beta 1 \ln (X_{1i}) + \beta 2 \ln (X_{2i} + \beta 3 \ln (X_{3i}) + \beta 4 \ln (X_{4i}) + Vi - Ui$$

Where,

Y_i - Dry rubber production of the i^{th} firm (kg/year),

X_{1i} - Extent of the Land (ha)

X_{2i} - Labour (Man Days/year)

X_{3i} - Quantity of fertilizer used (kg/year),

X_{4i} - Chemicals used (L/year)

V_i - Error component which stands for the random output variations

U_i - Technical inefficiency relative to the stochastic frontier

In order to determine the farm and farmer-specific attributes influencing the technical inefficiency of smallholder rubber farmers, the following model was formulated and estimated together with the stochastic frontier model in a single-stage maximum likelihood estimation procedure.

$U_i = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 Z_3 + \delta_4 Z_4 + \delta_5 Z_5 + \delta_6 Z_6$

Where,

Z_1= Education (Years)

Z_2= Labour involvement from family (number)

Z_3= Experience (years)

Z_4= Dummy for Adoption of Extension Services (1-Yes, 0-No)

Z_5= Dummy for Management of the Farm (1-Owner, 0-Care Taker)

Z_6= Dummy for Method of Harvesting (1-By family, 2-Hired Labour)

The software FRONTIER 4.1 was used to estimate technical efficiency values and determinants of efficiency jointly as described by Coelli (1996). The 'zeros' in the Cobb-Douglas model was handled as described by Battese (1996).

Correlation analysis between poverty and technical efficiency

A correlation analysis was conducted to analyze the relationship between poverty and technical efficiency. Poverty or income gap index was calculated to measure the depth of poverty in the sample. This measures the extent to which individuals fall below the poverty line (the poverty gaps) as a proportion of the poverty line (Asogwa *et al*., 2012). The official poverty line by district, which is calculated by the Department of Census and Statistics Sri Lanka was considered in the calculations (Anon., 2016d). The poverty gap index (P) can be written as,

$$P = \frac{1}{N}\sum_{i=1}^{N}\frac{(z-yi)}{z}$$

where,

N -Total population

Z - Poverty line

y_i - Monthly income of the farm families

Determinants of poverty

Generalized linear model (GLM) was employed to identify the farm and farmer characteristics that affect poverty as a means of overcoming the assumptions of linearity and equal variance in Ordinary Least Square regression. Further GLM uses maximum likelihood estimation to estimate parameters which are more accurate compared to ordinary least squares (Nelder and Wedderburn, 1972). The following generalized linear model (GLM) was used to measure the effect of farm and farmer characteristics on poverty.

$$Yi = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i} + \beta_5 X_{5i} + \beta_6 X_{6i} + \varepsilon_i$$

Where,

Y_i – Poverty gap index

X_1 – Gender

X_2 – Age (years)

X_3 – Dependency Ratio (sum of household members below 14 and above 65 divided by the total number of household members)

X_4 – Education (Years)

X_5 – Experience (Years)

X_6 – Family Size

X_7 – Farm Size (ha)

ε_i – error term

Results and Discussion

Analysis of technical efficiency

The summary statistics of the variables used in the stochastic frontier model and inefficiency model are presented in Table 1.

Table 1. *Descriptive statistics of variables used in the stochastic frontier model*

Variable	Mean	Standard deviation	Minimum	Maximum
Variables used in Production Model				
Dry rubber yield (kg/year)	1,048.05	671.46	150	3,500
Labour (Man days/year)	144.37	41.48	68	314
Fertilizer (kg/year)	119.06	146.29	1	641
Land area (ha)	0.86	0.51	0.20	2.02
Chemicals (L/year)	41.52	343.49	1	3,901
Variables used in inefficiency model				
Labor involvement from family (Number)	4	1.44	1	5
Experience (Years)	20.31	8.01	7	40

The majority of the farmers in the sample (42%) have studied up to ordinary level, while 27% of the farmers have primary education, 26% studied up to advanced level and about 6% of the sample farmers had higher education qualifications. The majority of the farmers (87%) have adopted the knowledge gathered from extension services. More than 90% of the rubber lands are managed by the owner of the land. While 44% of the farmlands are harvested by the family members, 56% of lands were harvested through hired labour. The mean experience level of farmers in the sample is 20 years which ranged from 7 to 40 years. The maximum likelihood (ML) estimates of the Cobb–Douglas stochastic frontier parameters and inefficiency model are given in Table 2.

Table 2. *Maximum likelihood estimates of Cobb-Douglas Stochastic production frontier*

Variable	Coefficient	Std. Err	t-value
Stochastic production frontier			
Ln (labour)	0.731	0.104	7.025***
Ln (Fertilizer)	-0.014	0.012	-1.117
Ln (Land area)	0.333	0.054	6.171***
Ln (Chemicals)	-0.056	0.132	-0.424
Constant	4.473	1.154	3.876
Inefficiency effects			
Education	-0.211	0.066	-3.188**
Family members	0.000	0.024	0.003
Extension	0.110	0.098	1.125
Experience	-0.029	0.006	-5.12***
Management	0.044	0.111	0.399
Harvest	-0.009	0.041	-0.228
Constant	-0.665	1.352	-0.490
Variance parameters			
Sigma squared	0.12		
Gamma	0.66		
Log Likelihood function	-47.25		

*** significant at 1% level ** significant at 5% level

The estimate of γ is 0.66, which indicates that only 66% of the total variation in dry rubber output was due to technical inefficiency and this satisfied the theory that the true γ should lie between zero and one. The estimated ML coefficient of labour showed a positive value of 0.731 which is statistically significant at 1% level. Similar results were obtained by Basnayake and Gunaratne (2002) and Wijesuriya *et al.* (2012). The estimated ML coefficient of land area showed a positive value of 0.333 which was significant at 1% level. These findings are also in line with Basnayake and Gunaratne (2002), Barnes (2008), Wijesuriya *et al.* (2012) and Fatima *et al.* (2016). The ML estimates of fertilizer and chemicals are not statistically significant. However, an increment of number of labour units and land area by one unit will increase the dry rubber output by 0.731 percent and 0.333 percent, respectively.

The effect of farm and farmer specific factors on inefficiency was simultaneously estimated with the production frontier. The estimated coefficients in the inefficiency model are presented in Table 3. The coefficient for education is negative and statistically significant at 5% level indicating that the educated farmers are more efficient compared to others. This result is consistent with Bettese *et al.* (1996), Basnayake and Gunaratne (2002), Wijesuriya *et al.* (2012) and Fatima *et al.* (2016). The coefficient for experience was also found to be negative and statistically significant at 1% level. This suggests that experienced farmers are more efficient compared to less experienced ones. This result confirms that of Fatima *et al.* (2016).

Accordingly, experience and education are the key factors affecting the technical efficiency of rubber smallholders. The other variables; *viz*. labour involvement from family, adoption of extension services, type of management and method of harvesting are not statistically significant. The frequency distribution of the estimated technical efficiency of rubber smallholders is given in Figure 1.

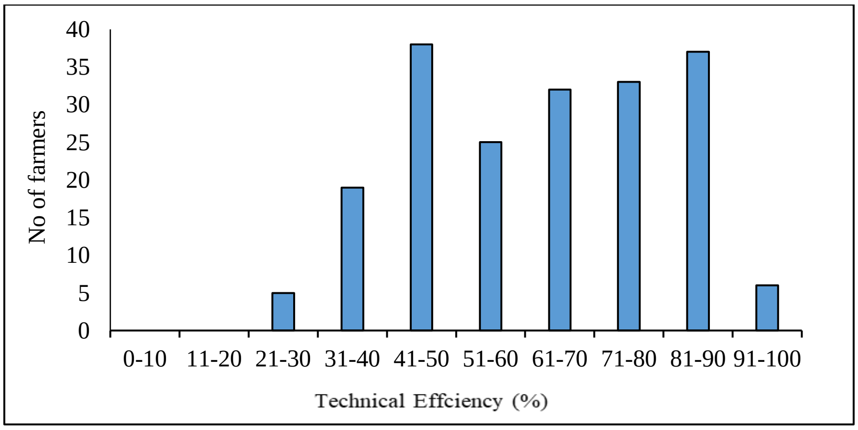

Fig. 1. Distribution of technical efficiencies (based on Cobb-Douglas specification)

The results revealed that the technical efficiencies estimated using Cobb-Douglas production frontier ranged from 21% to 92%. The mean technical efficiency in the sample is 63% indicating that 37% of the potential maximum productivity is lost due to technical inefficiency of the farmers in Kegalle District. Hence, there is a possibility to increase the TE further by 37%. Around 51% of farmers in the sample have TE higher than the average value of 63%. A relatively higher percentage of farmers was observed in the range of 41-50%. Whilst 3% of the farmers had efficiency levels higher than 90%, there were around 30% of the sample had technical efficiency of less than 50%.

Poverty status of the smallholder rubber farmers in Kegalle District

The minimum expenditure per person per month in Kegalle District in 2016 was Rs.4,073.00. It was observed that there were only 35 households out of total 195 households in the sample were found below this official poverty line.

Farm and farmer characteristics affecting poverty

The results of the GLM is presented in Table 3.

This GLM has a reasonable model fit with a R^2 value of 33%. Results of the GLM indicate that years of education of the farmer and farm size has a significant negative relationship with the poverty gap index.

It suggests that increasing farm size and improving the education level of the farmer helps to reduce the poverty level of farmers. Further, family size and age of the farmer have a significant positive association with the poverty gap index. Hence, increased family size and age of the farmer tends to increase the poverty level of farmers. However, gender, experience and dependency ratio do not have a significant relationship with the poverty gap index.

Table 3. *Effect of household variables on Poverty Gap Index*

Variable	Coefficient	Std. Error	Z	P>|z|	[95% Conf. Interval]	
Gender	0.071	0.169	0.420	0.672	-0.260	0.403
Dependency Ratio	-0.046	0.059	-0.780	0.434	-0.161	0.069
Education	-0.171	0.069	-2.470	0.013**	-0.307	-0.036
Family Size	0.387	0.071	5.450	0.000***	0.248	0.525
Age	0.101	0.058	1.740	0.082*	-0.013	0.214
Farm Size	-0.206	0.078	-2.630	0.009***	-0.359	-0.052
Experience	-0.105	0.080	-1.310	0.191	-0.261	0.052
Constant	-0.056	0.155	-0.360	0.718	-0.360	0.248

*** Significant at 1% level, ** Significant at 5% level, *Significant at 10 % level

Correlation analysis between technical efficiency and poverty

According to the results of correlation analysis, there is a significant negative (r=0.1478, P=0.0402) relationship between technical efficiency and poverty gap. Thus, there exists an inverse relationship between poverty and technical efficiency. These results are in line with the results of Gelaw (2013), Asogwa *et al*. (2012a) and Asogwa *et al*. (2012b).

Conclusion

The mean technical efficiency level in the sample is around 63%. Further, the technical efficiency in the sample ranged between 21% and 92%. Therefore, there is a possibility to increase the output level by 37% without any increase in the level of outputs. From the farm and farmer specific characters, farmer's experience and education have a negative relationship with the technical inefficiency. This suggests that more experienced farmers are more efficient compared to the newcomers. Hence it is necessary to conduct farmer training programs especially focusing on the newcomers to improve their exposure to the rubber management practices. Further, farmers with higher educational levels are more efficient compared to those with low educational levels. This may be due to the increased knowledge levels through education which probably help them to take appropriate managerial decisions. Thus, improving education facilities in the area will help to increase the efficiency levels of the farmers.

According to the poverty analysis and the poverty level, there are 35 smallholders below the official poverty line. Poverty determinant analysis reveals that the farmer's education, farm size, age of the farmer and the family size of the farmer has a significant influence on the poverty level. Hence, policymakers should critically consider these factors in poverty alleviation programmes.

Results of correlation analysis indicate that technical efficiency has a significant negative correlation with poverty. Hence, this study unveils that improving the technical efficiency of the farm will reduce the poverty level of farmers. As the education level and the experience have a significant positive impact on the technical efficiency of the farmers, the awareness of farmers on rubber cultivation and management practices needs to be improved through effective means of technology transfer. Adoption of these practices will eventually increase the productivity of smallholder lands and reduce the poverty levels of the farmers.

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Field screening of RRISL recommended rubber clones against Corynespora Leaf Fall Disease

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Abstract

Identification of resistant clones is of vital importance in the management of Corynespora leaf fall disease (CLFD) of rubber. The recommended and potential clones were screened in a bud wood nursery which was especially designed for screening purposes at Ratnapura, Kalutara, Moneragala and Padiyatalawa. The lesion types agreed with the symptoms observed in the field plants and new symptoms have been identified from Padiyatalawa, in non-traditional rubber growing areas. Analysis of results from test methods showed that 81% of the recommended clones by the Rubber Research Institute of Sri Lanka (RRISL) can be ranked as resistant. Among the clones screened, no clones were found to be severely susceptible, yet moderately or mildly susceptible clones have been identified. This information should be used in future breeding programmes and also should be considered by the growers while selecting clones for their own plantations. The cultivation of resistant clones with a wide genetic base is considered as the most reliable long-term solution in the management of CLFD.

***Key words*:** clonal screening, *Corynespora cassiicola, Hevea brasiliensis*

Introduction

Natural rubber is an important commodity to the economy of Sri Lanka in export earnings, providing livelihood to over thousands of people, supplementing thousands of hectares to the forest cover and providing many other socio-economic and ecological benefits. Corynespora leaf fall disease (CLFD) caused by *Corynespora cassiicola*, is a malady with relatively recent origin and has caused several global epidemics (Tan *et al.*, 1992; Soepena, 1983; Kajornchaiakul, 1987; Rajalakshmi and Kothandaraman, 1996; Jayasinghe, 2003; Fernando *et al.*, 2009; Dung & Hoan, 1999; Jean, 2000 and Begho, 2000). CLFD causes extensive damages to both immature and mature trees and the pathogen produces numerous types of lesions with characteristic blighted leaves followed by leaf fall. Repeated defoliation results in die-back of shoots and branches retarding growth, extending the period of immaturity and sometimes leading the plant to death (Edathil *et al.*, 2000; Jayasinghe *et al.*, 2005; Jacob, 1997). Sri

Lankan rubber growers experienced the first CLFD epidemic in 1985/86 period. One of the prestigious clones bred by the Sri Lankan scientists, RRIC 103 succumbed to this disease. At that time, the stakeholders were offered three options; to replace susceptible clones with resistant clones, base budding and crown budding. Among the options, uprooting the susceptible clones and replacing with the resistant clones became popular among the growers (Liyanage *et al.,* 1989). The second epidemic was in mid 1990s and devastated another prestigious clone, RRIC 110. During the recent past more than a dozen of potential clones were withdrawn from experimental sites as they became highly susceptible to the disease.

Since, 1980s screening of clones for foliar diseases, especially CLFD has played an important role in disease management. Because of this effort, our growers today enjoy CLFD free rubber plantations in spite of the fact that Sri Lanka was one of the worst affected countries during the past. The reason has been the selection of clones though intensive screening during the breeding programmes. During the past many methods have been investigated for disease screening purposes. Among them screening of clones in a bud wood nursery which was specially designed for screening purposes was proven to be effective (Fernando *et al.,* 2011). To compare the observations, clones have been selected from field clearings and they have been screened under natural conditions. This paper reports the results of clonal screening programmes against Corynespora leaf fall disease during 2014 - 2016 to identify CLFD resistant clones using the above mentioned methods.

Methodology

Screening of the clones in a bud wood nursery

Bud wood nursery experiments were established at the RRISL sub-stations in Ratnapura and Monaragala. The experimental plots consisted of 50 test clones, (recommended by RRISL and clones under consideration for recommendation). The susceptible clones (like RRISL 201 & RRISL 202) were planted randomly to release the necessary inocula to the test plants. The site selected was also adjacent to the fields with CLFD susceptible clones *viz*. RRIC 110, RRISL 202, RRISL 201 thus ensuring the continued exposure of test plants to natural inocula. The test clones were inspected for the incidence of CLFD for three consecutive years, from 2014 to 2016 using five plants per clone. A score was given to clones based on visual observations.

Screening of the clones under field conditions

Mature field clearings were selected from estates/RRISL collaborative trials, small scale and large scale plantings to include 41 clones (given below) recommended by RRISL. All clones were screened annually at 12 locations for three consecutive years (2014-2016).

Clones tested under field conditions

The following clones were tested under field conditions; *viz.* RRIC 100, RRIC 102, RRIC 121, RRIC 130, PB 217, PB 28/59, RRIC 117, RRIC 133, RRISL 201, RRISL 202, RRISL 203, RRISL 205, RRISL 206, RRISL 211, RRISL 215, RRISL 217, PB235, PB260, MPB24, RRISL 200, RRISL 208, RRISL 218, RRISL 220, RRISL 221, RRISL 222, RRISL 226, GPS 1, PB 255, PR 255, RRII 105, RRISL 2001, RRISL 2003, RRISL 2000, RRISL 2002, RRISL 2004, RRISL 2005, RRISL 2006, Cent 2, Cent 3, Cent 4 and Cent 5.

Sampling techniques

Eight randomly selected plants from each clearing and another five plants from every 100 trees of the clearing were examined. To select the test plants randomly, each field was divided into four quadrants. The test plants were selected along the directions randomly as given in the Figure 1. Four shoots were randomly removed from each canopy of each test plant. The number of leaves having lesions were counted and recorded as a percentage. Percentage of the fallen leaves was also assessed visually.

Assessment of disease severity

A scoring system adopted by Jayasinghe *et al*. (2004) which is given below was used for assessing the disease incidence and the severity.

Index for scoring of disease severity	**Description**
0	Highly resistant clones under field conditions. No symptoms on any of the leaves
1	Clones having few (less than 25%) leaves of the canopy with CLFD symptoms and no detectable defoliation due to CLFD (Light infections)
2	Clones having few (less than 25%) leaves of the canopies with CLF symptoms and up to 25% defoliation of the canopies due to CLFD (Moderate infections)
3	Clones having more than 25% of the leaves with symptoms and 26–75% defoliation due to CLF (Severe infections)
4	Clones having more than 75% defoliation due to CLFD (Very severe)

Development of average disease severity index (ADSI)

ADSI was calculated using following formula adopted by Jayasinghe *et al.*, (2004).

$$ADSI = \frac{[(0*n1)+(1*n2)+(2*n3)+(3*n4)+(4*n5)]}{N}$$

where,

n1 = No. of plants representing score index 0

n2 = No. of plants representing score index 1
n3 = No. of plants representing score index 2
n4 = No. of plants representing score index 3
n5 = No. of plants representing score index 4

Ranking of clones

Ranking was carried out based on the average disease severity index as follows.

ADSI value	Description
0	No disease (Resistant)
0.01 - 1.00	Light infections (Mild)
1.01 - 2.00	Moderate infections (Moderate)
2.01 - 3.00	Severe infections (Severe)
3.01 - 4.00	Very severe infections (Very severe)

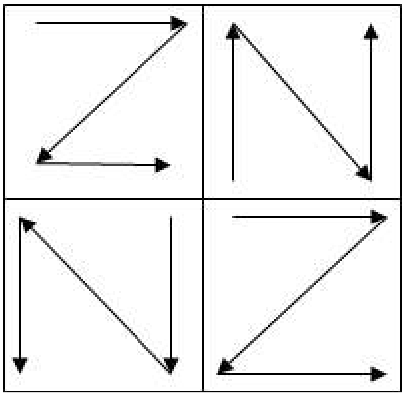

Fig. 1. The directions of selection of test plants in quadrants

Results and Discussion

Management of CLFD using resistant clonal material is the strategy for preventing epidemics of *C. cassiicola* that has been adopted in many rubber growing countries (Fernando *et al.*, 2010; Jayasinghe *et al.*, 2005, Situmorang & Budiman, 1984; Kajornchaiakul, 1987). There is a marked variation in the clonal susceptibility to CLFD and all the rubber growing countries have therefore prepared susceptible/resistant clone lists using different screening technologies (Kumar & Hidir, 1996; Dung & Hoan, 1999; Idicula *et al.*, 2000; Sujatno & Suhendry, 2000 and Fernando *et al.*, 2010).

The results taken annually in the bud wood nursery experiments are shown in Table 1. Screening of the major clones grown under field conditions are given in Table 2. The lesion type produced by these clones in the bud wood nursery experiments agreed with the symptoms produced by the field plants. Further, analysis of the results from the screening under natural field levels shows that 81% of the clones in RRISL recommendation list are free from CLFD and can be ranked as resistant. 10% of the clones showed mild infections, 3% moderate infections and 6% of the clones showed severe infections (Fig. 2). The highly susceptible clones have already been removed from the list of recommendation. The clones which showed mild infections too have been downgraded and are under constant observation.

Screening of clones under bud wood nursery conditions has shown to be comparatively rapid (Fernando *et al.*, 2010). With the observations from screening under field conditions, the results become more reliable. Some clones showed variable responses to the disease in different years due to the effect of pre disposing factors such as inoculum potential and weather conditions (Fernando *et al.*, 2011). It is expected that these results will be helpful in future planting programmes and also in future breeding programmes.

The cultivation of resistant clones with a wide genetic base is considered as the long term and most reliable solution for the management of CLFD in all the rubber growing countries including Sri Lanka. Furthermore, the selection or grouping into categories will ease the selection of resistant germplasm to be used in the conventional crossing programmes.

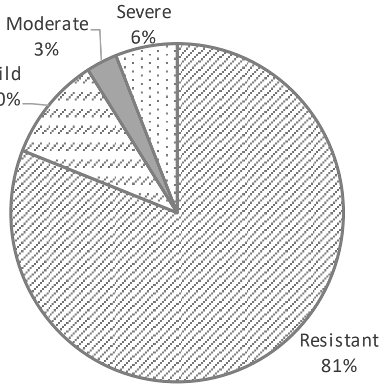

Fig. 2. Ranking of RRISL recommended clones for the susceptibility CLFD based on the clonal screening programmes

Table 1. *Mean Disease incidences of the clones established in the bud wood nursery experiments at Ratnapura and Moneragala*

Clone	Average disease severity score			Mean ADSI	Clone	Average disease severity score			Mean ADSI
	Year 2014	Year 2015	Year 2016			Year 2014	Year 2015	Year 2016	
RRISL 211	2	1	1	1.33	RRIC 133	0	0	0	0
RRISL 219	0	0	0	0	RRISL 210	0	0	0	0
RRISL 200	2	4	3	3	PB 235	0	0	0	0
PB 255	0	0	0	0	RRISL 2001	0	0	0	0
RRIC 117	1	0	1	0.66	RRIM 717	0	0	0	0
RRISL 206	0	0	0	0	GPS 1	1	1	1	1
RRISL 2006	0	0	0	0	RRISL 212	0	0	0	0

Clone	Average disease severity score			Mean ADSI
	Year 2014	Year 2015	Year 2016	
RRISL 202	3	2	3	2.66
RRISL 2004	0	0	0	0
RRISL 2005	1	0	1	0.66
RRISL 217	2	1	2	1.66
RRISL 205	0	0	0	0
RRISL 2002	1	0	1	0.66
RRIC 131	2	1	1	1.33
RRISL 203	0	0	0	0
RRISL 223	2	2	2	2
RRISL 201	2	1	2	1.66
RRISL 222	3	2	3	2.66
RRISL 215	0	0	0	0
RRISL 218	1	1	2	1.33
RRISL 220	1	1	2	1.33
RRIC 102	0	0	0	0
RRISL 221	0	0	0	0
RRISL 226	0	0	0	0
RRIC 130	0	0	0	0
RRISL 214	0	0	0	0
RRISL 2000	1	1	1	1
PB 260	0	0	0	0
PR 305	1	0	1	0.66
RRISL 2003	0	0	1	0.33
BPM 24	0	0	0	0
RRISL 207	1	0	1	0.66
RRISL 204	0	0	0	0
RRIC 121	0	0	0	0.66
IAN 717	1	0	1	0.66
PB 28/59	0	0	0	0
RRISL 216	0	0	0	0
RRIC 100	0	0	0	0
RRISL 225	1	0	1	0.66
RRII 105	3	2	2	2.33
PR 255	0	0	0	0
RRISL 227	3	3	3	3
RRIC 110	4	4	4	4

Average disease severity score:
0 - No CLFD infection
1 - <25% of the canopy infected
2 - 25-50% of the canopy infected
3 - 50-75% of the canopy infected
4 - >75% of the canopy infected

Table 2. *Disease severity of the clones grown in Sri Lankan rubber plantations evaluated under natural field conditions*

Clone	Average disease severity score			Mean ADSI
	Year 2014	Year 2015	Year 2016	
RRIC 100	0	0	0	0
RRIC 102	0	0	0	0
RRIC 121	0	0	0	0
RRIC 130	0	0	0	0
PB 217	0	0	0	0
PB 28/59	0	0	0	0
RRIC 117	0	0	0	0
RRIC 133	0.67	0.67	0.67	0.67
RRISL 201	2	2	2	2
RRISL 202	2.5	2.25	2.67	2.47
RRISL 203	0	0	0	0
RRISL 205	0	0	0	0
RRISL 206	0	0	0	0
RRISL 211	0	0	0	0
RRISL 215	0	0	0	0
RRISL 217	0.5	0.5	0.5	0.5
PB 235	0	0	0	0
PB 260	0	0	0	0
MPB 240	0	0	0	0
RRISL 208	1.25	1	1	1.08
RRISL 218	0	0	0	0
RRISL 220	0	0	0	0
RRISL 221	0	0	0	0
RRISL 222	0	0	0	0
RRISL 226	0	0	0	0
GPS 1	0	0	0	0
PB 255	0	0	0	0
PR 255	0	0	0	0
RRII 105	0	0	0.67	0
RRISL 2001	0	0	0	0
RRISL 2003	0	0	0	0
RRISL 2000	0	0	0	0
RRISL 2002	0	0	0	0
RRISL 2004	0	0	0	0
RRISL 2005	0	0	0	0
RRISL 2006	0	0	0	0
Cent 2	0	0	0	0
Cent 3	1	1	1	1

Clone	Average disease severity score			Mean ADSI	Clone	Average disease severity score			Mean ADSI
	Year 2014	Year 2015	Year 2016			Year 2014	Year 2015	Year 2016	
RRISL 200	3.5	3.5	3	3	Cent 4	0	0	0	0
RRISL 204	0	0	0	0	Cent 5	0	0	0	0

ADSI value:
0 – no CLFD lesions,
1 – Mild infection (<25% canopy shows Corynespora lesions)
2 – Moderate infection (25 – 50% canopy shows Corynespora lesions)
3 – Severe infection (50 – 75% canopy shows Corynespora lesions)
4 – Very severe infection (>75% canopy shows Corynespora lesions) with leaf fall

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Effectiveness of coir dust and rubber latex based slow release fertilizer on the growth of immature rubber (*Hevea*) and soil nutrient availability

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Abstract

Slow release type of fertilizers (SRF)enhance nutrient retention in soil, increase fertilizer use efficiency and mitigate environmental problems. As such techniques, this study examined the influence of encapsulated coir bricks (ECB) on the growth of immature Hevea plants at field conditions. Single application of two types of ECB;ECB type 1 and ECB type 2 which were produced by using different quantities of inorganic fertilizers with filling mediums were evaluated against the conventional type of four split applications. Plant diameter was measured at 6 months after planting and plant girth was measured at 12 and 18 months after planting. Leaf nutrients, soil nutrients and soil pH were measured at 18 months after planting. Application of two types of ECB and conventional type of fertilizer gave almost identical growth performances; with reference to plant diameter and girth. Moreover, ECB type 2 recorded the highest plant diameter at 6 months after planting (1.65 cm) and plant girth at 12 months after planting (10.545 cm) and 18 months after planting (14.81 cm) even though not shown significant differences among treatments. Leaf macro nutrients; N, P, K, Mg and soil total N, available P, exchangeable Ca and pH values were also comparable. Significantly higher exchangeable soil K values were observed with ECB applications over the conventional type fertilizer application. Moreover, the highest available soil P (26.4 ppm), exchangeable K (168 ppm), exchangeable Ca (258 ppm) and Mg (31.72 ppm) could be observed with SRF applications. On the above ground, there is a possibility of using single application of both types of ECB as a substitute for four split applications of conventional fertilizers recommended for immature rubber plants.

Key words: Hevea, leaf nutrients, plant growth, soil nutrients

Introduction

Application of N, P, K and Mg in a correct proportion is essential to obtain optimum growth rates especially during immature phase of rubber (Sivanadyan *et al.*, 1975 and Yogaratnam *et al.*, 1984) and to attain high yields and sustainable productivity throughout the mature period of rubber plants (Samarappuli and Yogaratnam, 1997 and Yogaratnam and Weerasuriya, 1984). Therefore different fertilizer mixtures were formulated to suit different soil groups mostly utilized for rubber plantations (Silva, 1971; Yogaratnam *et al*., 1984). However, the application of about 40-70% of N and 80-90% of P as conventional fertilizers are wasted in the environment or chemically bound in the soil hence are unavailable to plants (Giroto *et al.*, 2017). Loss of nutrients through removal of old rubber trees at replanting, erosion, leaching, volatilization and fixation of some nutrients are the processes which reduce nutrient availability in most of the rubber growing soils in Sri Lanka. Therefore, nutrient management of rubber growing soils needs to be done in a systemic manner (Samarappuli,1996).

The above mentioned losses cause uneconomical return on capital investment and adverse environmental impact (Majeed *et al*., 2015), which are challenges for the sustainability of modern agriculture. To avoid this negative environmental consequences, fertilizer use efficiency must be increased (Shaviv and Mikkelsen, 1993; Trenkel, 2010). Therefore, development of suitable alternative to optimize the use of fertilizers is essential approach to enhance nutrient retention in soil, increase fertilizer use efficiency and mitigate environmental problems (Li *et al*., 2015). There are a variety of strategies available to increase fertilizer use efficiency. It includes methods such as split application, precision fertilization, fertigation and the use of environmental friendly fertilizers (Shaviv, 2005; Li *et al*., 2016).

Slow release fertilizers (SRF) are purposely designed to release their nutrient contents gradually in order to match with the nutrient requirement of the plants and are available for plants over an extended period of time (Sempeho *et al*., 2014). SRF can be generally classified into several groups such as low solubility organic fertilizer, low solubility inorganic fertilizer, coated fertilizer and matrix based fertilizer etc. However, research on the preparation of slow release fertilizers have mainly focused on coated fertilizers. These fertilizers can be physically prepared by coating granules of conventional fertilizers with various materials that reduce their dissolution rates (Shavit *et al*., 2002). Various materials have been used as coating to retard nutrient releases and to increase fertilizer use efficiency. To develop environmental friendly fertilizers, effort has been put to utilize eco-friendly coating materials which are naturally available. These natural materials display multiple advantages over synthetic polymers due to their eco-friendly source, a low cost, and easily available and biodegradability (Wezel *et al*., 2014; Schneider *et al*., 2016). Chitosan, extracted from crustaceous water animals, sodium alginate extracted from brown seaweed, starch and its derivatives, cellulose and their derivatives, agricultural residues, biochar, polydopamine are the materials commonly used throughout the world for making environmental friendly coated slow release type fertilizers (Chen *et al*., 2018).

A huge amount of coir dust is produced after extraction of fiber from coconut husk and is available in coconut growing areas in Sri Lanka. Coconut fiber products are now exported and there is a market price for coir dust currently. However, it is a spongy material, can absorb ample quantity of water compared to its weight and showed high in nutrient retention capacity and highly resistant to environmental bio-degradation (Abad *et al*., 2005). Therefore, it is beneficial to utilize coir dust to produce slow release type high value product. The material corncob is also a byproduct of corn production. Recently, it has been utilized for the production of slow release type fertilizers (Wen *et al*., 2017). However, a new technology for producing Encapsulated Coir Bricks (ECB) has been developed using rubber latex and coir dust as the coating material. This has the advantages of simplicity, economy and not involving any organic or inorganic solvent, thus making it environmental friendly.

The objective of this study is to evaluate the effectiveness of coir and rubber latex based slow release fertilizer on growth of immature rubber plants and soil nutrient availability under field conditions.

Materials and Methods

An experiment was laid down at Rigama estate, Horana to study the effectiveness of ECB on soil fertility, and their influence on mineral composition of rubber leaves and growth of *Hevea* genotype Rubber Research Institute of Sri Lanka (RRISL) 203. Young budding polybag plants were planted in the field with the onset of rains. Treatments were arranged in randomized complete block design with five replicates and 25 plants per each replicate. Two months after planting, treatments were imposed according to the pattern shown in Table 1. Nitrogen (N), phosphorus (P), potassium (K) and magnesium (Mg) containing fertilizer mixture R/U 12:14:14 and kieserite were applied as two different ECB and 100% of the RRISL recommended inorganic fertilizers for immature rubber was applied as control treatment. Two types of ECB were applied as once per year and fertilizers for control treatment was applied at three months intervals with four split applications per year according to the recommendation of the RRISL throughout the experimental period from 2017 May to December 2018. During the first year after planting, the fertilizers and ECB were applied in a circle, free of weeds, 25-30 cm from the base of the plant. The radius of the circle increases with age, up to about 100-120 cm at the end of fifth year. This experiment was established at estate sector and maintained under normal weather condition.

Table 1. *Treatment combinations of the experiment*

Treatment	Description
T1	275g of NPK mixture R/U 12:14:14 and 75 g of Kieserite in 4 applications
T2	Application of four coir bricks, 50 g of NPK mixture R/U 12:14:14 and 10 g of Kieserite per brick, Type 1 (60 g of R/U 10:12:12:4)
T3	Application of four coir bricks, 60 g of NPK mixture R/U 12:14:14 and 15 g of Kieserite per brick, Type 2 (75 g of R/U 10:12:12:5)

Growth assessments

Stem diameter was taken at 15 cm above the ground level (Samarappuli, 1992) as a pretreatment measurement and at 6 months after planting and thereafter girth measurements were taken at 120 cm from the ground level (Tillekeratne and Nugawela, 2001) at 12 and 18 months after planting.

Plant analysis

Two mature leaves were collected from the middle whorl of the plant and composited the leaves of the randomly selected four plants to form one representative sample per each replicate. Leaf samples were analyzed for assessment of mineral nutrient contents (RRIM 1971a).

Soil analysis

Soil samples were taken from each replicate from three points across the replicate at the depth of 0-15 cm using soil auger. Samples within the replicate were bulked separately and then subsamples of approximately 1 kg of soil were taken and allowed to air dry. Dried soil samples were sieved through 2 mm sieve and used for the analysis of pH, available P, exchangeable K, Ca and Mg. The soil sieved through 0.5 mm sieve was used for the determination of total N.

a) Soil pH

Soil pH was measured using a Beckman pH meter in water suspension at 1 soil: 2.5water (Rowell, 1994).

b) Determination of acid extractable phosphorus

The extraction was done by weighing 2 g of air dried soil that was passed through a 2 mm sieve into 50 ml containers and adding 20 ml of extractant (200 ml of 0.5 N HCI and 15 ml of 0.03 N NH_4F diluted up to 1L with distilled water, pH adjusted to 1.8). This was shaken for one minute and kept for the soil to settle. The solution was filtered through Whatman No: 42 filter paper and was measured calorimetrically using SKALAR San^{++} Auto analyzer by the molybdenum blue method using 0.5 % ascorbic acid for reduction (Bremner and Muloaney, 1982).

c) Determination of soil total N

Ground samples (0.5 g) passed through a 0.5 mm sieve were weighed into pyrex tubes. One gram of sodium sulphate and 5 ml of conc. H_2SO_4/Se mixture were added and was mixed well and digested. After digestion and cooling, the contents of each test tube were poured into 100 ml volumetric flask and made upto mark with distilled water and were kept overnight. The content of each flask was then filtered through Whatman No: 42 filter paper and the filtrate were analyzed for ammonium (NH_4^+) nitrogen using Auto analyzer (Bremner and Muloaney, 1982).

d) Determination of exchangeable cations

Five grams of 2 mm sieved air dry soils were shaken 50 ml of 1 M ammonium acetate (pH = 4.8) for 30 minutes using an orbital shaker and left it for 30 minutes and again shaken for another 30 minute and left it another 30 minutes. The suspension was then filtered using Whatman No. 42 filter papers (RRIM 1971b). The extract was analyzed for cations by using the atomic absorption spectrophotometer (Dionisio *et al*., 2011).

Statistical analysis

Statistical analysis of the experimental data was done by analysis of variance followed by a mean separation procedure, Duncan's Multiple Range test (DMRT), at a probability level of 0.05.

Results and Discussion

The soil has been classified as Boralu series (Silva, 1964). These soils belong to great soil group of red yellow podzolic (RYP) soils and have been classified as Ultisols according to the FAO-USDA classification system. It is characterized by presence of iron concentrations throughout the soil mass. Pre-treatment soil analysis shown in Table 2.

Table 2. *Pre treatment soil properties at the experimental site*

Property	Value
pH	4.8
Cation Exchange Capacity (CEC) (cmol+/kg)	2.5
Organic carbon (%)	1.5
Total nitrogen (%)	0.076
Available phosphorus (ppm)	8-10
Exchangeable K (ppm)	125
Exchangeable Mg (ppm)	250

The assessment of plant diameter was made of the immature *Hevea* plants as a pre treatment measurement and six months after commencement of the treatments did not show any significant differences between different forms of fertilizer application treatments (Table 3). Further, the assessment of plant girth was made at the end of 12 months (one year) and eighteen months (1½ years) after commencement of the treatments did not show any significant differences between different forms of fertilizer application treatments (Table 3). It seems that conventional split fertilizer application treatment and single application of ECB treatments create similar nutrient availabilities in the environment, hence comparable growth parameters could be observed with different treatments.

Table 3. *Effect of different fertilizer applications on growth of immature rubber plants*

Treatments	Plant diameter (cm)		Plant girth (cm)	
	Pre treatment	After 6 months	After 12 months	After 18 months
T1	0.97[a]	1.6[a]	10.39[a]	14.54[a]
T2	0.99[a]	1.6[a]	10.145[a]	14.74[a]
T3	1.005[a]	1.65[a]	10.545[a]	14.81[a]
CV	4.66	5.14	4.35	2.16

Values in the same column followed by the same letter are not significantly different at p=0.05.

Nutrient contents of leaves were measured at the end of eighteen months after commencement of the experiment is given in Table 4. No significant differences could be observed between different fertilizer application treatments for leaf nutrients N, P, K and Mg. Several studies so far reported that soil nutrient levels of N, P, K and Mg in *Hevea* ecosystem are reflected by the leaf nutrient levels (Yew and Pushparajah, 1984; Guha and Yew, 1966; Tan, 1972). Accordingly, application of different fertilizers maintains nutrient availabilities in soils and their effect could be observed as assessment of leaf nutrient contents.

Soil fertility parameters were measured at the end of eighteen months after commencement of the experiment are given in Table 5. The parameters, soil pH, total N, available P and exchangeable Ca showed no significant differences between different fertilizer application treatments. However, exchangeable K content was significantly higher in ECB treatments (T2 and T3) compared to conventional fertilizer application treatment (T1) and no differences could be observed in ECB application treatments (T2 & T3) (Table 5). There is no significant difference between conventional fertilizer application treatment (T1) and ECB treatments (T2 & T3) for exchangeable Mg content. However, significant differences could be observed between ECB treatments and ECB type 2 treatment (T3) gave significantly higher exchangeable Mg content compared to ECB type 1 treatment (T2) (Table 5).

Table 4. *Effect of different fertilizer applications on leaf nutrient contents of immature rubber plants*

Treatments	Leaf nutrient contents (%)			
	N	P	K	Mg
T1	2.92[a]	0.112[a]	0.752[a]	0.21[a]
T2	2.91[a]	0.117[a]	0.785[a]	0.25[a]
T3	2.77[a]	0.122[a]	0.750[a]	0.23[a]
CV	7.19	16.78	5.72	26.99

Values in the same column followed by the same letter are not significantly different at p=0.05.

Table 5. *Effect of different fertilizer applications on soil pH, total N, available P, exchangeable K, Ca and Mg of the top 0-5 cm soil layer at the end of 18 months after planting*

Treatments	pH	Total N	Available P	Exchangeable K	Exchangeable Ca	Exchangeable Mg
T1	5.11[a]	0.162[a]	25.8[a]	158[b]	238[a]	29.17[ab]
T2	5.18[a]	0.152[a]	22.8[a]	175[a]	258[a]	26.82[b]
T3	5.12[a]	0.157[a]	26.4[a]	168[a]	242[a]	31.72[a]
CV	3.26	12.69	15.03	3.17	11.72	9.14

Values in the same column followed by the same letter are not significantly different at p=0.05.

Soti *et al*., 2015 observed that there were no differences in growth parameters among the different slow release fertilizers. Single application of polymer-coated urea fertilizer with varying degrees of N release (different formulations were made by varying the coating contents) could increase the N use efficiency, compared to normal urea split applications in the three major grain crops, rice (Yang *et al*., 2012b; 2013), wheat (Yang *et al*., 2011), and corn (Ning *et al*., 2012). Improved N use efficiencies were resulted from the use of polymer-coated urea providing 3.23-26% yield increases compared to normal split applications (Wang *et al*., 2016). Moreover, Yang *et al*., 2012b observed no significant increase in rice yield accompanying a 25% enhancement in N use efficiency with coated fertilizer when compared to normal application of N rate of 300 kgNha^{-1}in the first year. However, yield greatly increased by 18% with coated fertilizer in the second year with 22.9% in N use efficiency. According to Dong *et al*., 2016, some physiological characteristics such as chlorophyll content, photosynthetic rate, transpiration rate and chlorophyll fluorescence parameters have increased significantly providing 24-35% more grain yield and 57-74% more total yield with coated fertilizer treated maize plants when compared to application of conventional compound fertilizer. Similar to these results, present study revealed that there is a possibility of using ECB as a substitute for split application of conventional fertilizers.

Conclusions

In this study it was revealed that the growth parameters of plant diameter and girth of immature rubber plant, leaf nutrients; N, P, K & Mg and some soil nutrients; N, P Ca and Mg were comparable between ECB treatments and conventional split fertilizer application treatment. Enhancement of exchangeable K could be observed with ECB treatments compared to conventional fertilizer application. Further, ECB application reduces the labour cost of Rs.36,225/= per hectare is due to net saving for labour compared to the conventional type of fertilizer application. Hence, it can be concluded that there is a possibility of using single application of ECB as a substitute for four split application of conventional fertilizers recommended for immature rubber plants with net saving of Rs.36,225/= per hectare.

Future studies

The efficiency of the produced ECB was similar to the conventional split fertilizer application was proven for the rubber plants growing in Boralu series soils and to be evaluated in other rubber growing environments in future studies.

New technologies should be developed or existing technologies should be improved for mass production of ECB.

ECB has been developed using rubber latex and coir dust as the coating materials. Other environmental friendly low cost materials should also be explored for the preparation of slow release product.

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Training induced knowledge and adoption of harvesting technologies in rubber smallholdings in the Kegalle district of Sri Lanka

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Abstract

This study was carried out to evaluate the impact of training on improvement of knowledge and adoption of technologies developed by the Rubber Research Institute of Lanka (RRISL) for harvesting of rubber in the smallholder sector. The scores which were used to measure the knowledge (KNOW) and adoption (ADOP) of latex harvesters on recommendations related to latex harvesting were also used to evaluate whether systematic training could improve knowledge/adoption. Equal number of trained and non-trained harvesters; 80 each were selected for the study in Kegalle district. A questionnaire survey and field level observations were conducted in 2017, employing equal numbers from the two categories; Latex Harvesting Assistants (LHAs) who harvest their own rubber lands (OPER=1) and those who are hired by land owners (OPER=0) within the categories of trained and non-trained LHAs. The increase in KNOW and ADOP due to systematic training was statistically significant. The respective mean scores for trained and non-trained groups (for KNOW; 70 and 38, t=-12.85, P<0.001 and for ADOP; 71 and 40, t=-10.34, P<0.001) signifying that training has increased KNOW and ADOP by 84% and 78%, respectively. In the trained group, significant differences were observed for both KNOW and ADOP for OPER (for KNOW; OPER1=82.9 and OPER0=57.8; t=-6.45, P<0.001) (for ADOP; OPER1=84.3 and OPER0=56.3; t=-6.36, P<0.001), indicating that KNOW and ADOP to be high with OPER1. The experience in harvesting was negatively correlated with KNOW (r=-0.528, P<0.001) and ADOP (-0.638, P<0.001). Participation in other extension activities was positively related with KNOW (r=0.341, P<0.01) and ADOP (r=0.390, P<0.01). The variables, such as age, gender and education level and job satisfaction did not have significant relationships with KNOW and ADOP. It is evident that systematic training on rubber harvesting enhances knowledge and adoption of recommended practices, which may eventually improve the productivity of rubber smallholdings. Hence, this training is worth continuing for the improvement of future performance of the smallholder rubber sector.

Key words: harvesting practices of rubber, knowledge and adoption scores, latex harvesting assistants, smallholder rubber sector

Introduction

Rubber (*Hevea brasiliensis*) is one of the major plantation crops in Sri Lanka in terms of export earnings and employment generation and contributed nearly 0.3% to the GDP in 2018 (Anon., 2018). In the Sri Lankan context, smallholder rubber sector is considered as the most dynamic segment of the rubber sector as it represents 68% of the total rubber extent of Sri Lanka though it contributes 69% to the national rubber production, yet far behind the expected targets (Anon., 2017).

Latex is the major economic constituent of the rubber tree which can be extracted during its mature period once the harvestable girth is attained. The rubber tree is exploited by periodic excision of a thin shaving of the bark along a sloping groove placed spirally on the bark of the tree trunk to extract latex from latex vessels by a “tapping knife” and this procedure is known as harvesting. Latex Harvesting Assistant (LHA) is the person who extracts latex from the rubber plant. There are two types of harvesters; LHAs who harvest their own rubber lands and those who are hired by land owners. Harvesting of rubber is a highly skilled task and the LHAs have to be adequately trained to perform harvesting to get the best returns and also to protect the rubber tree to get an optimum economic result over the total lifespan of the tree. Harvesting determines the land productivity of rubber plantations, which is recorded as a low value less than 1000 kg/ha/year in the Sri Lankan context (Anon., 2017).

The low adoption in harvesting recommendations formulated by the Rubber Research Institute of Sri Lanka (RRISL) is one of the key issues which adversely affect the sustainability of rubber farming. Certain repercussions due to this issue could be identified, *viz.* damaged trees, early uprooting, less potential yield due to poor harvesting quality, abandoning of harvestable holdings which finally lead to low national rubber production (Wijesuriya *et al.*, 2007). Therefore, the adoption in harvesting recommendations is important in meeting up with the national rubber production targets.

RRISL is the nodal agency in the country with the statutory responsibility for research and development of all aspects of rubber cultivation, harvesting and processing for the benefit of the rubber industry and delivers extension services for the rubber sector. Technology transfer through training is one of the strategies in operation by RRISL and a number of novel approaches have been introduced to improve the knowledge and skills of smallholder rubber farmers. The Advisory Services Department (ASD) of RRISL conducts training programmes with a view to improving skills of rubber harvesters. Establishment of “Training Schools for Latex Harvesting Assistants (TSLHAs)” is one of the strategies to address the shortage of skilled LHAs while improving their knowledge which ultimately would help to increase the adoption of correct harvesting practices recommended by RRISL. The TSLHAs is a systematic training programme which is conducted to introduce new skilled LHAs to the rubber smallholder sector as a solution for the shortage of skilled harvesting assistants. The TSLHAs is based on a syllabus including both practical and theoretical aspects which are conducted in ten full days. Trainees are provided with both theoretical knowledge and practical skills in rubber harvesting by the Rubber Extension Officers (REOs) at convenient locations. Rubber logs are used for practical sessions, to practice harvesting with hands on support. At the end of each TSLHAs, trainees are evaluated by both oral and practical tests by the REOs (Anon., 2011). Yet, so far, no studies have been done to quantify the impact of training on improvement of knowledge and adoption of technologies in rubber harvesting. On the other hand, development of combined indices to assess knowledge and adoption levels for each individual LHA considering different components of harvesting makes it easy for comparing and clustering of farmers for further training to improve the adoption levels. The main objective of this study was to investigate the impact of training on knowledge and adoption of harvesting technologies on performance of the smallholder sector.

This paper describes the development of indices for knowledge and adoption of LHAs on recommendations related to latex harvesting employing a participatory approach to ascertain weights for each component of the indices. Through these indices the hypothesis of "whether latex harvester training could improve knowledge/adoption" is also tested for the type of operation, *viz.* hired or harvesting their own land.

Materials and Methods

Data collection and sampling procedure

The study was conducted in the Kegalle District in Sri Lanka (7.25° N, 80.35° E) during 2018. The survey was conducted with 160 LHAs in eight REOs regions. The sample was selected randomly after stratification in each REO region (Table 1). In the next step, from this stratified sample on REOs regions, two equal portions were selected based on whether the training received on harvesting at TSLHA or not and these categories were further divided into LHAs operated on hiring basis and who harvest their own rubber lands. A pre-tested questionnaire were used to collect data from the respondents accompanied with field observations. The questionnaire consisted questions to collect information on three main areas; *viz.* key information of smallholders, questions to test knowledge on recommendations in harvesting of latex and field testing on adoption of these recommended practices in each smallholding harvested by the LHAs.

Table 1. *The selected sample of LHAs from different REOs ranges in Kegalle district*

REO range	No. of Trainees/Non-trainees
Kegalle	13
Yatiyantota	12
Ruwanwella	13
Mawanella	10
Galigamuwa	14
Dehiovita	06
Warakapola	12
Total	80

Testing of knowledge on recommendations in harvesting of latex

The knowledge is defined as those behaviours and test situations, which emphasize memorizing by either recognition or recall of ideas, materials or phenomena. The knowledge is one of the important components of behaviour and it plays a vital role in the adoption in improved technologies (Bloom *et al.*, 1985). The knowledge becomes the power of a person, so that farmer's technical knowledge determines their ability to reach solutions (Verdiuin *et al*., 1979).

The technical knowledge of the LHAs was measured using a test, which is performed using a questionnaire. It referred to critical areas of the recommended practices of rubber farming introduced by the RRISL. They are; 1. Tapping system, 2. Tapping panel marking, 3. Time of tapping, 4. Girth at opening of tapping, 5. Height at opening of tapping, 6. Placement of spout, 7. Placement of the cup, 8. Cleanliness in tapping area and 9. Cleanliness of tapping utensils. There were five questions (questioned each respondent in the local language) from the above-mentioned areas and one mark is awarded for each correct answer. The test/questions were read by the researcher to LHA and scores, 1 for a correct answer and 0 for an incorrect answer was recorded for each question, and the total was calculated for each LHA.

Testing of adoption on recommendations in harvesting of latex

Rogers and Shoemaker (1971) defined adoption as a decision to make full use of a new idea as the best source of action available. The empirical referent of this concept has to take a time dimension in to account. The field testing on recommendations was done after one year of attending the training session. The adoption levels were also tested on the same areas used for testing the knowledge. For the areas from five to nine, as mentioned for testing of knowledge, randomly selected ten rubber trees were assessed to obtain the adoption level.

The level of adoption in each area was measured using an adoption scale which comprises three different levels of adoption, to which marks were given (2 - Good, 1 - Average and 0 -Poor), which resulted in a score for each recommendation. The final score was taken as a sum of all scores for each recommendation after weighting each recommendation on the priority.

A participatory approach was employed in weighting each recommended practice from one to nine, which were used for developing the knowledge/adoption score. A pair-wise ranking approach was employed to identify the priorities to set the weights for each activity selected to develop the indices. A group of rubber extension officers was involved in the pair-wise ranking exercise.

The equation for the Knowledge and Adoption scores for individual LHA; *KNOW* and *ADOP* is given in equation 1.

$$KNOW\ or\ ADOP = \frac{\sum_{i=1}^{n}(w_i * Xobs_i)}{\sum_{i=1}^{n}(w_i * Xmax_i)} * 100 \ldots\ldots (1)$$

$Xobs_i$ = Observed Knowledge or Adoption Score for i^{th} recommendation
$Xmax_i$ = Maximum Knowledge or Adoption Score for i^{th} recommendation
w_i = Weight for the i^{th} recommendation

Data analysis

Descriptive data analysis techniques were employed in this study to identify the differences of knowledge and adoption with training on harvesting related activities. A Correlation analysis was employed in understanding the relationship between knowledge/ adoption scores and other variables of interest. This analysis was done only for the trained group, to understand the impact of other variables listed in Table 2 on *KNOW* and *ADOP*. The Genstat version 19 was employed in statistical and descriptive analyses.

Key information of LHAs

The summary of the socio-demographic characteristics of LHAs is presented in Table 3. Female LHAs of both trained and non-trained categories had dominated, with a female: male ratio of nearly 2:1. The age of LHAs varied from 19 to 79 years. The majority of LHAs $_{\text{trained}}$ and LHAs $_{\text{non-trained}}$ were in the age category of >51 years. No one had followed degree programmes or diplomas. Further, only 8% of both LHAs$_{\text{trained}}$ and LHAs$_{\text{non-trained}}$ had attended tertiary level education (G.C.E. A/L). The majority of the sample (nearly 50 %) had less than 5 years of experience in harvesting, whilst 23% had 11 to 15 years of experience and 21% had 6 to 10 years of experience.

Table 2. *Variables used in the analysis*

Variable	Description
ADOP	Adoption Score, range from 0 to 100
KNOW	Knowledge Score, range from 0 to 100
TRAIN	Systematic training (Received = 1, Not received=0)
AGE	Age of harvester (years)
GENDER	Gender of harvester (Male = 1, Female = 0)
EDU	Education level of harvester (Years of formal education)
OPER	Harvesting operation (own land=1, others' land=0)
EXP	Experience in harvesting (years)
EXTPART	Participation in extension programmes (yes=1, no=0)
JS	Job satisfaction (1 – very unsatisfied, 2 – unsatisfied, 3 – unconcerned, 4- satisfied, 5 – very satisfied)

Table 3. *The summary of the socio-demographic characteristics of LHAs*

Characteristics of LHAs	% of LHAs trained (N=80)	% of LHAs non-trained (N=80)
Gender composition (female)	68	70
Age distribution (years)		
<=25	2	2
26-50	37	39
>51	61	59
Level of education		
Up to grade 6	9	8
Grade 6- O/L	83	85
GCE A/L	8	7
Higher education (diploma or degree)	0	0
Experience in harvesting		
<5	49	23
6-10	21	28
11-15	23	29
>16	7	20

Development of knowledge score (*KNOW*) and adoption score (*ADOP*)

The pair-wise ranking exercise revealed priorities for different criteria as listed under prioritization in Table 4. The weights for each criteria were decided based on prioritization as given in Table 4 and the maximum score could be obtained, which is 90, is presented as a percentage to derive both *KNOW* and *ADOP* according to equation 1.

Table 4. *Priority, weights and maximum scores for each criteria for the Knowledge (KNOW) and Adoption Score (ADOP)*

Criteria	Priority	Weight based on prioritization	Maximum score for each criterion
1. Tapping system	2	3	15
2. Tapping panel marking	4	2	10
3. Correct time of tapping	4	2	10
4. Girth at opening for tapping	1	3	15
5. Height at opening for tapping	3	3	15
6. Cleanliness of tapping area	4	2	10
7. Cleanliness of tapping utensils	5	1	5
8. Placement of spout	6	1	5
9. Placement of cup	7	1	5

Score = highest mark x weight

Descriptive statistics of knowledge score (*KNOW*) and adoption score (*ADOP*)

The impact of training is evident according to the information given in Table 5 and Fig. 1, that the systematic training through TSLHAs has improved both knowledge and adoption on harvesting related practices in rubber faming. Systematic training has increased *KNOW* and *ADOP* by 84% and 78%, when compared to the non-trained group. It is also noted that the variability in the 'trained' group is high compared to the 'non-trained' group. The results of t-tests suggest that there are significant differences between the means of trained and non-trained groups for *KNOW* and *ADOP* with t=-12.85, P<0.001 and t= -10.34, P<0.001, respectively.

It is also important to explore whether the LHAs who tap their own rubber lands (OPER=1) and others' lands (OPER=0) behave in a similar way with respect to acquiring knowledge and adoption of technologies in tapping operations. It was observed that in the non-trained group, there was no significant difference between *KNOW* for OPER (OPER1=36.4 and OPER0=38.6; t=1.2, P=0.234) while it was significant for *ADOP* for OPER (OPER1=43.5 and OPER0=35.5; t=-3.37, P<0.001) (Fig. 2). In the trained group, significant differences were observed for both *KNOW* and *ADOP* for OPER (for *KNOW*: OPER1=82.9 and OPER0=57.8; t=-6.45, P<0.001) (for *ADOP*: OPER1=84.3 and OPER0=56.3; t=-6.36, P<0.001) (Fig. 3).

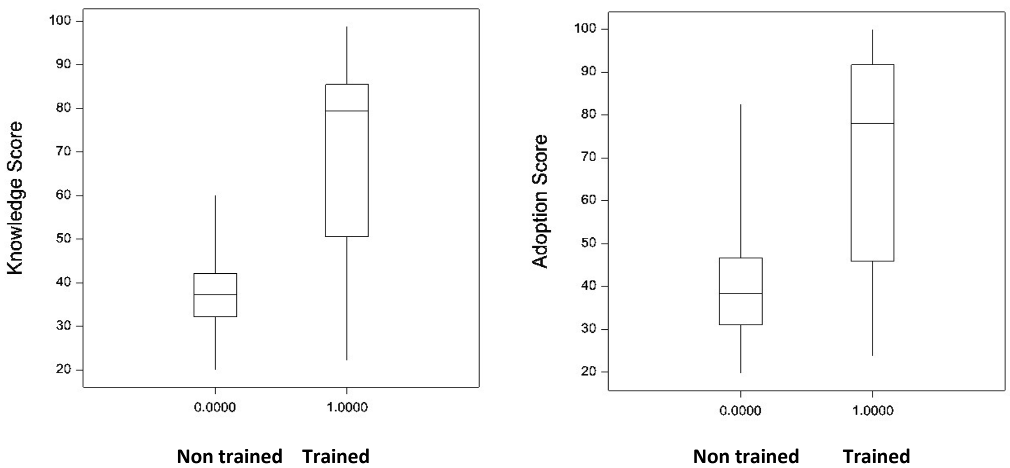

Fig. 1. The distribution of Knowledge Score (*KNOW*) and Adoption Score (*ADOP*) for trained and non-trained LHAs

Table 5. *Descriptive statistics of Knowledge Score (KNOW) and Adoption Score (ADOP)*

Statistic	Whether trained on harvesting techniques			
	Yes		No	
	KNOW	***ADOP***	***KNOW***	***ADOP***
Mean	70	71	38	40
Maximum	99	100	20	83
Minimum	22	24	60	20
SD	21	24	8	11

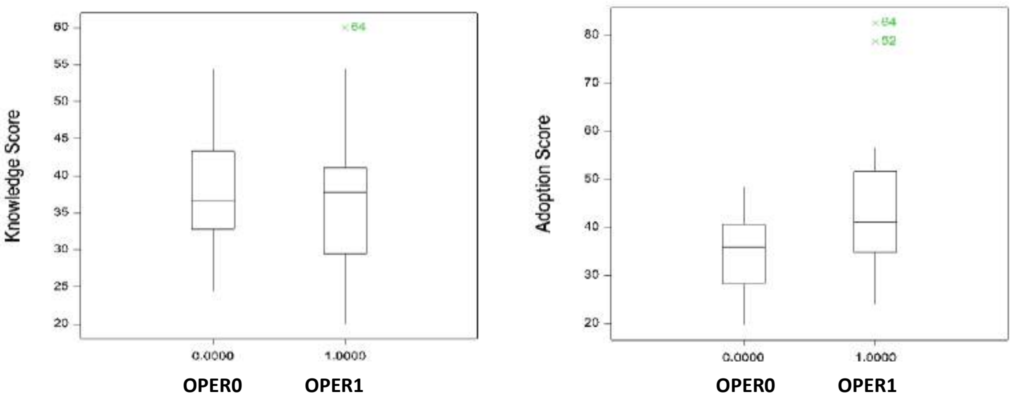

Fig. 2. The distribution of Knowledge Score (*KNOW*) and Adoption Score (*ADOP*) for the non-trained group under type of tapping operation (OPER1: tapping the own land and OPER0: tapping in others' land)

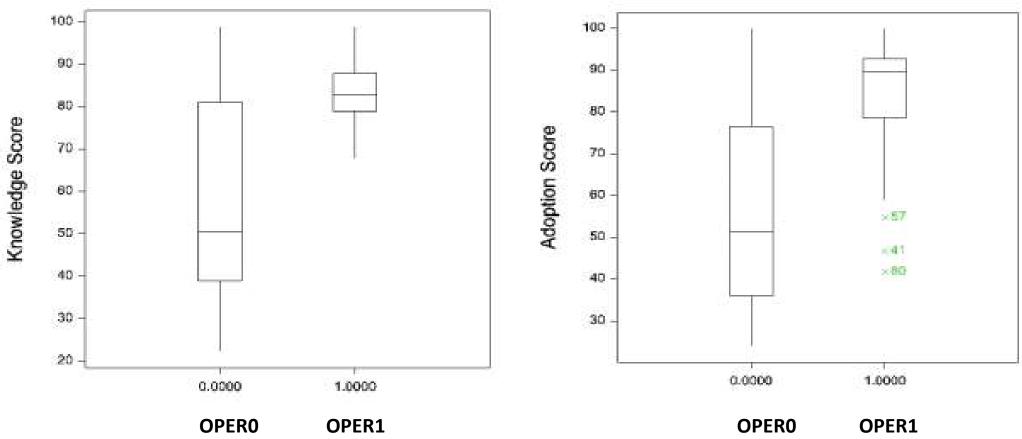

Fig. 3. The distribution of Knowledge Score (KNOW and Adoption Score (*ADOP*) for the trained group under type of tapping operation (OPER1: tapping the own land and OPER0: tapping in others' land)

Relationship between *KNOW* and *ADOP* and its relationship with participation in harvester training

Obviously, there is a positive relationship between knowledge and adoption as described by a number of authors (Sivayoganathan, 1982; Amarasinghe (1993); Niranjan *et al.*, 1991). In this study as shown in Fig. 4, a positive correlation was observed between *KNOW* and *ADOP*. Yet, the strength of the relationship is more pronounced in the trained group. It suggests that systematic training on rubber harvesting would enhance the adoption of recommended practices which would eventually improve the productivity of rubber plantations.

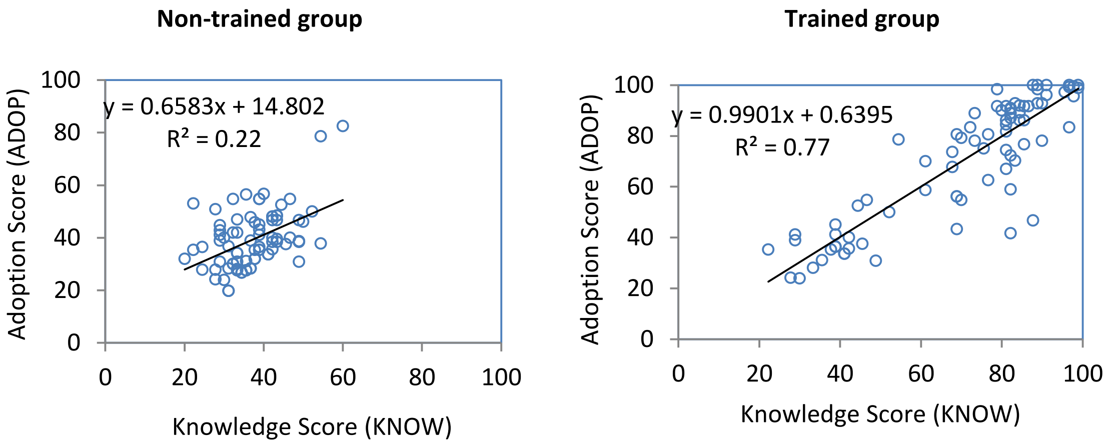

Fig. 4. The relationship of Knowledge Score (*KNOW*) and Adoption Score (*ADOP*) for trained and non-trained LHAs

Correlation analysis of *KNOW* and *ADOP* with relevant socio-demographic variables

Harvesting operation (Owner=1, Hired=0) yielded a positive correlation (Table 6) with *KNOW* and *ADOP* suggesting the scores would be higher when the owner harvest the rubber land. It is evident from Table 6, that experience in years (*EXP*) is negatively correlated with *KNOW* and *ADOP*, which means grasping of knowledge and motivation in adoption, especially in harvesting of rubber is in contrary to prior experience on harvesting. As expected, participation in other extension activities (*EXTPART*) is positively related with *KNOW* and *ADOP*, as evident from Table 6. It is also interesting to note that *AGE*, *GENDER* and *EDUC* do not have significant relationships with *KNOW* and *ADOP*. The relationship with job satisfaction (*JS*), although not significant, showed a positive correlation.

Table 6. *Correlations of adoption score (ADOP) and knowledge score (KNOW) with relevant variables listed in Table 2*

Variable	Correlation coefficients	
	KNOW	***ADOP***
AGE	0.112	0.105
GENDER	0.015	0.079
EDU	-0.002	0.076
OPER	0.523***	0.564***
EXP	-0.528	-0.638***
JS	0.341	0.390

Note: **, *** Statistically significant at 0.01 and 0.001, respectively

Conclusion

Systematic training through TSLHAs had enhanced knowledge and adoption of harvesting recommendations/ practices by 84% and 78%, respectively, when compared to the non-trained group of LHAs.

There was a positive and strong correlation observed between both knowledge and adoption for trained LHAs. Harvesting operation yielded a positive correlation with knowledge and adoption indicating that scores were higher when the owner harvests the rubber land. The experience in harvesting was negatively correlated with knowledge and adoption. The participation in other extension activities was positively related with knowledge and adoption. The age, gender and education level of harvesters did not have significant relationships with knowledge and adoption. Their relationship with job satisfaction, although not significant, showed a positive correlation.

Systematic training through TSLHAs on rubber harvesting would enhance the knowledge and adoption of recommended practices which will eventually improve the productivity of rubber smallholdings. Hence, this practice is worth continuing for the future for improved performance of the smallholder rubber sector.

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A study on different micro-irrigation techniques for mitigating water stress of immature rubber (*Hevea brasiliensis*) plants

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Abstract

The Intermediate and Dry Zones of Sri Lanka have been targeted in expanding the rubber plantations with a view to expand the extent under planting to achieve national targets in natural rubber production. However, climatic conditions of these regions are suboptimal for growing of rubber. The mid-year dry period in these areas extends from June to September and as a result, plants experience a severe water stress especially in nursery and immature period. Therefore, this study was carried out in the Kilinochchi District, which belongs to the Agro-ecological Zone, DL3 in order to assess the performance of micro-irrigation techniques for immature or young rubber plants. Two micro-irrigation systems; viz. drip and spray jet were tested under three soil moisture depletion levels; 30, 50 and 70% of available soil moisture.

Results showed that the growth of immature young rubber plants were highly responsive to moisture depletion levels and micro-irrigated systems. It was found that both drip and spray jet irrigation systems performed well in supplying water at 30% depletion level when compared to the depletion levels of 50 and 70%. Water stress is created by 70% depletion level with decreased chlorophyll content, stomata closure and increase in leaf temperature. Adequate irrigation at 30% depletion level in both systems resulted significant increment of chlorophyll content ($p < 0.05$). There was significant increment in chlorophyll content in plants which were irrigated with spray jet system when compared to drip system. Plants which were irrigated at 30% depletion level regulated higher stomatal conductance even under higher temperatures during mid-day period.

***Key words*:** chlorophyll, depletion, drip, immature rubber, micro-irrigation, spray jet

Introduction

Rubber is one of the main plantation crops in Sri Lanka with a total extent around 130.3 thousand hectares while the extent under tapping was around 98.6 thousand hectares in 2017 (Anon., 2017). In order to meet the demand for raw rubber, it is needed to increase raw rubber production through planting of genetically improved planting materials and continuously expanding the area under planting. There has been a continuous replanting rate of 3% or above as acceptable level, which indicates the average growth of the industry (Seneviratne, 2005). The increase in rubber extent was 1500 ha in 2017 due to the extent of new planting in traditional rubber growing areas (Anon., 2017). However, further expansion of rubber cultivation in the Western part of the country is limited largely due to non availability of lands due to urbanization and industrialization. Therefore, to meet the increasing global demand for natural rubber and considering its limited scope of expansion in the traditional areas, attempts are being made to extend its cultivation to marginally suitable areas in Dry and Intermediate Zones in the country. This initiative on cultivation of rubber in the Dry Zone is expected to improve the livelihoods of people who were entangled in thirty years' civil war. Rubber is a crop which has its all operations connected with the rainfall pattern. Wijesuriya *et al.* (2013) reported that the Agro-ecological regions, DL1, DL2 and DL3 in the Dry Zone are vulnerable to prolonged droughts during March to August in most of the years. Drought stress poses adverse effects on immature rubber including morphological and plant physiological changes. Receiving a rainfall below 500 mm over six consecutive months is considered detrimental to growing of rubber (Yogaratnam, 2001). High evaporation from the soil surface associated with low relative humidity, high temperature and wind conditions, affect the new plantings adversely.

Irrigation and soil conditioning are therefore necessary for the drier areas to ensure high quality plants with healthy growth especially under immature stage. To improve the early establishment and survival of immature plants, it is very important to have proper field water management practices with the selection of a proper irrigation method especially for the dry period of the year. Literature has reported that with irrigation the immaturity period in the dry region in India could be reduced from more than 10 years to six years (Devakumar *et al.*, 1998).

Irrigation technology has developed rapidly from border to micro irrigation and from manual to automation, over the last two decades. Micro irrigation systems are convenient with a potential for saving water and assures producing large and steady crop yields. The water availability, type of soil, topography of the land and labour availability determine the selection of the irrigation system (Nakandala *et al.*, 2008).

Mini sprinkler or spray jet and drip irrigation systems are two kinds of micro irrigation systems now widely used in many crops. The rate of applying water in a micro irrigation system is an important factor which governs moisture distribution in the soil profile. Precise irrigation schedule with the selection of a micro irrigation system and irrigation interval together with the desired depletion level will improve the water use efficiency and growth of plants especially in the immature phase.

Keeping the above facts in view, the growth of immature rubber plantations in the Dry Zone of the country under micro-irrigation was studied in irrigated rubber cultivation. The objective of the study was to assess the performance of drip and mini sprinkler or spray jet systems at different soil moisture depletion levels in order to evaluate the responses on the physiological and morphological growth performances of immature rubber plants.

Materials and Methods

Two types of micro irrigation systems (drip and mini sprinkler or spray jet systems) were installed in a newly established smallholder rubber field with an extent of 0.4 ha in Kilinochchi District of the Dry Zone in 2018. The system was designed with main, sub main and lateral lines from the water source to the experimental site. To maintain the required operating pressure in the system, the main line was connected with the pumping source along with a gate valve for regulating water as per the requirement of the treatment. Average discharge rates of drip and micro spray jet were eight litres per hour (lph) and 16 lph, respectively. Two on-line drippers were installed between the plant and one spray jet sprinkler was setup near the plant. The time of irrigation was adjusted in both systems in order to supply the same volume of water to each plant. A six months old rubber field which was established in November, 2017 was used for the experiment with two irrigation systems. Three levels of moisture depletion; *viz.* 30%, 50% and 70% were tested under drip and spray jet irrigation systems according to a Randomized Complete Block Design (RCBD) with three replications. Morphological and physiological attributes of plant growth were gathered throughout the study period. Moisture availability of the soil to maintain each depletion levels was measured by using a Theta probe device and moisture meter (Delta T Model DL6). Morphological attributes such as stem diameter, plant height, leaf area and number of leaves of each treatment were gathered in monthly periods. Physiological measurements were taken on chlorophyll content and stomatal conductance of plants.

Field capacity (FC) and permanent wilting point (PWP) of the soil in the experimental site were measured prior to irrigation. Undisturbed samples at 10 cm soil depth were taken daily to measure soil moisture near the treatment plants in order to schedule the irrigation interval along with the depletion levels. At each depletion level, two irrigation systems were operated to a maximum of one hour until the soil reached the field capacity. Irrigation was not given to the experimental field at the times of rainfall. Plant stem diameter and plant height were measured once a month as morphological parameters. Leaf area was determined as an on-site measurement by using a portable leaf area meter (Delta T MK2). Fifteen plants in each treatment in three replicates were taken for measurements. Total number of leaves of the plants was counted together with leaf area at monthly intervals.

Plant physiological parameters such as; stomatal conductance, chlorophyll content and leaf temperature were measured once a month throughout the study period. Stomatal conductance and leaf temperature were measured by a portable porometer (Delta T AP4). Measurements were taken from the top mature leaf and middle leaflet of each treatment. Leaf chlorophyll content was measured by non-destructive method using a chlorophyll meter (SPAD 502DL Plus). The meter gives chlorophyll content as an index value (SPAD value) which is proportional to the amount of chlorophyll content of leaves. Average measurements were taken from one of the top mature leaves.

Data were gathered in rainless dry months. Statistical analysis was done using analysis of variance followed by mean separation employing 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 and Discussion

Moisture depletion pattern

Figure 1 shows the soil moisture depletion patterns of soils under treatment plants. Daily moisture measurements were taken as percentage of moisture in the soil under volume basis.

Field capacity and PWP of soils were 18.7 and 4.7%, respectively. Moisture depletion patterns indicate the depletion of water at each irrigation interval with respective to each depletion level *i.e.*; 30%, 50% and 70%. Moderate to severe drought condition was created with the levels at 50 to 70% depletion levels and irrigation at 30 % depletion level, once in two days interval minimized the drought stress of the treatment plants.

Morphological responses of immature rubber plants on micro-irrigation

Two micro irrigation systems (drip irrigation system, spray jet irrigation system) were tested under three levels of depletion and stem diameter, height, leaf area and number of leaves were measured as morphological growth attributes of immature plants during the first year of field planting. Table 1 shows the variation in morphological characters of eight months aged plants according to the different depletion levels under two micro irrigation systems after three months of commencement of irrigation.

According to Table 1, the application of two micro irrigation systems at 30% depletion level has significantly ($p \leq 0.05$) increased all growth parameters of eight months old plants irrespective of the type of micro irrigation systems. Plant diameter increased with high moisture level in the soil. Higher depletion levels (*i.e.* 50% and 70%) resulted drought stress to the plants and showed significantly low ($p \leq 0.05$) plant stem and height. Total leaf area and number of leaves in a plant at 30% depletion level, showed a significantly higher value ($p \leq 0.05$) irrespective of two micro irrigation systems than that of the drought stressed plants at 70% depletion in both irrigation systems.

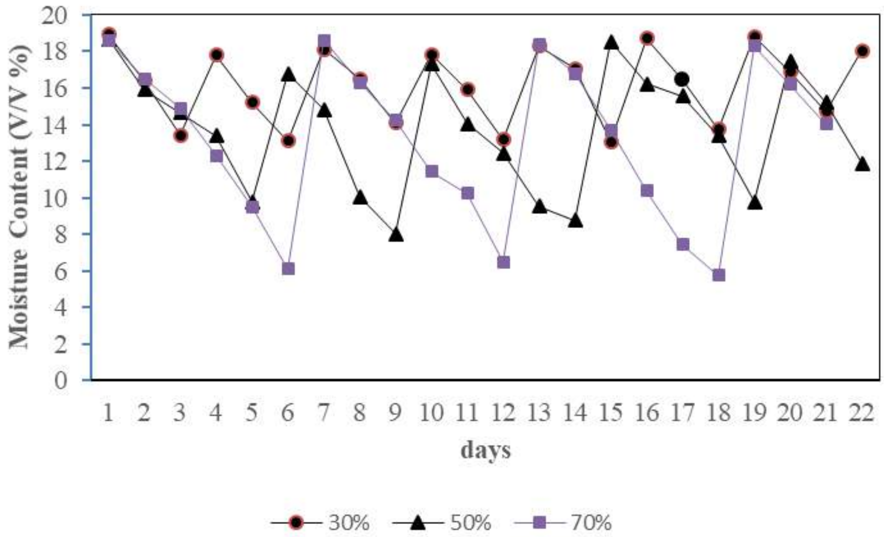

Fig. **1**. Moisture depletion patterns of different moisture depletion levels

Morphological attributes of young plants showed that the growth of immature rubber plants was highly responsive to moisture depletion levels in irrigated agriculture. It has found that drip and spray jet irrigation systems performed well in supplying water to the soil and significantly increased ($p \leq 0.05$) growth of plants at 30% depletion level when compared to higher depletion levels. Plants irrigated with regular intervals at 30% depletion level in both systems provided necessary water requirement for plant growth (Table 1). As evident in the Table 1, spray jet system creates a cooler micro-environment to the plants that enables to grow plants with less stress compare to the drip irrigation system. Similar results were obtained for leaf area and number of leaves per plant. There was significant decline of leaf area ($p \leq 0.05$) in drought stressed plants at 70% depletion level due to drying or senescence of lower mature leaves and wilting of new leaves in upper whirls. Scorching or drying of leaf margins, whole leaves of rubber plants caused by the direct effect of high temperature and water deficit have reduced the total number of leaves and leaf area per plant (Samarappuli *et al.*, 1998).

Table 1. *Morphological characters of eight months rubber plants on depletion levels and two micro irrigation systems*

Type	**Depletion level (%)**	**Diameter (mm)**	**Height (cm)**	**Leaf area (cm^2)**	**Leaf count** (nos.)
Drip	30	20.6^a	141.0^a	2862.5^a	43.8^a
	50	17.5^b	120.0^b	2027.6^b	38.7^b
	70	15.5^c	110.9^b	1368.1^c	24.4^c
Spray jet	30	21.6^a	183.9^a	2532.8^a	39.6^a
	50	16.5^b	100.1^b	2367.5^b	32.7^b
	70	14.0^c	95.1^b	1559.1^c	25.1^c

(Means with the same letter along the column are not significantly different at 0.05 probability level)

Physiological responses

Leaf chlorophyll content is a major component of the photosynthetic system. Figure 2 shows the variation of chlorophyll content of eight months old plants under drip and spay jet irrigation at different depletion levels. There was a significantly lower chlorophyll content per plant ($p \leq 0.05$) at drought stressed condition of 70% depletion level, when compared with all other treated plants. Figure 2 shows that the plants which were irrigated with both systems under 30% depletion level resulted higher chlorophyll content. When compared to the two systems irrespective of depletion levels, there was an increment in chlorophyll content in plants which were irrigated with spray jet system (Fig. 2).

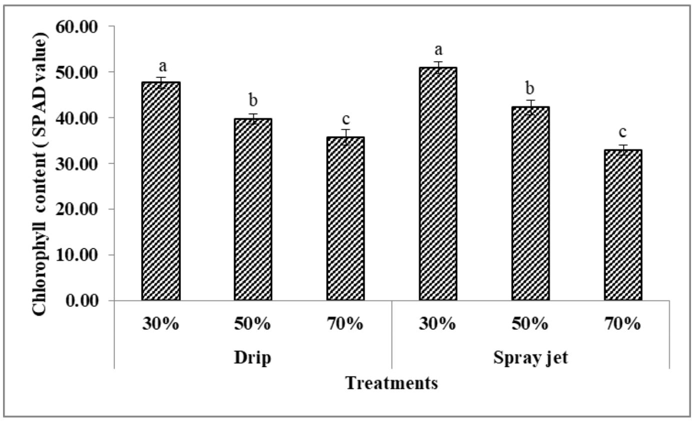

Fig. **2.** Chlorophyll content of immature rubber plants of eight months under two irrigated conditions at different depletion levels of 30, 50 and 70% (Means with the same letter are not significantly different at the probability level, 0.05)

Chlorophyll content as photosynthetic pigments is important to the plant mainly for harvesting light and production of organic compounds. Drought stress at higher levels of depletion causes large decline in chlorophyll content and low concentrations of chlorophyll pigments can directly limit photosynthetic potential and hence, primary production (Anjum *et al*., 2011).

Stomatal regulation is a key process that involve in the photosynthesis process. Measurement of stomatal conductance varied with leaf temperature and influence of decreasing water availability in the soil. Figure 3 shows the variation in stomatal conductance of plants under drip irrigated (a) and spray jet irrigated (b) on different temperatures of leaf surface. Plants which were irrigated with regular intervals at 30% depletion level, regulated higher conductance even at higher temperatures during mid-day. However, plants had its defense mechanism on stomatal opening and closing under high-temperature regimes (Habibi, 2012). Stomatal conductance of plant cells under higher depletion levels decreases progressively with increase of leaf temperature (Fig. 3). Figure 3b shows higher values for stomatal conductance in spray jet system. This may be due to mini sprinkling of water at the base of plants under spray jet system.

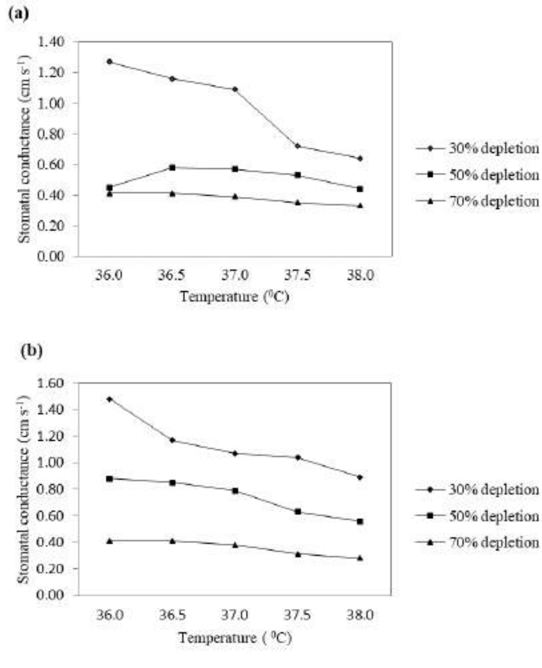

Fig. **3**. Stomatal conductance under leaf temperature of eight months old plants after three months of irrigation (a) drip irrigation system under three depletion levels and (b) spray jet irrigation system under three depletion levels (30, 50 and 70%)

Conclusion

A significant impact on micro irrigated cultivation has been observed on physiological and morphological growth performance of immature plants, alleviating water stress of young rubber plants.

Irrigation scheduling at 30% of soil moisture depletion level gives significantly effective results on morphological and physiological growth of immature rubber plants under micro-irrigated conditions. Water stress was formed by 70% depletion level and differences in two types of micro irrigation systems at each deletion level were not significant in this study.

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Effect of waste polyethylene on properties of methyl salicylate treated natural rubber/low density polyethylene/waste polyethylene composites

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Abstract

Polymer blending has been employed to enable the reuse of recycled industrial and/or municipal plastic waste. Used polythene sheets, which are considered as waste polyethylene (wPE) are a major threat to the environment and hence recycling of these is a way to reduce environmental pollution. The main aim of this study was to develop natural rubber (NR)/low density polyethylene (LDPE) /wPE composites with improved properties using methyl salicylate as the coupling agent. A series of 70:30 NR:LDPE/wPE composites with methyl salicylate were prepared by replacing LDPE with wPE from 0 (control) -25 phpp (parts per hundred parts of polymer) at 5 phpp intervals. Calcium carbonate, 20 phpp and methyl salicylate, 0.5 phpp were also incorporated into every blend composition. The composites were prepared using a laboratory scale internal mixer by melt mixing at a temperature of 150 ^{0}C and a rotor speed of 60 rpm. Physico-mechanical properties and fourier transform infrared (FTIR) analyses of the composites were conducted. Water absorption capacity of the composites was also studied. Incorporation of 20 phpp wPE into NR/virgin LDPE composites improved most of the properties. Strength properties and hardness of the composites containing wPE showed an increasing trend with the increase of wPE loading. Water absorption decreased with the increase of wPE loading. Furthermore, it was evident from the results that all the six composites treated with methyl salicylate are highly flexible. Results in overall indicated that the 70:10:20 NR/LDPE/wPE composite is the best in terms of properties.

Key words: low density polyethylene, methyl salicylate, natural rubber, polymer composites, waste polyethylene

Introduction

Mixing of two or more polymers with different chemical compositions or structure and processing conditions is an effective way of combining performance and economic relationships using existing materials. Fundamental problems that affect the properties of blends include weak interfacial behavior and unstable equilibrium phase, unwanted physical and chemical interactions between the constituents, incompatible phase morphology, inappropriate blend ratios and complex rheology (Keskkula *et al.*, 1996). However, the blending of wPE with polymer materials is more difficult, and many transitional situations can occur: increasing separation at the intermolecular level formation of co-continuous morphology, dephasing into dispersed hetero phase morphologies of increasing phase size. Hence, coupling agents are needed to reduce some of such difficulties and to achieve better performance.

Elastomer-thermoplastic is a material that consist of two polymeric materials one having elastomeric behavior at room temperature and the other showing thermoplastic behavior at processing temperature (Montoya *et al.*, 2004). Mostly, they are prepared by melt mixing thermoplastic materials and elastomers under high shearing action. Elastomers such as ethylene-propylene-diene monomer (EPDM), natural rubber (NR) and styrene-butadiene-rubber (SBR) and plastics such as polypropylene (PP), polyethylene (PE), and nylon are usually used as blend components (Petrovic *et al.*, 1996). In this study, NR and LDPE were used to prepare NR/LDPE composites. The soft grades of NR/LDPE blends can replace vulcanized rubber and flexible plastic for applications in footwear, seals, sports items and injection moulded, extruded and thermoforming products.

However, NR/LDPE composite is immiscible and technically incompatible. Interfacial interactions across the phase boundaries could be enhanced by incorporating a suitable compatibilizing agent (Gajanayake *et al.*, 2012). Compatibilization is a method which is used to modify the interfacial properties of the immiscible polymer blends. It causes a reduction of the interfacial surface tension, surface coefficient and stabilization of the desired blend morphology (Utracki, 2003). In literature, LLDPE/GRT (ground rubber tyre) blends have been prepared with ethylene-1-octene copolymer (EOC) compatibilizing agent and physico-mechanical properties were improved (Rocha *et al.*, 2014). Physico-mechanical properties of the reactive blends prepared with diallyl maleates suggest its activity as a good compatibilizer for NR/LLDPE blends (Gajanayake *et al.*, 2012).

NR is an elastomer with excellent properties, which has been exploited in a wide range of applications. LDPE combines high impact strength, toughness, and ductility to make it the material of choice for packaging films, soft grade applications, which is one of its largest applications. Films are used for different applications such as shrink film, thin film for automatic packaging, heavy sacking, and multilayer films where LDPE acts as a seal layer or a water vapor barrier (Baker *et al.*, 2000). Hence, LDPE was selected for this research to make a flexible material by blending with NR.

A large amount of polyethylene waste is generated from plastic product manufacturing industries. Hence, recycling of discarded PE waste (wPE) is a widely adopted method of reducing municipal solid waste by preparing blends for constructive applications using lower levels (Rector, 2006). Work carried out by Rector, 2006, has revealed that wPE is one of the solid waste types that could be blended with NR and pure LDPE to prepare thermoplastic elastomers (TPEs). As it can be seen in the literature, composite prepared with recycled high density polyethylene (rHDPE)/NR/(Kenaf powder) KP reduced the tensile strength, elongation at break, but increased the stabilization torque and the tensile modulus. SEM images of fracture surface showed that fibrillation due to addition of rHDPE (Cao *et al.*, 2012).

Filler is another major component widely added to the TPE blends to achieve cost benefits and certain property improvements in real industrial applications. $CaCO_3$ is one of such important inorganic powders and widely used as a filler in plastic and rubber industry. Dispersion of inorganics in polymers, and adhesion of a polymer to inorganic filler are difficult since many thermoplastics and rubbers, such as olefin-based polymers, are non-polar. However, it is known that $CaCO_3$ is the most widely used non-reinforcing filler in natural rubber composites as an inexpensive filler and could be used at high loadings.

The overall performance of the TPEs is enhanced upon dynamic vulcanization (DV). DV is used to make 'semi-rigid' rubber-plastic compositions. Also, DV process makes the morphology of the system more stable. Hence, in this study, each composite was prepared by DV method. In this work, performance of NR/LDPE/wPE blends, compatibilized using a novel coupling agent namely methyl salicylate through $CaCO_3$. was studied. Methyl salicylate would perform as an intermediate between $CaCO_3$ and nonpolar NR, LDPE and wPE phases. Methyl salicylate chemically interacts with $CaCO_3$ and the resultant complex interacts with NR, LDPE and wPE phases. These interactions via methyl salicylate are expected to enhance the compatibility of $CaCO_3$ with NR/LDPE/wPE composite.

Materials and Methods

Natural rubber (RSS-2) was supplied by the Rubber Research Institute of Sri Lanka. LDPE was supplied by Deluxe Plastics Ltd., Sri Lanka. $CaCO_3$ (filler) having a mean particle size of 2 µ was obtained from Lanka Minerals & Chemicals (Pvt.) Ltd., Sri Lanka. Other compounding ingredients; sulphur and dicumyl peroxide (DCP) (vulcanizing gents), stearic acid and zinc oxide (ZnO) (activator system), N-tert-butyl-2-benzothiazole sulfenamide (TBBS) (accelerator), IPPD (N-isopropyl N'-phenyl p-phenylene diamine) (antioxidant) and methyl salicylate were purchased from the local market and used as received. wPE was obtained from Elastomeric Engineering (Pvt.) Ltd., Sri Lanka.

Preparation of NR/LDPE composites

A series of NR/LDPE/wPE composites was formulated by varying wPE loading from 0 to 25 phpp. The formulation of the composites is given in Table 1. The composite without wPE was considered as the control. The composites were prepared by melt mixing using a Brabender Plasticorder operated at a temperature of 130 °C, and at a rotor speed of 70 rpm. Total mixing time was kept constant at 14 minutes. Mixing cycle used in the preparation of the composites is given in Table 2.

Table 1. *Formulations of the NR/LDPE/wPE composites*

Ingredient	Parts per hundred parts of polymer (pphp)					
NR	70					
LDPE	30	25	20	15	10	5
wPE	0	5	10	15	20	25
$CaCO_3$						
DCP	0.5					
Sulphur	0.5					
Zinc oxide	3.5					
Stearic acid	2.0					
TBBS	0.5					
IPPD	0.7					
Coupling agent	0.5					

Table 2. *Mixing cycle of the NR/ LDPE/wPE composites*

Total time (min)	Ingredient
0	LDPE
4	NR
6	ZnO + Stearic acid +IPPD
7	½ $CaCO_3$+ ½ CA
9	½ $CaCO_3$+½ CA
11	TBBS
12	Sulphur + DCP
14	Dumping the compound

NR/LDPE/wPE composites were compressed in an electrically heated hydraulic press at 150 °C under 3.5 bar pressure for 15 minutes to produce 2 mm thick sheets. The processing conditions and compression moulding conditions were selected within the standard parameter ranges used in preparation of NR/LDPE/wPE composites. Test specimens were stamped from the moulded sheets according to the ISO standard.

Physico-mechanical properties

Tensile properties and tear strength of NR/LDPE composites were determined using Instron tensile testing machine according to BS ISO 37:2010 and BS ISO 34-1:2010, respectively. Dumbbell shaped tensile test specimens and angle shaped tear test specimens were used. Strain rate was maintained at 50 mm/min, and the extension was measured as the separation of the crosshead. Hardness of the composites was determined using dead load hardness tester according to BS ISO 48:2010.

FTIR spectroscopy

FTIR spectra of the oven dried gels were obtained using attenuated total reflectance (ATR) technique, using a Nicolet 380 FTIR spectrometer. Spectra were recorded in the range of 400 to 3500 cm^{-1} operated at a resolution of 4 cm^{-1}.

Water absorption

Water absorption was obtained by immersion of test specimens having dimensions 30 mm × 10 mm × 2 mm in water at room temperature for 72 hours. Increase in weight to the initial weight of the specimen, as a percentage was reported as the water absorption.

Results and Discussion

Physico-mechanical properties of NR/LDPE/wPE composites

Hardness of NR/LDPE/wPE composites at different wPE loadings is shown in Figure 1. Hardness of all composites was in the range of 40 to 60 IRHD. According to the Figure 1, composite prepared with wPE loading 20 phpp shows the highest hardness value and it is even higher than that of the control (without wPE). Highest stress value is also shown by the former composite (Fig. 2), which means that it has the highest crystallinity compared to other composites. Further, composites prepared with wPE loading of 10 phpp showed the lowest hardness value compared to other wPE composites and control. Other than that, the hardness of composites fluctuates and shows a cyclic pattern with wPE loading. Sulphur and DCP were used as the main vulcanizing agents in this study. DCP initiates radical formation on the LDPE backbone by hydrogen abstraction and chain scission (Maziad *et al*., 2009) and it makes strong C-C crosslinks with NR, LDPE and wPE phases. Therefore, it could be a reason for the enhancement of crosslink density of composites. In contrast, literature suggests that peroxides could act as chemical devulcanizing agents for sulphur vulcanized rubbers (Joseph *et al.*, 2016). This would be a possible reason for the decrease in hardness at 10 phpp wPE loading.

Figure 2 shows crystalline behavior of composites at 0 phpp and 5 phpp wPE loadings and semi-crystalline behavior for the other composites. When more wPE containing long branches are present in the composite, short branches

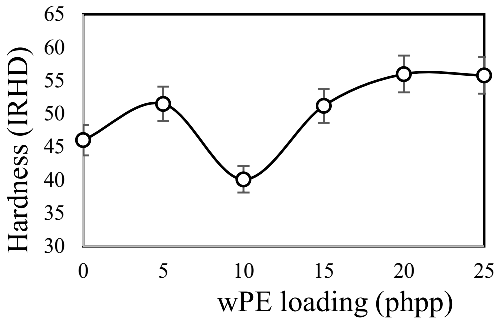

Fig. 1. Variation of hardness of NR/LDPE/wPE composites with wPE loading

may generate during reprocessing resulting in increasing crystallinity. According to the Figure 2, the composite prepared with wPE loading of 20 phpp shows the highest elongation and it is even higher than that prepared without wPE. In addition, highest stress value is shown by the former composite, which means that it has the highest crystallinity compared to other composites.

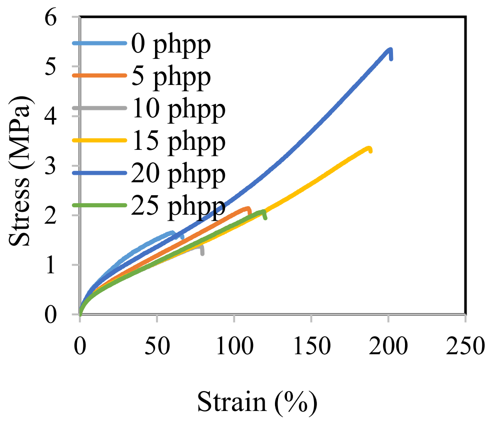

Fig. 2. Strain–stress curves of NR/LDPE/wPE composites

Figure 3 shows a marked increase in tensile strength from wPE loading of 10 to 20 phpp. This could be attributed to a phase change. The tensile strength of wPE loading at 20phpp is higher than that of the control. The reason for the higher tensile strength of wPE loading at 20phpp could be attributed to good inter molecular interaction between the two polymer phases and lower surface tension at the interface (Rector, 2006). This in turn would result in making a good intermediate between NR and LDPE. Further, the tensile strength of the composites depends mostly on the adhesion between the two phases (Borovanska *et al.*, 2012) and it may be concluded that the adhesion between the components in the 70 phpp NR and 10/20 LDPE/wPE is better than that in the other composites at 20 wPE ratio. According to statistical analysis (one way ANOVA) at 95% confidence interval, there is an effect of wPE loading on properties of 70/30 NR/LDPE:wPE composites ($p<0.001$).

Elongation designates elasticity and amorphous behaviour of a polymer material. Figure 4 shows a sin pattern of elongation at break from control to wPE loading of 25 phpp. There is a significant variation in difference between wPE loading of 10 phpp and 15 phpp, however the variation from wPE loading of 15 phpp to 20 phpp is not so significant. The wPE loading of 20 phpp shows the highest elastic properties compared to the other composites. This could be due to good dispersion of the filler $CaCO_3$ through methyl salicylate. The control exhibits the lowest elongation at break. According to the stress-strain curves (Fig. 2), the pattern of control shows crystalline behavior. On the other hand, crystalline materials generally show low elongation properties (Monticelli *et al.*, 2012) and this could be another reason for lower elongating ability of the crystalline composite.

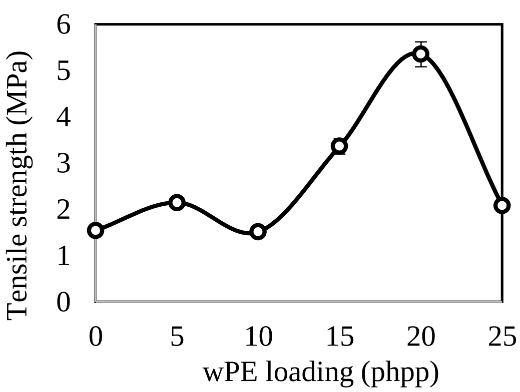

Fig. 3. Variation of tensile strength of NR/LDPE/wPE composites with wPE loading

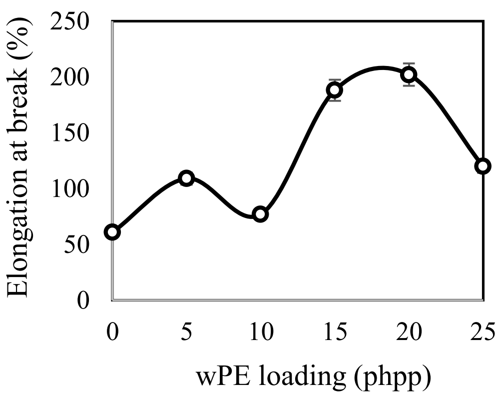

Fig. 4. Variation of elongation at break of NR/LDPE/wPE composites with wPE loading

Modulus can be taken into account when explaining crystallinity, amount of orientation and material strength. Modulus at 5% elongation shows a decreasing pattern from wPE loading of 0 phpp to 10 phpp. Hence, low amount of wPE could act as a filler and it will not be uniformly distributed throughout the composite resulting in a lower modulus at 5 phpp and 10 phpp compared to that of the control. The composite prepared with wPE loading of 20 phpp shows the highest modulus. This is probably due to formation of a stronger intermediate between NR and LDPE with the increase of excess curatives generating from wPE (Atuanyaa *et al.*, 2004). On the other hand, presence of a higher amount of curatives increases crosslink density and hence crystallinity. Therefore, wPE loading of 20 phpp indicates the highest crosslink density and hence highest crystallinity, which in turn gives the highest modulus. Further, modulus at 5% elongation of composites shows a cyclic pattern in the variation of wPE loading. Moreover, wPE is a cured material and it could have unreacted chemicals or ingredients of different loadings such as crosslinking agent, processing aid, *etc.* (Burillo *et al.*, 2002). Furthermore, unreacted crosslinking agent would have remained in the wPE and it would have reacted with the virgin NR and LDPE at the processing temperature. Therefore, this could be a possible reason for the fluctuation observed in Figure 5.

Tear strength of a polymeric material depends mainly on the crack propagation property. Crack propagation of the composites decreases with the increase of wPE loadings up to 10 phpp. Tear strength results (Fig. 6) also confirm the formation of a good intermediate between the two polymer phases when the amount of wPE is increased. Further, tear property has been significantly increased when the wPE loading is increased from 10 phpp to 25 phpp. According to literature, waste plastics are compatible with thermoplastics and thus are frequently used for impact modification and improvement in stress-crack resistance (Borovanska *et al.*, 2012).

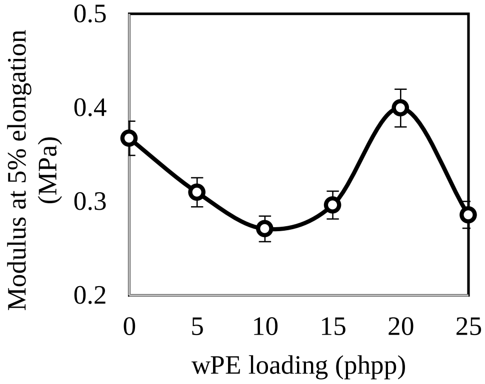

Fig. 5. Variation of modulus at 5% elongation of NR/LDPE/wPE composites with wPE loading

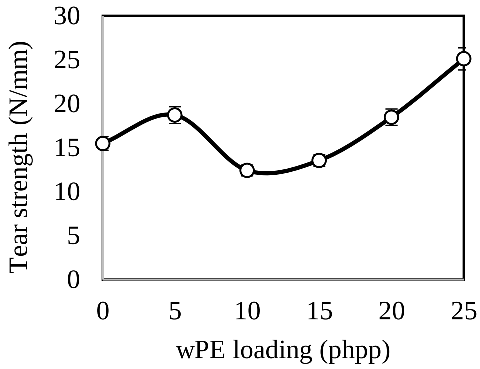

Fig. 6. Variation of tear strength of NR/LDPE/wPE composites with wPE loading

Fourier Transform Infrared (FTIR) Spectroscopic Analysis

Figure 7 presents the FTIR spectra of the composites at different wPE loadings. The composite prepared with wPE loading of 20 phpp exhibits a peak assignment at1378 cm^{-1} (Fig. 7b). This could be assigned to –C–O–H in-plane bending vibrations (Brook, 2000). Thus, the formation of above bonds proves that the composite at wPE loading of 20 phpp achieved a better interaction between NR, LDPE, and other ingredients. This would also support increased tensile and tear properties at 20 phpp wPE loading.

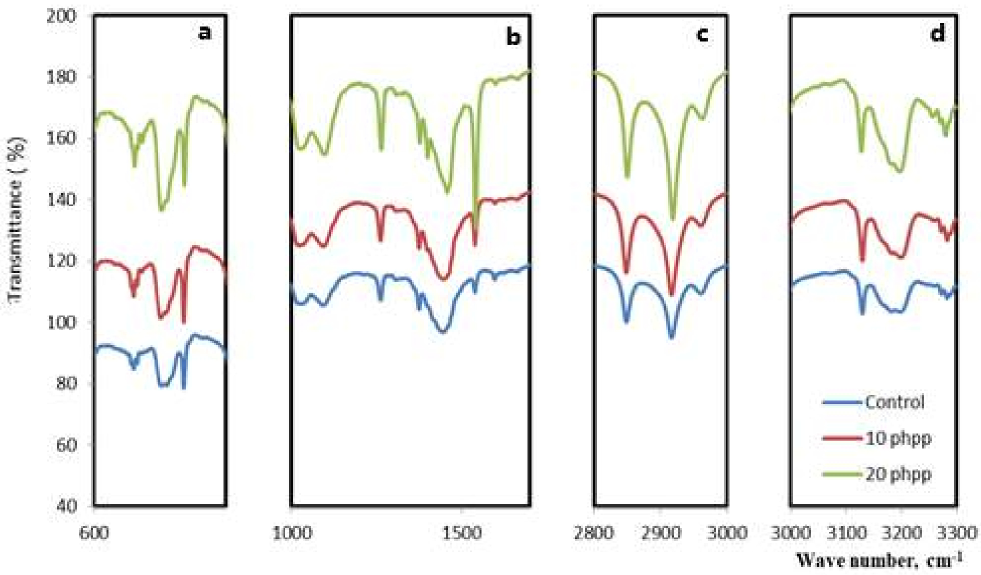

Fig. 7. FTIR spectra of gels of the control and composites with wPE for different regions **a)** 600 to 1000 cm^{-1} **b)** 1000 to 1700 cm^{-1} **c)** 2800 – 3000 cm^{-1} **d)** 3000- 3300 cm^{-1}

Water absorption of NR/LDPE/wPE composites

As per Figure 8, water absorption of all the composites is less than 0.35%. Water absorption decreases with the addition of wPE loading of 5 phpp, and further declines from wPE loading of 10 phpp to 20 phpp. NR and LDPE are organic polymers, and hence they do not react with inorganic water molecules. The composite prepared with wPE loading at 10 phpp indicated the highest water absorption and, it could be due to the presence of unreacted organic methyl salicylate. The lowest water absorption at wPE loading of 20 phpp confirms a good adhesion between NR and LDPE phases of the composites at that wPE loading. Further, wPE-aggregate at all replacement levels is due to the higher porosity of these composites, as higher water absorption generally indicates higher porosity (Saikia *et al.*, 2013). In addition, 20 phpp loading of $CaCO_3$ has affected to make a strong adhesion with 20 phpp loading of wPE via methyl salicylate. As a result, the free volume is decreased in the 70/10/20 NR/ LDPE/wPE composite due to increase in the dispersibility of $CaCO_3$.

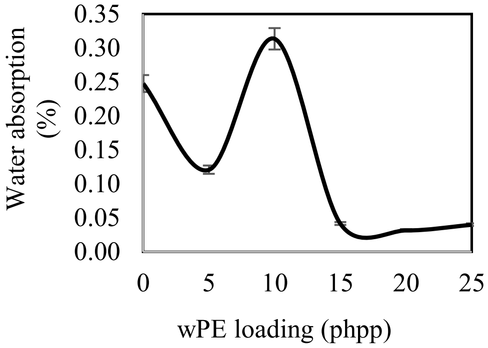

Fig. 8. Variation of water absorption of NR/LDPE/wPE composites with wPE loading

Conclusion

The composite prepared with 20 phpp loading of wPE showed remarkable physico-mechanical properties in terms of hardness, tensile strength, tear strength, and elongation at break. Therefore, 20 phpp is identified as the optimum loading for 70/30 NR/LDPE composites. In addition, the properties of composites fluctuated with the addition of different loadings of wPE due to different amounts of cured and unreacted substances present in wPE. Further, water absorption decreased with the addition of wPE. The composite with wPE loading of 20 phpp showed the lowest water absorption capacity. Hence, this composite would be suitable to produce water resistant products such as roofing sheets and flow tiles.

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Effect of nitrosamine safe diisopropyl xanthogen polysulfide accelerator on cure and static mechanical properties of natural rubber compounds

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Abstract

Sulfur vulcanization of natural rubber (NR) is mainly carried out with the use of accelerators in order to achieve desired network structure and consequently the specific material properties. Many traditional organic accelerators are made from secondary amines and are capable of nitrosation during and after vulcanization in the presence of nitrosating agents. Therefore, the use of most of the nitrosamine generating traditional accelerators in rubber formulations are restricted by stringent rules and regulations imposed by world environmental and health-related government agencies. Diisopropyl Xanthogen Polysulfide (DIXP) has been identified as a nitrosamine safe novel accelerator and literature on use of this accelerator in natural rubber compounds is limited. The aim of this study was to evaluate the influence of DIXP on cure and static mechanical properties of NR compounds. A series of NR compounds was prepared with DIXP by varying the accelerator dosage from 0.2 phr to 2.2 phr at 0.4 phr intervals. Cure and static mechanical properties of the compounds were evaluated and compared with those of the compounds prepared with the commonly used nitrosamine safe N-tert-butyl-2-benzothiazole sulfenamide (TBBS) accelerator. Results showed that most of the properties of NR compounds prepared with DIXP are inferior in comparison to those of the compounds prepared with TBBS. Nevertheless, NR compounds prepared with DIXP possessed satisfactory results in regard to optimum cure time and elongation at break.

Key words: cure characteristics, mechanical properties, nitrosamine safe accelerators, natural rubber, sulphur vulcanization

Introduction

Human exposure to nitrosamines in the rubber industry has been a matter of concern in recent years with the presence of N-nitrosamines in vulcanized rubber products (Blackley, 2012). N-nitroso compounds, which are known as genotoxic and carcinogenic (Fishbein, 2011; Vieira *et al.,* 2006; Iavicoli and Carelli, 2006) are formed by the reaction of a substance containing secondary amine groups and a nitrosating agent derived from the oxides of nitrogen (NOx) or nitrite as shown in the Fig. 1 (Goss *et al.,* 2006). Four classes of common rubber accelerators have been identified as generating secondary amine intermediates during vulcanization (Goss *et al.*, 2006). They are dithiocarbamates, sulfenamides, sulfur donors and thiurams (Goss *et al.*, 2006). Most of the accelerators used in the industry belong to the above classes and are used in amounts of up to 1% by weight of rubber. Hence, substantial amount of secondary amines are capable of nitrosation during and after the vulcanization (Stevenson, 1987).

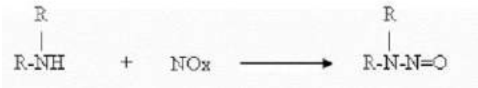

Fig. 1. Nitrosation of secondary amines

Therefore, use of such accelerators are restricted by stringent rules and regulations specially in food grade rubber products and products directly used by humans including gloves, balloons, toys, baby bottle teats, soothers and condoms. For instance, European legislation has limited the release of N-nitrosamines and N-nitrosatable compounds in teats and soothers to 0.01 and 0.1 mg/kg rubber respectively (Proksch, 2001).

Development of nitrosamine safe accelerators, which do not produce nitrosamines or which produce non-regulated nitrosamines is an alternative to reduce or eliminate the production of nitrosamines and recently research work on incorporation of such accelerators in rubber formulations has gained considerable scientific interest.

Sulfenamides are known as semi-ultra, delayed-action accelerators due to their fast cure rate and good processing safety. Three commercially available sulfenamide accelerators have been identified as accelerators which do not produce regulated nitrosamines (Goss *et al.*, 2006). They are N-cyclohexyl-2-benzothiazole sulfenamide (CBS), N-tert-butyl-2-benzothiazole sulfenamide (TBBS) and N,N'-dicyclohexyl-2-benzothiazole sulfenamide (DCBS). The other three popular sulfenamides are based on morpholine and can generate the regulated nitroso-morpholine. They are 2-morpholino dithiobenzothiazole (MBSS), N-oxydiethylene-2-benzothiazole sulfona-mide (OBTS or MBS) and N-oxy diethylene thiocarbamyl-N-oxydiethyl sulfenamide (OTOS) (Goss *et al.*, 2006).

Xanthogen accelerators contain oxygen in the accelerator backbone. Diisopropyl xanthogen polysulfide (DIXP) is a nitrogen free commercially available novel accelerator and thus it does not produce harmful N-nitrosamines during curing (Ohbi *et al.*, 2007). Further, DIXP is believed to be totally consumed during the vulcanization process without leaving any reaction byproduct (Ohbi *et al.*, 2007). Although utilization of DIXP has been reported in natural rubber (NR) latex, its use for curing of dry NR is rare. The aim of this study was to determine the effect of nitrosamine safe DIXP accelerator on cure and static mechanical properties of dry NR based efficient sulfur vulcanized (EV) compounds.

Materials and Methods

Materials

NR (crepe 1X) used in this study was obtained from the Payagala Estate crepe rubber manufacturing factory. The accelerator DIXP (Robac AS100) was supplied by Robinson Brothers Limited, Phoenix Street, West Bromwich, B70 0AH, UK. Accelerator TBBS as well as other commercial grade rubber chemicals namely 99.5% zinc oxide (ZnO), stearic acid, styrenated phenolic type antioxidant (Lovinox WSP) and sulphur were purchased from Glorchem (Pvt.) Ltd., Sri Lanka.

X= 3, 4 or 5

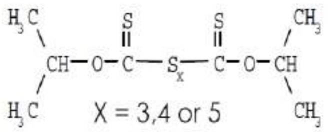

Fig. 2. Chemical structure of DIXP

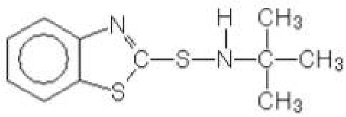

Fig. 3. Chemical structure of TBBS

Compounding and testing methods

Two series of NR compounds were prepared with DIXP (D series) and TBBS (T series- Control) by varying the accelerator loading from 0.2 phr to 2.2 phr at 0.4 phr intervals. The formulation employed for the study is shown in Table 1. The compounding of NR was done on a two-roll open mill as per ASTM D 3184. The rheographs of the mixes and their cure characteristics were obtained using Rubber Process Analyser (Model: TA Instruments - RPA *Flex*). The test specimens were prepared by molding in an electrically heated hydraulic press at 150 ^{0}C for the optimum cure time. Tensile and tear strengths were measured according to ISO 37:2010 and ISO 34-1:2010, respectively using an Instron tensile testing machine, at a cross-head speed of 500 mm/min. Hardness of the cured compounds was measured according to ASTM-D-2240 using a Shore A type Durometer.

Results and Discussion

Cure characteristics

The rheographs of the mixes cured at 150 ^{0}C using DIXP and TBBS are given in Fig. 4 and 5, respectively. Influence of DIXP accelerator on cure characteristics of NR compounds were compared with those of the control compounds prepared with TBBS (Fig. 6 and Fig. 7).

Fig. 6 shows that the cure time (t_{90}) of the compounds reduced with the increase of DIXP, while that of the compounds accelerated with TBBS is increased as the accelerator concentration is increased. This could be attributed to the ultra-fast activity of DIXP and semi-ultra-delayed-action activity of TBBS. TBBS accelerated systems provide two functions during vulcanization of rubber compounds. Initially, they retard the vulcanization that increases the scorch time and the rubber compounds can be safely processed. Secondly they react with zinc oxide to form a complex that accelerates polysulfidic crosslink formation (Coran, 2003; Ghosh *et al.*, 2003). The higher cure times observed for vulcanizates prepared with TBBS in comparison to that of vulcanizates prepared with DIXP is probably a result of the above mentioned delayed action process.

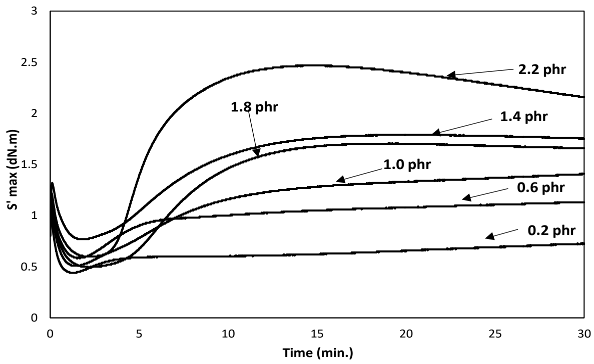

Fig. 4. Rheographs of NR compounds cured using different DIXP dosages

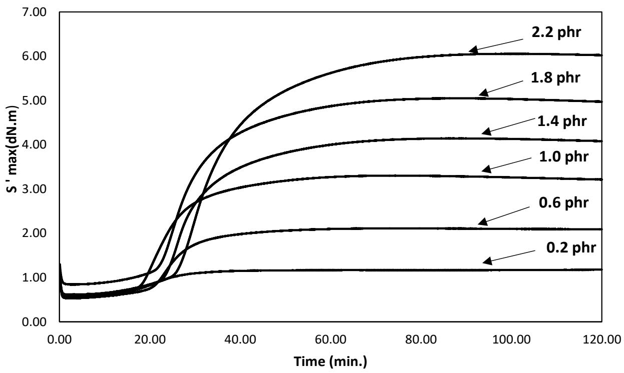

Fig. 5. Rheographs of NR compounds cured using different TBBS dosages

Table 1. *Formulations of the two series (T and D) of NR compounds*

Ingredient	**Parts per hundred parts of rubber (phr)**											
	T 0.2	T 0.6	T 1.0	T 1.4	T 1.8	T 2.2	D 0.2	D 0.6	D 1.0	D 1.4	D 1.8	D 2.2
NR	100	100	100	100	100	100	100	100	100	100	100	100
ZnO	5	5	5	5	5	5	5	5	5	5	5	5
Stearic acid	2	2	2	2	2	2	2	2	2	2	2	2
WSP	1	1	1	1	1	1	1	1	1	1	1	1
TBBS	0.2	0.6	1	1.4	1.8	2.2	-	-	-	-	-	-
DIXP	-	-	-	-	-	-	0.2	0.6	1	1.4	1.8	2.2
Sulphur	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

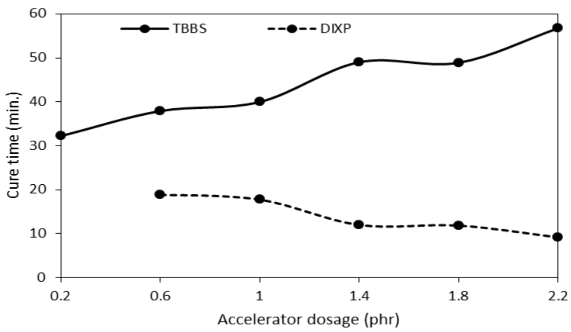

Fig. 6. Variation of cure time of DIXP and TBBS accelerated compounds

Maximum torque (S′ max) generally corresponds with stiffness and shear modulus of vulcanized rubber and indicates the state of cross linking. As the concentration of both DIXP and TBBS increases, it is seen that S′ max value also increases indicating an increase in the stiffness of the compounds (Fig. 7). Also the Fig. 7 shows that S′ max values observed for the compounds prepared with DIXP is low compared to that of the compounds prepared with TBBS. Hence, a lower state of cross linking and shear modulus is indicated for the former compounds in comparison to the latter compounds.

Delta cure [(maximum–minimum) torque] of the former compounds is also lower than that of the latter compounds (Fig. 7) and this indicates a higher crosslink density for the compounds prepared with TBBS. This would result in higher stiffness or hardness for the vulcanizates prepared with TBBS (Coran, 1978). S′ max and delta cure results of this study are not in agreement with the findings of Formela *et al.*, (2015) who conducted a study on the effect of TBBS, CBS and TMTD accelerators on cure and mechanical properties of efficiently vulcanized (EV) unfilled thermo-mechanically reclaimed ground rubber tyre (GRT).

In the work conducted by Formela *et al.*, S′ max and delta cure values of vulcanizates prepared with TBBS and CBS were lower in compared to those of the vulcanizates prepared with the commonly used ultra-fast accelerator TMTD. This is probably due to the high sulphur donor activity of TMTD, which increases the crosslink density due to release of sulphur and hence the above mentioned two cure characteristics. From the results of the present study it appears that although DIXP is a sulphur donor accelerator (“Robac AS100 - Robinson Brothers - datasheet,” 2002), its activity is lower than that of TMTD.

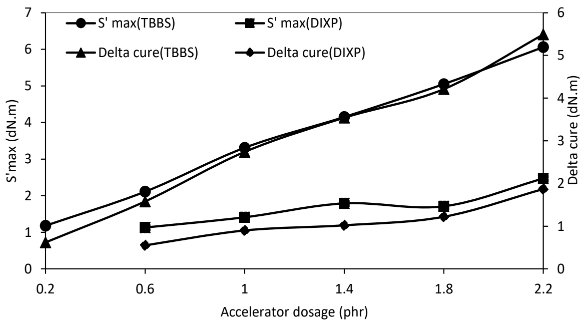

Fig. 7. Variation of S′ max and delta cure of DIXP and TBBS accelerated compounds

Static mechanical properties

The stress–strain curves of the NR vulcanizates prepared with DIXP and TBBS are shown in Fig. 8 and 9, respectively. The typical stress-strain curve of an elastomer is shown by the vulcanizate prepared with 2.2 phr of DIXP and those of the other three vulcanizates prepared with lower dosages of the accelerator show a much lower value for stress at break (Fig. 8). On the other hand, vulcanizates prepared with TBBS show a progressive increase in stress at break with the increase in the dosage of the accelerator.

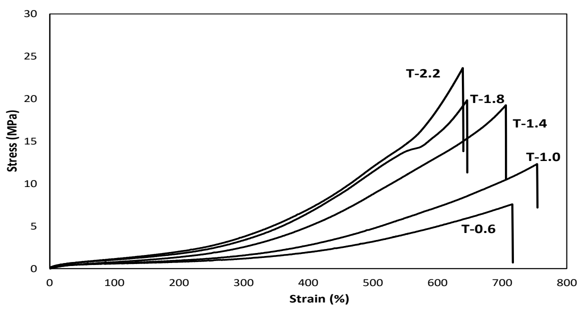

Fig. 8. Stress–strain curves of NR vulcanizates prepared with different DIXP dosages

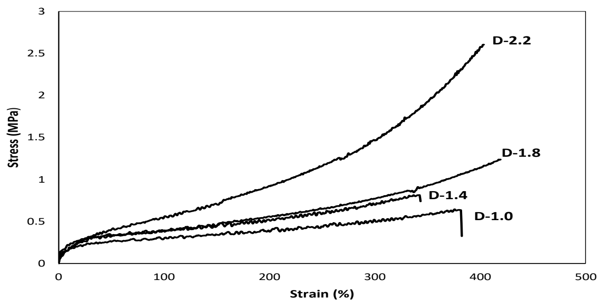

Fig. 9. Stress–strain curves of NR vulcanizates prepared with different TBBS dosages

The vulcanizate prepared with DIXP shows lower values for tensile strength (Fig. 10) and elongation at break (Fig. 11) compared to those of the vulcanizate prepared with TBBS at the same dosage. This is in agreement with the work of Formela *et al.* (2015) conducted with TBBS, CBS and TMTD accelerators. In their study, vulcanizates prepared with TMTD showed higher tensile strength, elongation at break and modulus at 100% elongation due to higher crosslink density compared to those prepared with the two sulphenamide accelerators. In the present study also, the lower values for tensile strength of the vulcanizates containing DIXP could be attributed to lower crosslink density as indicated by the delta cure values (Fig. 7). As expected, the elongation at break values of the vulcanizates prepared with DIXP is lower than that of the vulcanizates prepared with TBBS at the same dosage (Fig. 11) and is in agreement with the results of tensile strength. The increasing trend of tensile strength of vulcanizates prepared with both DIXP and TBBS with the increase of the accelerator dosage could also be attributed to the increase in crosslink density as shown in Fig. 7 by the delta cure values. Elongation at break is expected to reduce with the increase of accelerator dosage due to the increase in crosslink density, which decrease mobility of elastomer chains. However, there is no decrease in elongation at break with the increase of accelerator dosage, especially in the case of the series of vulcanizates prepared with DIXP. Elongation at break of vulcanizates prepared with DIXP has increased with the increase of accelerator dosage.

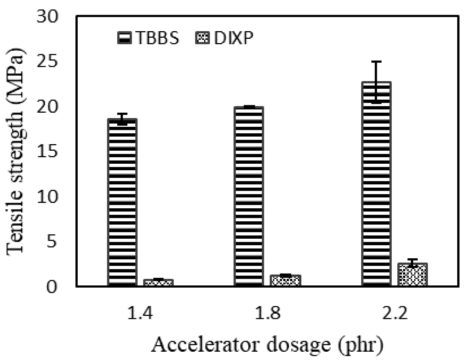

Fig. 10. Tensile strength of the vulcanizates prepared with DIXP and TBBS

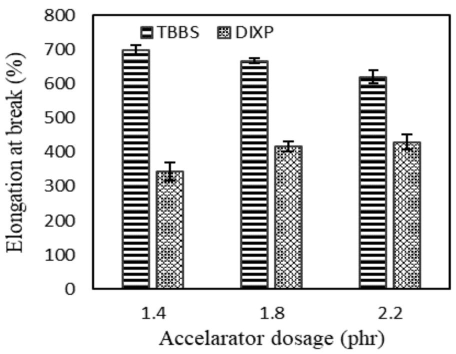

Fig. 11. Elongation at break of the vulcanizates prepared with DIXP and TBBS

Modulus at 100% and 300% elongations (M_{100} and M_{300}) increase in both the series of vulcanizates with increasing concentration of accelerators (Figs. 12 and 13) confirming the increase in crosslink density as indicated by the delta cure values (Fig. 7).

Fig. 14 shows the variation of hardness of the vulcanizates prepared with the two accelerators at different dosages. In general, hardness is a measure of stiffness of a vulcanizate and it is directly proportional to modulus at 100% elongation. Variation of hardness of the vulcanizates is in agreement with that of S′ max (Fig. 7) and modulus at 100% elongation (Fig. 12).

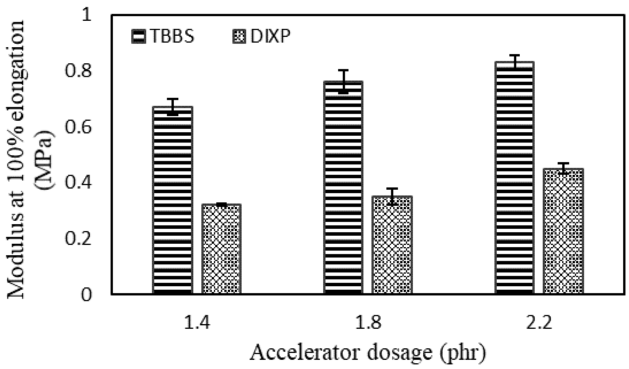

Fig. 12. M_{100} of the vulcanizates prepared with DIXP and TBBS

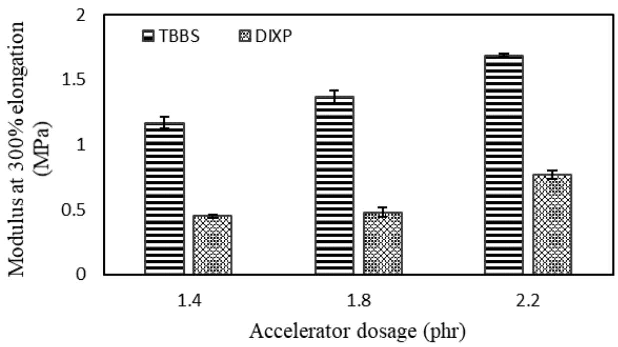

Fig. 13. M_{300} of the vulcanizates prepared with DIXP and TBBS

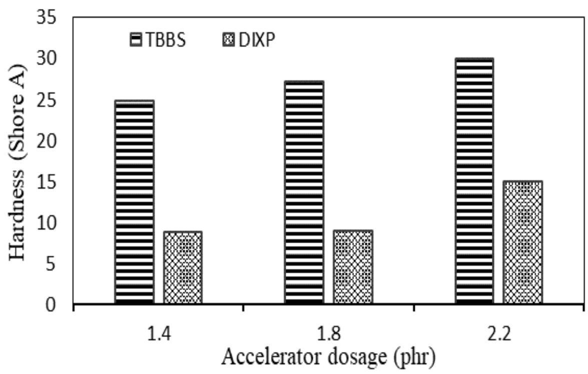

Fig. 14. Hardness of the vulcanizates prepared with DIXP and TBBS

Tear strength indicates the capacity of the vulcanizates to resist cutting, chipping and tearing actions during service. As in the case of tensile strength, vulcanizates prepared with DIXP show a lower tear strength compared to the control vulcanizates prepared with TBBS indicating a lower resistance to crack propagation for the former vulcanizates (Fig. 15). Further, tear strength increases with increasing accelerator dosage for both the series of vulcanizates. The above behavior in tear strength may also be due to crosslink density variations as mentioned earlier for the other mechanical properties.

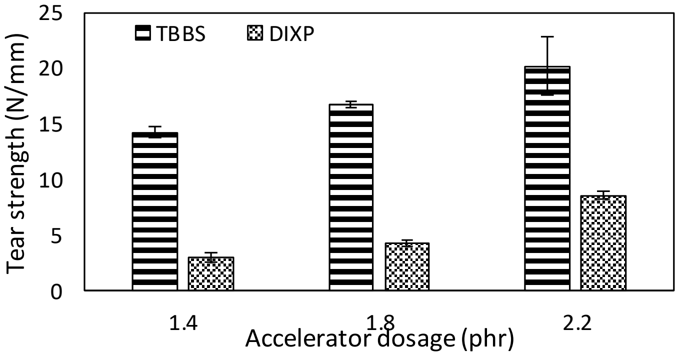

Fig. 15. Tear strength of the vulcanizates prepared with DIXP and TBBS

Conclusion

Although DIXP is known as a nitrosamine safe accelerator, most of the cure and static mechanical properties of NR compounds prepared with this accelerator are inferior to those of the compounds prepared with the commonly used nitrosamine safe accelerator TBBS. Nevertheless, NR compounds prepared with DIXP possess satisfactory results in regard to optimum cure time and elongation at break. In overall, results reveal that DIXP alone cannot be used in efficient vulcanization of NR compounds.

Acknowledgements

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Effectiveness of a locally developed ethephon formulation on yield and related latex physiological factors of *Hevea brasiliensis*

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Abstract

Ethephon is an essential agrochemical in low intensity harvesting of rubber (Hevea brasiliensis). Currently the total requirement for rubber industry is being imported in ready-mixed form adding a considerable cost to the plantations. Therefore, a new ethephon formulation was developed locally and the present study aimed to assess its effectiveness under Sri Lankan condition.

The newly developed ethephon formulation was tested against a commercially available formulation with a small-scale field trial. No significant variation was observed in sucrose availability in laticifers with the new ethephon formulation. Significantly higher thiol and lower inorganic phosphorous contents of latex in trees may ensure long-term sustainability of the new ethephon formulation as a yield stimulant in rubber. Average dry rubber content of latex and latex volume obtained from a tree was comparable with both formulations. Accordingly, dry rubber yield resulted from trees applied with new ethephon formulation was comparable with the existing formulation and average values were 83.22 g and 86.67 g, respectively for new and existing formulations.

***Key words*:** 2-choloroethylphosphonic acid, ethephon, exploitation, *Hevea*, low intensity harvesting, rubber, stimulation

Introduction

Stimulation based low intensity harvesting (LIH) systems designed with various combinations of cut lengths, frequency of tapping and stimulation techniques are accepted by the growers as modern exploitation techniques to overcome constrains such as high cost of production (COP), lack of skilled harvesters and high bark consumption rates in rubber plantations. Suitable stimulation protocol is used with LIH systems to overcome low yields due to lowering the harvesting intensity thus to achieve comparable yields to that of conventional tapping *i.e.* S/2 d2 system (Gao *et al*., 2018). A wide spectrum of chemical compounds including ethylene generating compounds, auxins, auxin analogues, herbicides and inorganic salts had been tried as yield stimulants from the beginning of rubber plantation industry. Few of them were ethylene generators while others appeared to be more or less phytotoxic which may induce endogenous ethylene production. Ethephon (2-chloroethylphosphonic acid) was found superior to all other chemicals and even today ethephon is the only stimulant used in commercial application. Hence, nowadays ethephon has become an essential agrochemical used in harvesting of rubber. Ethephon stimulation based LIH systems enhance the sustainability of rubber farming with a better income to the harvester and lower cost of production (COP) to the management.

Ethephon is a plant growth regulator with systemic properties, penetrates into the plant tissues, translocate and in the presence of water. It progressively decomposed to ethylene (Tseng *et al.*, 2000), which is a kind of plant hormone that affects the biochemical and physiological status of the tree resulting in high yields.

It is a whitish solid readily soluble in aqueous solutions and stable below pH 3.5 (Anon., 1987) and could not be applied on trees as it is. So it is usually mixed with an inert material *i.e.* methyl cellulose, starch, palm oil or a mixture of such materials to make it more viscous enabling easy application on bark of tree whilst increasing the slow release properties.

Stimulation effect of ethephon depends on the length of cut and frequency of tapping or combination of them (Njukeng *et al.*, 2011). A large number of low intensity systems have been used with different levels of ethephon in many rubber growing countries (Karunai-chamy *et al.*, 2001; Kewi & Sivakumaran, 1994; Rodrigo *et al*., 2011; Xuehua *et al.*, 2004). Judicious application of ethephon with correct harvesting systems may only give long term sustainable yields.

In Sri Lanka ethephon based low intensity harvesting systems *i.e*. S/2 d3 (Nugawela *et al*., 2000), S/2 d4 (Rodrigo *et al*., 2011) and S/4 d3 (Rodrigo *et al*., 2012) have been recommended and currently adopted in plantations in an increasing trend. Total requirement of the ethephon to Sri Lankan rubber plantation industry is presently imported and marketed at a price of about LKR 1000 per kg. Some Regional Plantation Companies import 3 to 6 MT of ethephon annually (personal communication) and CIF value of such amount is about 1-2 Mn LKR (1USD = 180 LKR). In view of minimizing the cost involved, a formulation of ethephon was developed locally and the present study aimed to assess its suitability under field conditions in Sri Lankan rubber plantations.

Materials and Method

A new formulation with 2.5% ethephon has been developed by Rubber Research Institute of Sri Lanka by using concentrated ethephon available in the market. Mixture of carbohydrate derivatives (methyl cellulose, starch and xanthan gum) were used to increase the viscosity of mixture thus improve the slow release properties of the new formulation. Organic acids were used to reduce the pH to prevent decomposing of ethephon. By using motorized blender all the ingredients were thoroughly mixed to give about 1200 cP viscosity and final ethephon concentration of the mixture was set to 2.5% ± 0.1%.

Rainguarded monoclonal mature rubber field replanted in 2011 with RRIC 121 in Gallewatta Division of Dartonfield Estate was selected for testing the efficacy of new ethephon formulation developed by the Rubber Research Institute of Sri Lanka. Ethephon-Plus currently available water-based commercial ethephon mixture in the local market was used for comparison as the control. Both treatments were tested using a randomized complete block design (RCBD) with three replicates comprising 10 trees in each plot. Efficacy was tested using recommended protocol for S/2 d4 system in Sri Lanka with application of 2.5% ethephon, monthly. The amount applied per tree per application was 1.6 g (Rodrigo *et al.*, 2011).

Analyses of latex samples were done in each tapping day. Latex was collected into vessels immersed in ice between 5th and the 35th minutes after tapping and immediately taken to the laboratory for analysis. Extractions were prepared by coagulating the latex samples with 2.5% tricloroacetic acid (TCA). Standard test methods were used for analysis of sucrose (Scott and Melvin, 1953), inorganic phosphorous (Taussky and Shorr, 1953) and thiol (Boyne and Ellman, 1972). Standard laboratory method (Anon., 1984) was used to analyse dry rubber content of latex. Plugging index was determined by measuring the initial flow rate and total volume of latex obtained as described by Milford *et al.* (1969). Applied area of the bark has been frequently observed for any fungal or bacterial growth.

Performance of the new formulation was statistically compared with the existing formulation by performing a paired t-test for each variable tested using Genstat 16th edition.

Results and Discussion

Generally, the stimulants are known to enhance yield by increasing latex regeneration, flow rate and duration of latex flow (Lacrotte *et al*., 1985). Physiological parameters of latex are associated with either latex regeneration or latex flow or both effects. Ultimately the productivity of the tree is a combined effect of all these factors. In plants, the sucrose produced by photosynthesis is finally the basic molecule in all synthesis. In *Hevea,* sucrose is metabolized into polyisoprene in the latisifers cells (Bealing, 1976; Tseng *et al.,* 2000). Sugar content in laticifers positively correlates with isoprene production (Lacrotte *et al*., 1985; Mesquita *et al*., 2006).

Average sucrose content of latex of trees applied with new and existing formulations were 3.47 mM and 3.97 mM, respectively and statistically comparable. In both formulations, latex sucrose content increased immediately after ethephon application and tended to decrease with time (Fig. 1a). The massive outflow of latex induced by stimulation leads necessarily to an increase in the anabolic activities in the cells and specially biosynthesis of rubber and proteins involved in this renewal (Mesquita *et al*., 2006). Tupy (1973) explained that rise in latex pH after stimulation results in an increase in invertase activity which, intensify sucrose mobilization and transported towards vessels where regeneration of latex and metabolism activated. Increase of the activity of invertase; the key enzyme of glycolysis leads to increased production of pyruvate and ATP. Availability of these molecules enhances mevalonate production and ultimately the rubber biosynthesis (d'Auzac, 1989). Latex thiols consist of cysteine, methionine and glutathionine which are able to neutralize various forms of reactive oxygen species that harms membranes of latex organelles thus promoting colloidal stability and flow of latex hence, directly correlate with production (De Costa *et al.*, 2006; Jacob *et al*., 1986). Variation of latex thiol content with application of new formulation showed an increase with time (Fig. 1b) and average of trees applied with new formulation was 230% higher than that with existing formulation. This ability of the new formulation is highly favorable to remove reactive oxygen species evolved during rubber production and may lower the incidence of tapping panel dryness.

Latex inorganic phosphorous may reflect its energy metabolism and significantly correlates with latex production in trees (Eschbach *et al.*, 1984). Ethephon stimulation activates the laticifer metabolism and also increases the inorganic phosphorous content (d'Auzac and Pujarniscle, 1959). Both formulations showed a similar pattern of variation in latex inorganic phosphorous content. However, in trees applied with the new ethephon formulation, latex inorganic phosphorous content was significantly lower than that with the existing ethephon formulation (Fig. 1c). This reveals that energy needed for latex regeneration is comparatively lower in trees applied with new ethephon formulation.

Ethylene is thought to enhance yield by delaying plugging of latex vessels (Emuedo *et al.*, 2017; Gao *et al*., 2018) and enhancing both initial flow rate (de Jonge, 1955) and duration of flow (Coupe, *et al*., 1976 &1977; Coupe & d'Auzac, 1974). Researchers commonly accept that the increase of yield is mainly due to the extension in drainage area (Pakianathan *et al*., 1976; Ribaillier & d'Auzac, 1970).

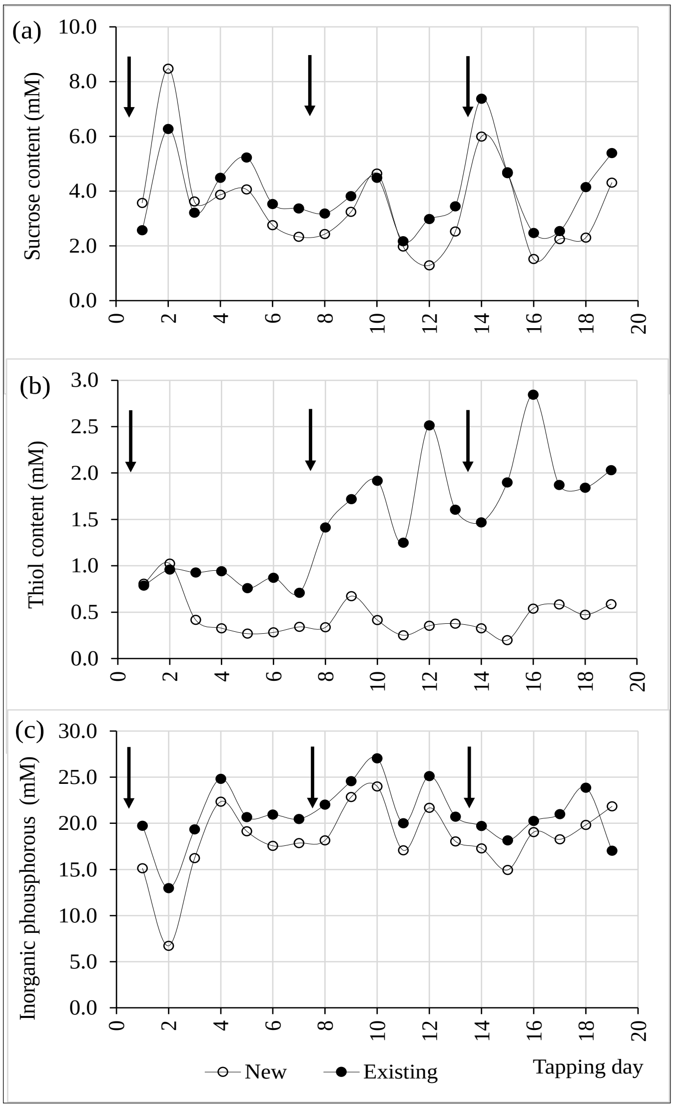

Fig. 1. Variation of latex **(a).** sucrose, (**b).** thiol and **(c).** inorganic phosphorous contents of trees stimulated with two ethephon formulations (Time of ethephon application is indicated by arrows)

Duration of latex flow with existing ethephon formulation was significantly lower than that with new formulation. However, the average difference is 19 min. (Fig. 2a). Immediately after stimulation, average latex flow duration extended to 3.8 hrs and 3.7 hrs with new and existing formulations, respectively.

At the end of first month, the flow duration decreased up to 2.4 hrs and 2.0 hrs, respectively (Fig. 2a). Average initial flow rate of trees applied with new ethephon showed statistically significant decrease over existing formulation (Fig. 2b). Respective average values of new and existing formulations were 4.32 ml/min. and 4.74 ml/min. (Fig. 2a). Plugging index of trees showed a significant difference among two ethephon formulations with averages of 1.96 and 2.36 with new and existing formulations, respectively (Fig. 2c).

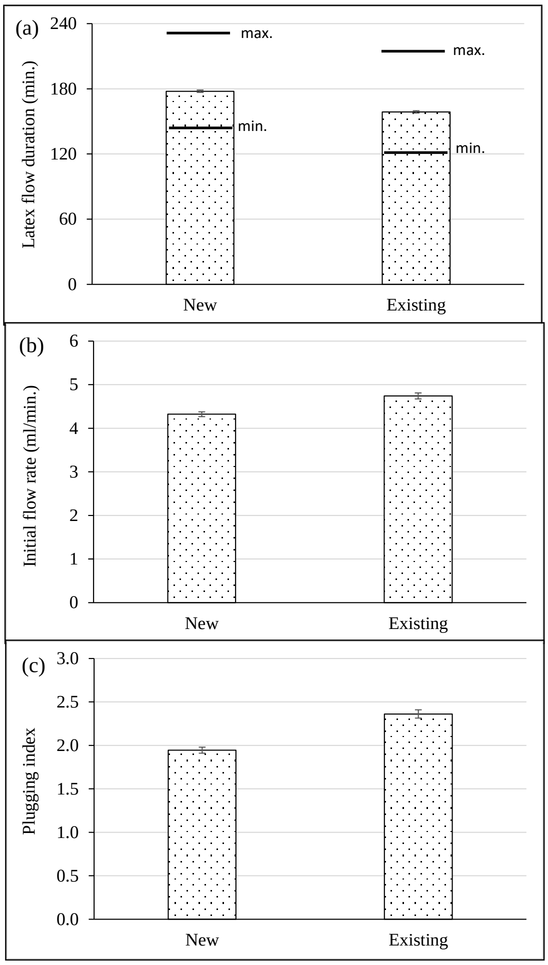

Fig. 2. Average **(a).** latex flow duration, **(b).** initial flow rate and **(c).** plugging index of trees stimulated with two ethephon formulations

Pattern of variation of latex volume of trees applied with new ethephon formulation was more or less similar to the existing formulation. With both formulations latex volume showed a significant increase after ethephon application and gradually decreased with time. Average daily volume of latex per tree with application of new and existing formulations was 208 ml and 222 ml, respectively and statistically comparable (Fig. 3a). Immediately after stimulation, observed maximum latex volumes with new and existing formulation were 380 ml and 433 ml, respectively whilst minimum values *i.e*. 112 ml and 120 ml observed towards the next application (Fig. 3a). Irrespective of the formulation, average daily volume of a tree increased by 155%, immediately after ethephon application.

With application of ethephon, dry rubber content (DRC) tended to decrease immediately and then increased towards the next application. The DRC of latex varied in a similar pattern with both ethephon formulations and significant variation has not been observed among two formulations (Fig. 3b). However, throughout the period, DRC did not fall below 35% at any instance with both formulations (Fig. 3b).

Dry rubber yield obtained from a tree with both ethephon formulations was statistically comparable. Average daily dry rubber yield of a tree was 83.22 g and 86.67 g, respectively with new and existing formulations (Fig. 3c). After stimulation, dry rubber yield with existing formulation increased to a value around 162 g/tree and yield with new formulation was 149 g/tree. At the end of first month towards next ethephon round, dry rubber yield decreased to 48 g/tree with both formulations.

During the period of investigations any fungal or bacterial growths have not been observed in ethephon applied area of the bark confirms that there is no effect on bark of tree.

Results revealed that new ethephon formulation is capable in resulting comparable yields to the existing formulation. Latex DRC and volume of latex did not show any significant variation among the two formulations. Significantly lower inorganic phosphorous content with new formulation indicates lower energy requirement in metabolic process of biosynthesis. So far, a stimulant capable in increasing similar higher amount of latex thiol has not been reported. Increased thiol content together with low inorganic phosphorous content of latex in trees applied with the new ethephon formulation may ensure long term sustainability of health of rubber tree. With the new formulation, initial flow rate increased significantly and comparatively higher plugging index in existing ethephon formulation applied trees lower the latex flow time than in the trees applied with the new formulation. Although, the duration of flow has extended with the new formulation, it would not affect significantly on time taken for commercial latex harvesting as the difference is less than 20 minutes. According to the average daily yield per tree observed, yield that could be obtained from a tree (@ 80 tapping days/yr under S/2 d4 system) with new and existing formulations accounted for

6.76 kg and 7.00 kg and corresponds to productivity values of 2,702 kg/ha/yr and 2,799 kg/ha/yr (@ tapping stand of 400 trees/ha), respectively. Annually about 30MT of 2.5% formulated ethephon is imported for rubber plantations in Sri Lanka. If we could produce this quantity locally by importing active ingredient in 40% concentration, the quantity to be imported will reduce by sixteen times. Further investigations are needed to assess long- term sustainability of the new ethephon formulation with advanced features developed by the Rubber Research Institute.

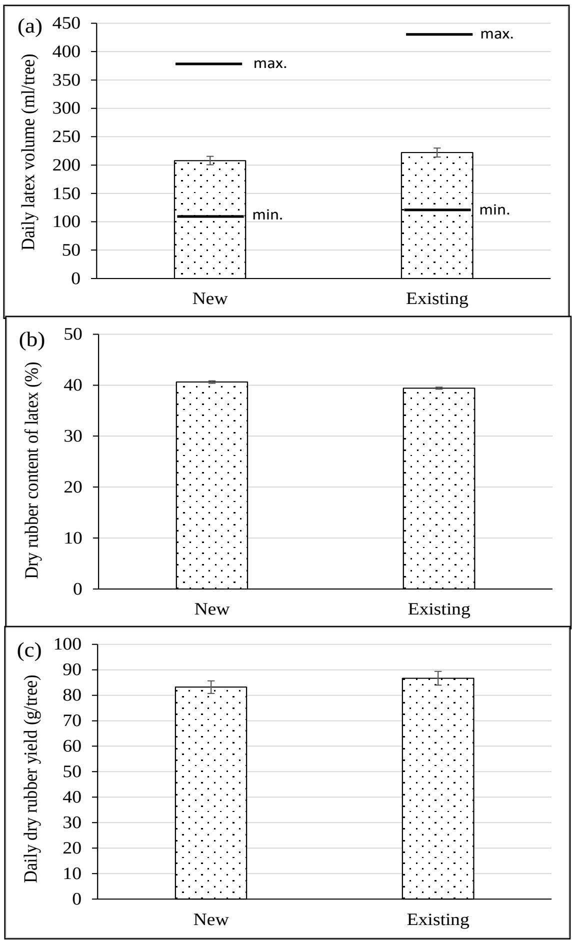

Fig. 3. Average **(a).** latex volume, **(b).** latex dry rubber content and **(c).** daily dry rubber yield of trees stimulated with two ethephon formulations

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Assessment and selection based on girth and yield performance of new *Hevea g*enotypes generated from controlled hybridization

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Abstract

The objective of this study was to evaluate the girth and yield performance of new Hevea genotypes obtained from the 1998 hand pollination (HP) program. Sixty-five new genotypes were assessed along with the control clones viz. RRIC 121, RRIC 130 and RRISL 205. Dry rubber yield for six years, annual girth at the 14th year and girth increment, percentage of tappable trees, survival trees and tapping panel dryness affected trees and latex properties of selected genotypes were evaluated. Considering the results, 63% of the genotypes were recorded as significantly higher or similar average yield compared to control clones. The genotypes, 98-80 and 98-219 were the top-rankers with average yields of 53.7 g and 52.0 g per tree per tapping, respectively. Moreover, the progeny generated from 1998 hand pollination consisted of good yielders similar to the yield of the clone RRIC 121 and could be considered as potential candidates for future clonal selection programmes to develop elite clones. Eighty-two percent of the genotypes showed significantly higher or similar mean girth compared to controls. Genotypes, 98-276 and 98-68 were ranked at number one and two, which have obtained respective girth values of 80.6 cm and 76.5 cm. Eighteen percent of genotypes recorded more than 70 cm of mean girth, which was an indicator of the development of vigorous timber clones in the future. Moreover, these genotypes possess high yield potential. Almost all the genotypes had significantly high girth increment during the immature phase than the post tapping phase. Genotypes 98-80 and 98-219 had performed well based on the dry rubber content (DRC), sucrose and inorganic phosphorus values. In conclusion, the 1998 HP programmes has generated a valuable pool of genotypes that have paved the path to producing outstanding Hevea clones.

Key words: controlled hybridization, genotypes, girth, *Hevea brasiliensis*, tapping panel dryness, yield

Introduction

Almost all the popular clones available in major rubber growing countries are entirely developed through conventional breeding procedures (Reju *et al.*, 2016) and the hybridization is a major conventional breeding procedure in rubber breeding other than introduction and selection (Goncalves *et al.*, 2007 & 2011). The breeding procedure is mainly focused on developing high yielding clones. Yet, other characteristics such as vigour and disease resistance are also considered. Breeding trials related to natural rubber research in Sri Lanka is done mainly in three stages. In the first stage, a progeny obtained from the hand pollination is planted in the nursery and subjected to preliminary evaluation. The best genotypes selected from the preliminary evaluation are then established in small-scale clonal trials (SSCTs) as the second stage. For SSCTs bud grafted genotypes are used with 15-20 replicates from each genotype along with recommended clones as controls. It takes approximately 10-12 years to select the best performing genotypes from SSCTs and the selected genotypes are incorporated to Estate/RRI colaborative trials (ECTs) at the third stage. It takes another 10-12 years to select outstanding genotypes from the ECTs and to include in the Group III of RRISL clone recommendation. It will take another 20-25 years to upgrade new clones into Group II and Group I respectively, from Group III. However, this procedure takes many more years to reach a clone up to Group I. Thus, currently only five clones represent group I and these clones occupy a large share in the rubber sector in Sri Lanka. Department of Genetics and Plant Breeding of RRISL involve in the annual hand pollination procedure to improve genotypes through hybridization to increase the number of clones along with the interim clone recommendation procedure to solve this problem. Under interim clone recommendation, Group II and III clones are also evaluated in smallholder level in addition to estate level, before up graded into Group I (Attanayake, 2001 and Withanage *et al.*, 2014).

During the breeding procedure, both girth and yield parameters are widely used as attributes of growth and good harvesters. Girth is the key factor taken into consideration for evaluating growth and attainment of crop maturity for harvesting (Chandrasekhar *et al.*, 2005). Average yield is an important factor for *Hevea* clonal selection (Reju *et al.*, 2016). Therefore, at the final stage of selection, average yield per tree per tapping is considered as the main selection criterion.

This article focuses on assessing genotypes obtained from 1998 hand pollination programme based on average girth, girth increment, average yield and latex physiological properties evaluated in small-scale clone trials in selecting best performing genotypes for developing new clones for future.

Materials and Methods

Location

The experiment was carried out at the Department of Genetics and Plant Breeding at Kuruwita sub-station, Rubber Research Institute, Sri Lanka. Kuruwita is located in Ratnapura district experiencing a tropical climate which is favorable for rubber cultivation.

Small-scale clone trial of 98HP progeny

Two hundred and eighty four seedlings were generated from 1998 hand pollination (HP) programme by using clones PB 260 and RRIC 130 as parents. Better performing seedlings were selected after evaluating their juvenile yield (micro tapping), girth, bark thickness and other secondary attributes such as disease resistance at the three years old mother plant nursery. From these, 65 genotypes were selected and cloned through bud grafting and the plants were established in a small-scale clone trial along with RRIC 121, RRIC 130 and RRISL 205 as controls at the RRISL sub-station in Kuruwita in 2001. The small-scale clone trial was conducted as three separate trials with 22 genotypes and three control clones (25 treatments) per trial. Each trial was laid according to a completely randomized design with 16 trees per genotype/clone (per treatment). Tappability of the genotypes was determined when more than 65% of trees under each trial have reached a girth of 50 cm and beyond. The trees were opened for tapping at the age of eight years. The tapping system followed was ½ SD2.

Measurement of girth, yield and other growth parameters

Dry rubber yield per tree per tapping in grams (g/t/t) over six years and girth of the trees, 14 years after planting were recorded. Data on average annual yield in consequent six years were recorded after opening the panel for tapping by the cup coagulation method, in two normal tapping days per month. During the cup coagulation method 2% acetic acid solution was added to the latex of individual trees in the collecting cup and stirred. Thereafter, coagulated rubber was pressed and dried until a constant weight to record the test tapped yield. Annual girths of the trees were recorded at the height of 120 cm above the bud union; which was started during the second year of planting and were used to determine the girth increment. Incidences of diseases were also assessed by visual observations during the experimental period. The data on percentage of survival at the opening of tapping and the percentage of Tapping Panel Dryness (TPD) at sixth year of tapping was calculated. The data on yield and girth were statistically analyzed using Analysis of Variance (ANOVA) followed by mean separation by Duncan's Multiple Range Tests using SAS ver. 9.2.

Measurement of latex physiological properties

The selected best performing genotypes and the control clone, RRIC 121 were subjected to testing of latex physiological properties. Randomly selected latex samples (five replicates from each genotype) were collected to the vessels, immersed in ice, avoiding latex dripped for the initial five minutes after tapping and then serum was extracted by coagulating 2.5 g of latex in 25 ml of 2.5% trichloro acetic acid (TCA) and used to quantify sucrose content (Scott and Melvin, 1953), inorganic phosphorus content (Taussky and Shorr, 1953), thiol content (Boyne and Ellman, 1972) and polyphenol content (Turkmen *et al.*, 2006). By using standard ISO method (Anon., 1984), dry rubber content of latex of each sample was analyzed.

Results and Discussion

Yield performances

The values of average dry rubber yield of all the tested genotypes from three trials including control clones are given in Table 1, ranking in descending order. In the early years of tapping, yield per tree (g/t/t) is a good indication of the yield potential than the yield per hectare, due to wide variations in tappability or tappable stand per hectare among clones at opening (Gonçalves *et al.*, 2007). Mean dry rubber yield varied among genotypes and controls. Average tree yield per tapping for six years showed that yield level among genotypes varied between 52.0 g and 23.46 g in trial 1, 53.7 g and 23.9 g in trial 2 and 45.1 g (RRIC 121) and 18.8 g in trial 3. Genotypes, 98-219 and 98-80 showed the highest mean dry rubber yields, which were greater than the control clone, RRIC 121. There were 33 genotypes above the yield of RRIC 130 and 38 genotypes above the yield of clone RRISL 205. Collectively, there were 40 new genotypes (62.5%) which were superior to the control clones in this aspect. Genotype, 98-219 of the trial 1 and genotype 98-80 of the trial 2 were the top-ranking genotypes which have given the highest mean yield of 52 g/t/t and 53.7 g/t/t (Table 1).

Table 1. *Sixth year average yield (g/t/t) of 1998 HP genotypes along with control clones from Trial 1, Trial 2 and Trial 3*

Trial 1			Trial 2			Trial 3		
Clone	**Average yield**	**Rank**	**Clone**	**Average yield**	**Rank**	**Clone**	**Average yield**	**Rank**
98-219	52.04^{a}	1	98-80	53.66^{a}	1	RC121*	45.14^{a}	1
RC121*	51.58^{ab}	2	RC121*	43.66^{ab}	2	98-223	44.90^{a}	2
98-105	48.48^{abc}	3	98-68	43.11^{abc}	3	98-278	39.29^{ab}	3
98-124	47.26^{abc}	4	98-73	41.96^{abcd}	4	98-220	37.11^{abc}	4
98-143	46.46^{abcd}	5	98-58	37.77^{bcde}	5	98-154	35.28^{bc}	5
98-236	45.88^{abcde}	6	98-44	37.26^{bcde}	6	98-200	34.47^{bcd}	6
98-98	44.84^{abcde}	7	98-67	35.83^{bcde}	7	98-30	33.23^{bcde}	7
98-207	40.51^{abcdef}	8	98-74	34.32^{bcde}	8	98-19	33.01^{bcde}	8
98-276	40.29^{abcdef}	9	98-70	33.72^{bcde}	9	RC130*	32.49^{bcde}	9
98-11	40.18^{abcdef}	10	98-51	31.63^{bcde}	10	98-196	32.04^{bcdef}	10
98-89	39.93^{abcdef}	11	98-54	30.88^{bcde}	11	98-222	30.77^{bcdef}	11
98-230	37.83^{abcdefg}	12	RL205*	30.74^{bcde}	12	98-23	30.66^{bcdef}	12
98-237	37.72^{bcdefg}	13	98-62	29.84^{bcde}	13	98-257	29.86^{bcdef}	13
98-135	37.57^{bcdefg}	14	98-37	28.45^{cde}	14	RL205*	29.3^{bcdef}	14
98-84	36.22^{cdefg}	15	RC130*	28.25^{cde}	15	98-18	29.15^{bcdef}	15
RC130*	34.86^{cdefg}	16	98-77	27.20^{cde}	16	98-193	27.53^{cdefg}	16

Trial 1			Trial 2			Trial 3		
Clone	**Average yield**	**Rank**	**Clone**	**Average yield**	**Rank**	**Clone**	**Average yield**	**Rank**
98-153	32.70^{defg}	17	98-71	26.32^{de}	17	98-15	24.41^{defg}	17
98-164	32.11^{defg}	18	98-41	25.56^{de}	18	98-149	23.57^{efg}	18
98-201	31.92^{efg}	19	98-07	25.48^{de}	19	98-224	23.34^{efg}	19
RL205*	29.13^{fg}	20	98-50	24.53^{e}	20	98-26	22.03^{fg}	20
98-120	29.05^{fg}	21	98-59	24.48^{e}	21	98-12	21.94^{fg}	21
98-83	28.75^{fg}	22	98-55	24.46^{e}	22	98-38	18.88^{g}	22
98-25	24.76^{g}	23	98-64	24.23^{e}	23	98-194	18.79^{g}	23
98-81	24.54^{g}	24	98-56	24.06^{e}	24			
98-205	23.44^{g}	25	98-78	23.90^{e}	25			
Mean	37.65		Mean	31.98		Mean	30.07	
Root MSE	9.92		Root MSE	12.48		Root MSE	8.81	
CV	26.36		CV	39.04		CV	29.32	

*Control clones: RRIC 121, RRISL 205, RRIC 130
Means followed by the same letter within a column are not significantly different one another at $p < 0.05$

There were 13 genotypes along with RRIC 121 in all 3 trials, that have shown an average yield higher than 40 g/t/t, which was nearly 20% from the total number of genotypes. RRIC 121 is one of the best performing clones in the country. In this study, it was always ranked at the top level among genotypes in all 3 trials. Thus, 1998 HP progeny consisted of good yielders comparable with RRIC 121, which include potential candidates for the future clonal selection programmes to release high yielding clones for the industry.

Girth performances

Average girth at the 14th year and average girth increment of immature and post tapping phases were ranked among the tested genotypes from three trials including control clones (Table 2 and Table 3). Average girth at the 14th year after planting in trial 1, 2 and 3 ranged from 51.1 - 80.6 cm, 41.3 - 76.5 cm and 55.4 - 71 cm, respectively. Genotypes 98-276 (80.6 cm), 98-68 (76.5 cm) and 98-223 (71 cm) have recorded the highest girth at the final year of evaluation, while these genotypes have represented a mean yield around 40 g/t/t.

Table 2. *Average girth of genotypes and control clones at the 14th year after planting*

Trial 1		Trial 2		Trial 3	
Clone	**Average girth (cm)**	**Clone**	**Average girth (cm)**	**Clone**	**Average girth (cm)**
98-276	80.61^{a}	98-68	76.50^{a}	98-223	71.00^{a}
98-230	72.60^{ab}	98-50	73.11^{ab}	98-200	66.71^{ab}
98-98	72.42^{ab}	98-80	72.93^{ab}	98-26	66.00^{ab}
98-219	71.61^{bc}	98-51	72.19^{abc}	98-18	63.61^{ab}
98-89	70.06^{bcd}	RL205*	68.67^{bcd}	98-38	63.35^{ab}
98-84	69.23^{bcde}	98-73	67.25^{bcde}	98-149	63.19^{ab}
RC121*	68.84^{bcde}	98-58	67.03^{bcde}	98-193	62.65^{ab}
98-11	68.47^{bcdef}	98-54	66.50^{bcdef}	98-15	62.17^{ab}
RL205*	68.30^{bcdef}	RC121*	66.40^{bcdef}	98-30	62.08^{ab}
98-207	66.86^{bcdefg}	98-71	64.73^{cdefg}	98-278	61.83^{ab}
98-83	66.38^{bcdefg}	98-64	62.37^{defgh}	98-154	61.67^{ab}
98-236	66.10^{bcdefg}	98-44	61.57^{defghi}	98-220	61.04^{ab}
98-143	63.57^{bcdefgh}	98-41	61.23^{defghi}	98-29	61.04^{ab}
98-124	63.06^{bcdefgh}	98-62	60.29^{efghi}	98-194	60.92^{ab}
98-153	62.22^{cdefghi}	98-07	59.11^{fghij}	98-23	60.68^{ab}
98-164	62.03^{cdefghij}	98-77	58.77^{fghij}	RL205*	60.60^{ab}
98-105	60.62^{defghij}	RC130*	58.29^{ghij}	RC130*	60.46^{ab}
98-135	59.73^{efghijk}	98-67	57.81^{ghij}	98-224	59.37^{ab}
RC130*	59.00^{fghijk}	98-56	57.73^{ghij}	RC121*	59.05^{ab}
98-25	58.53^{ghijk}	98-70	56.92^{ghij}	98-257	58.87^{ab}
98-201	56.18^{hijk}	98-37	55.10^{hijk}	98-12	58.64^{ab}
98-237	55.00^{hijk}	98-59	53.75^{ijk}	98-19	58.57^{ab}
98-120	53.00^{ijk}	98-74	52.25^{jk}	98-196	56.92^{b}
98-205	52.67^{jk}	98-55	48.17^{k}	98-222	55.44^{b}
98-81	51.08^{k}	98-78	41.28^{l}		
Mean	64.06	Mean	61.57	Mean	61.61
Root	10.90	Root MSE	9.04	Root MSE	13.72
CV	17.02	CV	14.68	CV	22.28

*Control clones: RRIC 121, RRISL 205 and RRIC 130
Means followed by the same letter within a column are not significantly different one another at $p < 0.05$

Table 3. *Average girth increment of genotypes before and after opening for tapping along with the control clones in Trial 1, Trial 2 and Trial 3*

Trial 1 – Girth increment			**Trial 2 – Girth increment**			**Trial 3 – Girth increment**		
Clone	**Before tapping opening**	**After tapping opening**	**Clone**	**Before tapping opening**	**After tapping opening**	**Clone**	**Before tapping opening**	**After tapping opening**
98-276	7.42(1)	1.96 (1)	98-68	7.11 (1)	1.57(4)	98-223	6.25 (2)	2.15(1)
98-230	7 (2)	1.06(15)	98-50	6.53 (6)	2.04 (1)	98-200	6.28 (1)	1.17(11)
98-98	6.93 (3)	1.41 (7)	98-80	7.04 (2)	1.37(7)	98-26	5.89 (6)	1.68 (2)
98-219	6.39 (8)	1.70 (3)	98-51	6.65 (4)	1.65 (3)	98-18	5.97 (4)	0.98(19)
98-89	6.26(10)	1.84 (2)	RL205*	6.83 (3)	1.10(10)	98-38	5.74 (11)	1.40 (3)
98-84	6.73 (5)	0.98(17)	98-73	6.15 (8)	1.42 (6)	98-149	5.77 (9)	1.35(4)
RC121*	6.68 (6)	1.46 (6)	98-58	6.58 (5)	0.90(14)	98-193	6.02 (3)	0.9(21)
98-11	6.49 (7)	1.24(9)	98-54	5.67 (16)	1.91(2)	98-15	5.90 (5)	1.03(17)
RL205*	6.92 (4)	0.91(20)	RC121*	6.52 (7)	1.09(11)	98-30	5.69 (14)	1.19(9)
98-207	6.33 (9)	1.15(13)	98-71	5.88 (12)	1.53(5)	98-278	5.85 (7)	0.88(22)
98-83	5.78(16)	1.65 (4)	98-64	5.73 (14)	1.22 (8)	98-154	5.72 (13)	1.21(7)
98-236	5.96(12)	1.56 (5)	98-44	6.05 (9)	0.82(17)	98-220	5.68 (15)	1.15(12)

Trial 1 – Girth increment			Trial 2 – Girth increment			Trial 3 – Girth increment		
Clone	**Before tapping opening**	**After tapping opening**	**Clone**	**Before tapping opening**	**After tapping opening**	**Clone**	**Before tapping opening**	**After tapping opening**
98-143	6.11 (11)	0.97(18)	98-41	6.04 (10)	0.63(21)	98-29	5.64 (16)	1.08(15)
98-124	5.92(13)	1.17(12)	98-62	5.8 (13)	0.78(20)	98-194	5.73 (12)	0.99(18)
98-153	5.85(15)	1.1(14)	98-07	5.96 (11)	0.47(23)	98-23	5.55 (18)	1.25(6)
98-164	5.92(14)	0.82(22)	98-77	5.7 (15)	0.79(19)	RL205*	5.76 (10)	0.88(23)
98-105	5.75(17)	0.95(19)	RC130*	5.44 (19)	1.2 (9)	RC130*	5.61 (17)	1.05(16)
98-135	5.34(21)	1.29 (8)	98-67	5.64 (17)	0.86(16)	98-224	5.52 (19)	1.18(10)
RC130*	5.57(18)	1.21(11)	98-56	5.43 (20)	1.02(13)	RC121*	5.83 (8)	0.71(24)
98-25	5.49(19)	0.88(21)	98-70	5.48 (18)	0.8(18)	98-257	5.51 (20)	1.15(12)
98-201	4.95 (24)	1.23(10)	98-37	5.09 (23)	1.08(12)	98-12	5.46 (21)	1.20 (8)
98-237	5.16 (22)	0.71(23)	98-59	5.1 (22)	0.87(15)	98-19	5.39 (22)	1.11(14)
98-120	5.36 (20)	0.42(25)	98-74	5.12 (21)	0.60(22)	98-196	5.39 (22)	0.90(20)
98-205	4.97(23)	0.68(24)	98-55	4.66 (24)	0.47(24)	98-222	4.93 (24)	1.30(5)
98-81	4.75 (25)	1.04(16)	98-78	3.87 (25)	0.40(25)			

*Control clones: RRIC 121, RRISL 205, RRIC 130

Means followed by the same letter within a column are not significantly different from one another at $p < 0.05$

High yielders did not necessarily associate with high girth increment (Gonçalves *et al.*, 2011), but according to the results, some of the high yielding genotypes such as; 98-219, 98-80, 98-68, and 98-223 have also recorded higher girth values. Forty six genotypes (82% of genotypes) were comparatively superior to the control clones in terms of girth, while 18% of genotypes reached above 70 cm, indicating vigorous breeding pool for timber clones.

Average girth increment of the trees provides information on the possibility of the early tappability and vigorous growth. Girth increment of all genotypes has represented a high girth increment at the immature phase compared to post tapping period. It was clear that tapping of the bark has slowed down the growth of the plant. Mean girth increment prior to opening for tapping ranged from 4.8 in genotype 98-81 to 7.4 in genotype 98-276, 3.9 in genotype 98-78 to 7.1 in genotype 98-68 and 4.9 in genotype 98-222 to 6.3 in genotype 98-220 in Trial 1, 2 and 3, respectively. Control clone RRIC 121 has recorded the mean girth increments of 6.7 (Trial 1), 6.5 (Trial 2) and 5.8 (Trial 3) before tapping. Around 12% of the genotypes were at the top ranks achieving an increment of 7 cm/year the girth before opening for tapping. The mean girth increment during the tapping period has also varied among the genotypes and it was equivalent or less than 2 cm/year for all genotypes. Genotypes 98-223 (Trial 3), 98-50 (Trial 2) and 98-276 (Trial 1) have recorded higher girth increments. There were five genotypes in Trial 1, 10 genotypes in Trial 2 and 23 genotypes in Trial 3 that have reported higher girth increments when compared to the control clone RRIC 121. Gonçalves *et al.* (2011) have mentioned that good girthing rate during tapping is a key important factor for a sustainable yield and reduces losses due to wind damage.

Performances of secondary growth parameters

Recommended minimum girth for opening of tapping is 50 cm at the height of 120 cm from the bud union (Onokpise, 1981). At the time of opening, 25 genotypes showed higher percent of tappable trees compared to the control clone RRIC 121. Yet, the control clone RRISL 205 has reported a higher percentage of tappable trees than RRIC 121. Genotypes, 98-230, 98-276, 98-41, 98-50, 98-71, 98-19, 98-196, 98-223 and 98-29 have reported 100% tappable trees at the time of opening for tapping (Table 4). High percentage of tappable trees ensures a better tapping stand and also reduces the immature phase.

Dead plants were recorded up to the sixth yielding year and survival percentage is given in Table 4. Most probable reasons for the losses are due to wind damages and white root disease. A white root disease patch was identified and the affected plants were uprooted. The incidence of wind damage has caused problems in different forms such as; of branch snap, trunk snap and uprooting (Gonçalves *et al.*, 2007). Severely affected damages were counted as losses. Percentage of survival varied among genotypes. Genotypes; 98-124, 98-25, 98-105, 98-201, 98-41, 98-71, 98-51, 98-54, 98-62, 98-44, 98-64, 98-58, 98-56, 98-59, 98-74, 98-78, 98-223, 98-29, 98-278, 98-220, 98-12, 98-224, 98-257, 98-18, 98-222, 98-149, 98-15 and 98-26 were recorded with 100% survival. Control clones had better survival percentages. This attribute helps to maintain the proper tapping stand throughout the economic life of the crop and ultimately a good yield.

Incidences of Tapping Panel Dryness (TPD) were also recorded (Table 4) as clonal vulnerability to dryness can be evaluated only after several years of tapping (Gonçalves *et al.*, 2007). Only true cases of dry trees were considered and those became dry due to wind damage have been excluded. Incidence of TPD was observed in almost all the genotypes and control clones except for four genotypes; *viz.* 98-67, 98-29, 98-220 and 98-193. Genotype 98-84 was the most susceptible genotype which has recorded 80% of incidence of dryness, followed by 98-236, 98-124 and 98-135 with 73% incidence of dryness.

Performance of chemical composition in latex

In order for a comprehensive analysis, chemical properties in latex were also used to identify potential candidate genotypes aiming to reduce the time period taken for the clone development program. Thus, selected eight genotypes and the control clone RRIC 121 were subjected to measurements of chemical composition of selected compounds in latex (Table 5).

Inorganic phosphorus content of latex is directly correlated with the metabolic activity during latex production (Jacob *et al.*, 1989). This attribute ranged from 6.18 mM in genotype 98-124 to 10.93 mM in genotype 98-80 among the selected genotypes during high yielding period. When compared to control clone RRIC 121, genotypes 98-80 and 98-219 showed significantly higher yields (Table 1) and also showed significantly higher inorganic phosphorus during both high yielding and wintering periods. Further, genotypes 98-276 and 98-236 showed significantly higher inorganic phosphorus content than the control (Table 5).

Sucrose content ranged from 4.68 mM in genotype 98-219 to 12.19 mM in genotype 98-236 (Table 5). Sucrose content in latex may signify a good loading to the laticifers (Jacob *et al.*, 1989) which may optimistically affect latex regeneration. On the other hand, genotypes 98-80 and 98-219 have reported higher yields reflecting the high rate of latex regeneration, thereby indicating high amount of sucrose utilization for rubber biosynthesis, resulting lower sucrose level in latex. However, comparatively high level of sucrose content has observed during high yielding period and a low sucrose level in wintering season. This revealed the poor performance in yielding during the wintering season in genotype 98-80 though it has performed well under favorable conditions. High level of sucrose content in genotype 98-236 together with low inorganic phosphorous content reflects its suitability for ethephon stimulation based harvesting systems in future.

Table 4. *Percentage of tappable trees, percentage survival trees and tapping panel dryness (TPD) of Hevea genotypes from the 1998 HP progarmme compared to the control clones in the small scale trials (1, 2 and 3) at Kuruwita sub-station*

Trial 1				Trial 2				Trial 3			
Clone	**% tappable trees**	**% Survival**	**% TPD**	**Clone**	**% tappable trees**	**% Survival**	**% TPD**	**Clone**	**% tappable trees**	**% Survival**	**% TPD**
98-230	100	87.5	57.14	98-41	100	100	31.25	98-19	100	92.86	53.85
98-276	100	75	33.33	98-50	100	87.5	28.57	98-196	100	92.31	9.09
98-11	93.75	93.75	53.33	98-71	100	100	46.67	98-223	100	100	16.67
98-84	93.75	93.75	80	RL205*	100	93.75	13.33	98-29	100	100	0
98-89	93.75	75	58.33	98-51	93.75	100	50	RL205*	100	84.62	18.18
RC121*	93.75	100	25	98-54	93.75	100	18.75	98-30	92.86	92.86	38.46
RL205*	93.75	100	12.5	98-62	93.75	100	50	98-154	91.67	92.31	30
98-98	93.33	81.25	46.15	98-68	92.86	93.75	66.67	98-278	91.67	100	60
98-219	92.86	87.5	35.71	98-44	87.5	100	20	RC121*	91.67	78.57	30
98-143	87.5	93.75	53.33	98-58	87.5	100	68.75	98-220	86.67	100	0
98-236	87.5	93.75	73.33	98-64	87.5	100	37.5	98-23	84.61	92.31	18.18
98-164	86.67	93.75	33.33	98-73	86.67	93.75	20	98-12	76.9	100	30.77
98-124	81.25	100	73.33	98-77	84.61	81.25	38.46	98-193	70	92.31	0

Trial 1				**Trial 2**				**Trial 3**			
Clone	**% tappable trees**	**% Survival**	**% TPD**	**Clone**	**% tappable trees**	**% Survival**	**%TPD**	**Clone**	**% tappable trees**	**% Survival**	**% TPD**
98-207	81.25	81.25	30.77	98-07	80	93.75	33.33	RC130*	69.23	92.86	50
98-25	81.25	100	33.33	RC121*	80	93.75	7.14	98-224	69.2	100	28.57
98-83	78.57	81.25	53.85	98-67	75	75	0	98-200	66.67	76.92	22.22
98-105	75	100	56.25	98-56	60	100	40	98-257	66.67	100	58.33
98-135	75	93.75	73.33	98-59	56.25	100	31.25	98-18	64.29	100	14.29
RC130*	75	87.5	71.43	RC130*	53.33	100	57.14	98-38	64.29	92.86	38.46
98-153	68.75	93.75	33.33	98-70	50	93.75	46.67	98-222	54.54	100	33.33
98-237	56.25	93.75	46.67	98-74	43.75	100	37.5	98-149	44.44	100	22.22
98-201	53.33	100	46.67	98-37	26.67	93.75	33.33	98-15	41.67	100	41.67
98-120	50	75	20	98-55	26.67	93.75	14.29	98-194	33.33	93.33	21.43
98-81	46.15	75	50	98-78	12.5	100	37.5	98-26	28.57	100	28.57
98-205	37.5	87.5	28.57	98-80	6.25	93.75	40				
Mean	79.04	89.75	15.02	Mean	71.13	95.5	34.72	Mean	74.54	94.755	27.68
SE	3.55	1.76	3.67	SE	5.8	1.28	3.44	SE	4.53	1.38	3.53

Table 5. *Chemical composition of selected compounds in latex of selected genotypes and the control clone RRIC 121 during high yielding and wintering season*

HP progeny	Sucrose (mM)		Inorganic phosphorus (mM)		Thiol (mM)		Polyphenol (mM)		Dry rubber content (%)	
	High yielding	Wintering	High yielding	Wintering	High yielding	Wintering	High yielding	Wintering	High yielding	Wintering
98-219	4.68^{d}	1.9^{g}	10.9^{a}	0.87^{a}	0.11^{cd}	0.24^{a}	1.35^{d}	2.08^{a}	49.04^{e}	39.28^{c}
98-80	7.53^{b}	2.61^{f}	10.93^{a}	0.92^{a}	0.18^{bc}	0.02^{g}	1.4^{cd}	1.29^{f}	48.69^{f}	40.72^{b}
98-105	3.74^{e}	5.35^{b}	8.29^{d}	0.48^{bc}	0.13^{bcd}	0.02^{h}	1.13^{e}	1.56^{d}	49.92^{d}	38.68^{c}
98-124	5.19^{d}	2.86^{ef}	6.18^{e}	0.53^{b}	0.11^{cd}	0.10^{b}	1.4^{cd}	1.39^{e}	50.83^{b}	44.64^{a}
98-143	6.14^{c}	3.49^{d}	10.63^{a}	0.39^{d}	0.43^{a}	0.02^{i}	1.09^{e}	1.49^{d}	54.78^{a}	34.77^{d}
98-236	12.2^{a}	4.98^{bc}	9.2^{c}	0.41^{cd}	0.14^{bcd}	0.03^{f}	1.71^{b}	1.66^{c}	50.34^{c}	38.21^{c}
98-276	6.5^{c}	4.59^{c}	9.65^{b}	0.52^{b}	0.08^{d}	0.03^{c}	1.03^{e}	1.50^{d}	40.49^{i}	31.99^{e}
98-68	6.64^{c}	3.2^{ed}	6.28^{e}	0.26^{e}	0.17^{bc}	0.03^{d}	2.65^{a}	2.07^{a}	47.97^{g}	33.71^{d}
RRIC 121	6.75^{c}	15.9^{a}	8.43^{d}	0.15^{f}	0.21^{b}	0.03^{e}	1.48^{c}	1.83^{b}	47.44^{h}	44.17^{a}
Mean	6.6	4.99	8.94	0.51	0.16	0.06	1.48	1.65	48.83	38.46
CV	6.39	5.06	2.12	7.80	24.45	-	3.57	2.92	-	1.63
Root MSE	0.42	0.25	0.19	0.04	0.04	-	0.05	0.05	-	0.63

Means followed by the same letter within a column are not significantly different from one another at $p < 0.05$

Dry rubber content (DRC) during the high yielding period ranged from 47.4% (RRIC 121) to 54.8% (98-143). All the selected genotypes showed significantly higher DRC values compared to control clone RRIC 121. Furthermore, genotypes 98-124 and 98-236 also showed high DRC values, 50.8% and 50.3%, respectively. Though genotypes 98-80 and 98-219 showed comparatively higher DRC, a reduction in DRC was observed in genotype 98-219 during the wintering season and therefore 98-80 would be a better genotype than 98-219 (Table 5).

Thiol content in selected genotypes ranged from 0.08 mM in genotype 98-276 to 0.43 mM in genotype 98-143 (Table 5). Thiol content in latex has a direct correlation with latex production *via* acting as a potential activator for key enzymes such as pyruvate kinase and invertase (Jacob *et al*., 1989). In addition, they act as antioxidants that protect cells against damages caused by reactive oxygen species (De Costa *et al*., 2006). Genotypes 98-219 and 98-124 showed comparatively higher thiol content even during the wintering season.

High level of phenols could be resulted due to reduced levels of polyphenol oxidase enzyme, which is a key enzyme in latex coagulation (Coupe and Chrestin, 1989). In addition, high level of polyphenol content in latex may cause discoloration in the presence of polyphenol oxidase enzyme (Yapa, 1976). Polyphenol content in selected genotypes ranged from 1.03 mM in genotype 98-276 to 2.65 mM in genotype 98-68. Genotype 98-68 may produce rubber with high color index due to higher level of polyphenol content. Genotypes 98-219, 98-80, 98-105, 98-124, 98-143 and 98-276 showed significantly lower level of polyphenol content compared to the control RRIC 121 during the high yielding period (Table 5).

Conclusion

A proportion of 63% of new genotypes showed higher mean yield compared to the control clones. Genotypes 98-80 and 98-219 were the top-ranking genotypes that recorded the highest mean yields. When compared to the control clones, 82% of genotypes have represented higher or comparable mean girth. In terms of girth, 18% of genotypes showed more than 70 cm of mean girth and those could be considered as potential genotypes to develop vigorous timber clones in the future. Further, these genotypes showed better yields compared to control clones. Genotypes 98-276, 98-68 and 98-223 recorded respective girth values of 80.6 cm, 76.5 cm and 71 cm which were the top most at the final year, based on their girth. With respect to increment in girth, 12% of the genotypes showed an increment of nearly 7 cm/year before opening for tapping. Genotypes 98-223, 98-50 and 98-276 have recorded the highest girth increments, *viz.* 2.2 cm, 2.0 cm and 1.9 cm, respectively after commencement of tapping. In 25 genotypes, higher percent of tappable trees than control, RRIC 121 was observed. According to the chemical properties in latex; genotypes, 98-80 and 98-219 performed well based on DRC, sucrose and inorganic phosphorus. To confirm these results, further evaluation of chemical composition in latex should be carried out in a field tapped in virgin panel during the next evaluation stage.

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Journal of the Rubber Research Institute of Sri Lanka
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Towards achieving sustainable development goals in the plantation sector

In today's world, proactive measures are required for the sustainability of any industry. In doing so, research is mandatory as it provides new knowledge and technological innovations together with the confidence on their application. Under such environment, Plantation Crop Research Institutes (PCRIs) mandated for research on tea, rubber, coconut and sugarcane, have proven to hold lead role in sustaining the respective industries by providing knowledge and technologies required. PCRIs jointly hold the Symposium on Plantation Crop Research as a biennial event to present their latest research findings to relevant parties. The origin of this event was recorded in 2004 and Seventh Symposium was held in Colombo in 2019 under the theme of "Towards achieving sustainable development goals in the plantation sector" with the leadership of the Rubber Research Institute of Sri Lanka (RRISL). It was a great success with number of participants exceeding 300 and 39 research presentations with novel findings under the thematic areas of Crop Improvement, Crop Agronomic Practices & Crop Production, Nutrients & Water Management, Product, Process & Machinery Development, Plant Protection and Socioeconomics & Extension. The symposium was able to attract a wide range of participants including scientists, academics, industrialists, inventors, practitioners in plantation crops and policy makers and also, to provide a healthy environment for all to have productive interactions. In this 7th Symposium, 14 papers were presented by the scientists in the RRISL. In view of giving the due recognition to the high quality papers presented at the symposium, the editors of this journal selected 13 papers through a stringent reviewing process for republishing as journal papers. This collection comes in the 99th Volume of the Journal of the Rubber Research Institute of Sri Lanka and therefore, will be a contributor in achieving sustainable development goals in the rubber industry.