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ADVANCING EFFICIENCY AND CONSISTENCY IN AGARWOOD INOCULUM PRODUCTION THROUGH AGARWOOD-INDUCE INOCULUM MIXING MACHINE

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ABSTRACT

Agarwood is a bio-resin that withstands a consistent market demand worldwide due to its exceptional formula of fragrant resin and rare essence of herbal aromatic compounds. However, the Agar-resin is formed only in the Thymalaeaceae family trees as a self-defense mechanism towards plant stress. In commercial-level agarwood production, artificial inoculation is essential for reliable agarwood production. However, the prevailing method of agar-based inoculum preparation has been plagued by the tedious, time-consuming, and poor texture of insufficient blending via particle blockages in the field operation is frequent. As such, this study invented a novel Agarwood-Induce Inoculum Mixing Machine addressing the shortcomings of the prevailing hand-held type mixing machine. The operation performance of both machines was systematically evaluated for the time required for a single bend, electrical energy consumption, and the quality of the final product. The results revealed a drastic reduction of time required for the completion single blend by 6 times i.e. from 18 minutes to 3 minutes by using the newly invented machine. The total electric energy savings for the completion of one batch of the blend was found to be 2.4 times (energy reduction from 0.48kWh to 0.2kWh) than the existing method. In addition to the two sample T-test results, a substantial reduction of time and energy with p-values close to zero ($p<0.001$), an exceptional quality homogeneous creamy foam of the final blend which is vital for a successful inoculation was received. The quality of the produced inoculum was rigorously assessed by a custom-formulated five-parameter index and 96.25% of the sample from the new machine and ranked "excellent" while the existing hand-mixing machine was with diverse performance. According to the chi-square test, there was a statistically significant difference ($p<0.001$) in the quality of the output inoculum between the two methods. The final blend of inoculum produced by the new machine was found to have exceptional quality homogeneous creamy foam texture which is vital for providing a hassle-free convenient operation background of the fields during the inoculation process.

Keywords: Agarwood, Artificial inducing, Fungal inoculation, Mixing Machine, Oud

INTRODUCTION

Agarwood formation is an intriguing process that occurs in response to injury inflicted upon previously healthy trees, as healthy trees typically do not yield agarwood (Faizal *et al*., 2017; Zhou *et al*., 2022). Once the formation process begins, agarwood exists in tyloses or gel form during its initial stages (Xu *et al*., 2013). The remarkable antibacterial and anti-disease properties of agarwood can be attributed to sesquiterpenes (Li *et al*., 2015).

The inciting mechanism for agarwood production is vital, particularly in species within the Thymelaeaceae family (Akter *et al*., 2013). This process is intricately linked to the tree's self-defense mechanism, which is triggered when the tree experiences distress, leading to the production of resins (Persoon 2007). It's important to note that this process involves deliberate harm to the trees, and two primary methods are employed for inducing this immune response. These methods encompass both natural and man-made approaches. Natural inoculation events are infrequent, making it imperative to resort to artificial inoculation methods, especially when considering commercial agarwood production (Herath and Jinendra, 2023b).

In the absence of the inoculation process, the agarwood output from these trees is insufficient to yield profitable results (Lee and Mohamed, 2016). Therefore, the deliberate initiation of the inciting mechanism through inoculation becomes a crucial aspect of agarwood production, ensuring a reliable supply of this valuable and sought-after resource.

Artificial agarwood induction stands as a highly effective means of ensuring a productive agarwood yield in the context of commercial agarwood plantations (Turjaman *et al*., 2016). A plethora of methods have been developed for this purpose, and within the global commercial agarwood industry, various techniques find widespread application (Herath and Jinendra, 2023b). These include nailing, drilling, aeration, the agar-wit and agar-sit methods, partial trunk pruning, burning-chisel drilling, and fungal inoculation, among others, which are commonly employed on a global scale (Chowdhury *et al*., 2016).

In large-scale agarwood production in Sri Lanka, producers have developed their own agar-based inoculum to induce agarwood formation, with fungal inoculation being a favored method. This involves injecting the inoculum into holes drilled approximately 8 cm deep and spaced 20 cm apart vertically and arranged in 2-3 holes per horizontal line around the tree trunk at a height of 50 cm above ground level. After drilling, a specialized culture medium is used for fungal growth. Once introduced, the site is wrapped with rubberized fabric to secure the culture. This method ensures systematic and controlled agarwood production in commercial plantations, optimizing yields and product quality (Herath and Jinendra, 2023b).

The artificial agarwood induction method in the industry faces notable challenges, as highlighted by commercial agarwood producers (Azren et al., 2019). Issues such as frequent nozzle blockages due to solid particles in the inoculum have been observed. The inconsistency in texture and the use of standard caulking guns led to frequent malfunctions (Herath and Jinendra, 2023b). The root cause was identified as poorly blended solid particles in the inoculum paste. This inconsistency is directly linked to the current mixing method. A specialized mixing and grinding machine is essential to address this challenge and facilitate inoculum preparation for the industry.

In the context of the Sri Lankan agarwood industry, inoculum paste preparation currently relies on hand-held industrial electric mixers, originally designed for the construction sector for mixing wall putty. However, these machines exhibit insufficient torque for effective mixing, necessitating extensive labor and time commitments. Their frequent maintenance requirements render them economically unviable.

A new machine for agarwood inoculum preparation has been developed to address these challenges. It's been systematically evaluated for operation and final mix quality, tailored to industrial needs. This design enhances operational efficiency, reduces energy and labor costs, and saves time in the production process. It produces a uniform creamy foam texture, resolving issues with particle blockages and uneven mixing. Performance testing showed a significant increase in productivity with the new machine.

MATERIALS AND METHODS

Design and Construction of the Agarwood-Induce Inoculum Mixing Machine

The agarwood-inducing inoculum mixing machine was designed and constructed with the primary goal of enhancing the efficiency of the inoculation process by uniformly preparing the inoculum paste within a short time. The device consists of four main parts, a heavy iron base with an operator's stage, a stainless-steel mixing blade within a frustum-shaped stainless-steel jar, a power transmission unit with a motor, and a fluid sealing unit.

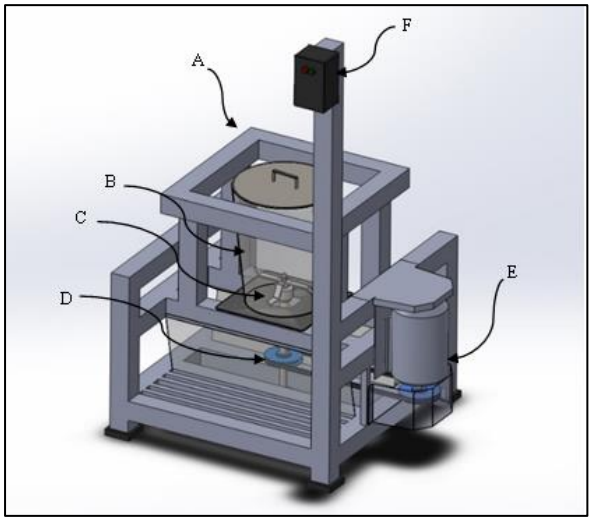

Figure 1: Design model of Agarwood induce inoculum mixing machine. (A) Heavy iron base, (B) Frustum-shaped stainless-steel jar, (C) Mixing blade, (D) Power transmission unit, (E) Induction motor, (F) Control panel.

Figure 2: Agarwood-induce inoculum mixing machine

The heavy iron base was designed to place all the parts of the machine and stabilize the machine when it is working. The base mainly consists of an operator's stage, control panel bar, and platform to place the frustum-shaped stainless-steel jar. The iron base was made of 3-inch heavy iron box bars. Four legs are used to place on the floor. At the end of the four legs, rubber bushes were fixed. The upper part of the base was designed as a protector for the jar. In the base, two iron plates with 3mm thickness were fixed to place the 1-inch bearings with square flange seat housing. In this iron base, another plate was fixed vertically to attach a 5-horsepower 3-phase motor. The operator's stage comprises 1-inch box bars. The control panel bar is 42 inches in height and in the upper part of it, the contactor-type motor starter

switch was placed. This height was added to the control panel bar to avoid possible contact of water and ensuring safety.

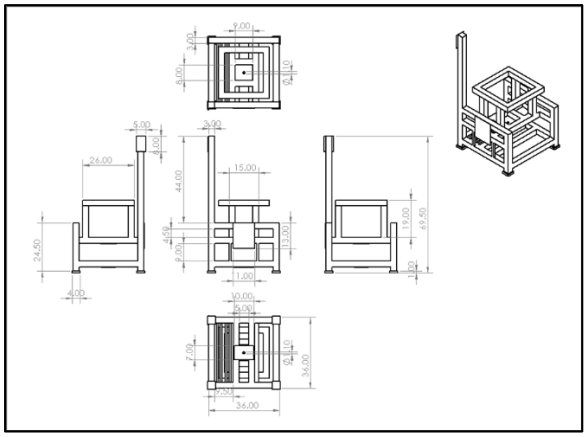

Figure 3: Design sketch of Heavy iron base (Note. all in inches to reduce no. of digits)

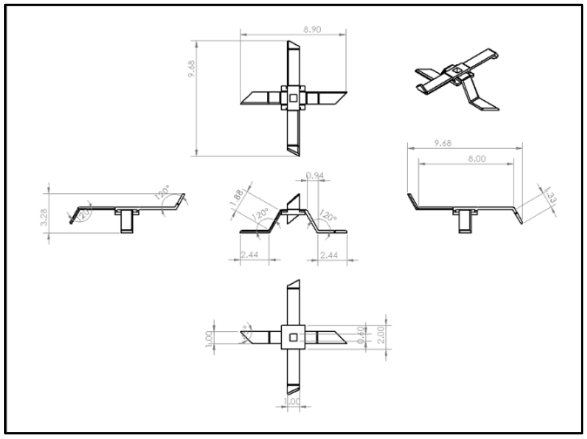

Figure 4: Design sketch of SS mixing blade

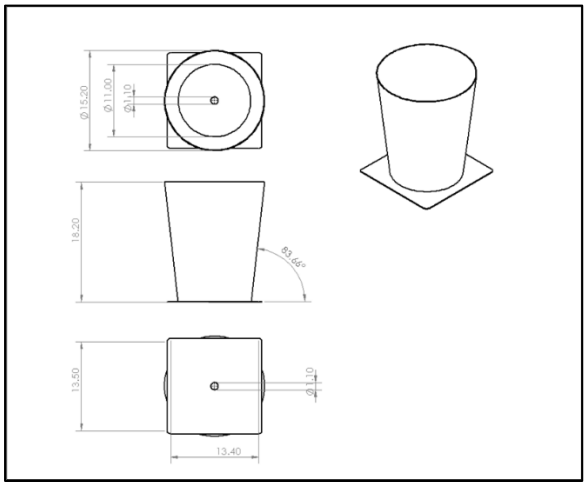

Figure 5: Design sketch of frustum-shaped SS jar

The complete Stainless steel mixing blade consists of 4 blade parts. Blade design was kept in two different levels, two of them are on the upper level and the other two are below them. The end of the blade parts was made with pointy tips and one side of the blade edge was sharpened. It is done to face the rotating side. The bottom side of the blade has a square shape SS plate to increase the strength of the blade. In the center, there was a square-shaped bore to attach the blade to the stainless-steel power transmission shaft. Wings of the blades were 3mm in thickness and the center part of the blade was 17mm in thickness. The stainless-steel mixing blade was located inside the jar and was attached to the square head of the stainless-steel power transmission shaft. By using a stainless-steel nut, the blade was fixed to the shaft. A sprig washer was used for a better tightening. The mixing blade and all setups are designed by maintaining the 1-inch gap between the jar bottom and the lowest level of the blade. Blade parts consist of 120° angels in each bend. The entire mixing blade is in the bottom of the frustum-shaped stainless-steel jar.

Frustum-shaped stainless-steel jar with a lid that has two clip locks. The lid has a handle on it. The bottom of the jar was fixed to a square-shaped plate that had 4 nut holes to attach the jar to the heavy iron base. In the center of the jar's bottom, a bore was there to enter the power transmission shaft into the jar. To avoid leakages from the mentioned bore in the bottom of the jar, a fluid sealing mechanism was inside the jar. A square-shaped rubber sheet was placed between the jar bottom and the iron base when fixing the machine.

The machine was powered by a 5-horsepower 3-phase motor attached to the heavy iron base and the motor shaft was faced downward. The power transmission unit consists of a pulley system and a power transmission shaft was made of stainless steel. Pulleys were made up of cast iron. In the pulley system, a 6-inch diameter pulley attached to the stainless-steel power transmission shaft was driven by a 5.5-inch diameter drive pulley fixed to the motor shaft. Both pulleys were attached to the power transmission shaft by tightening the bolt with spring washers. The pulleys were connected with a B-type V-belt with 62-inch in size. The stainless-steel power transmission shaft was fixed to the machine base by using 2 bearings with square flange seat housings. The power transmission shaft was 1 inch in diameter and 19.6 inches in height. At the top of the shaft, square shape head was designed to fix the blade without slipping and a thread was created to apply an SS nut to tighten the blade and fix it to the power transmission shaft.

The fluid sealing unit consists of two main parts. The brass bush and nylon cap. In addition, there was a flat rubber ring. Brass bush is 1.2 inches in height. The outer diameter is 2 inches and the inner bore was 1 inch in diameter. The bottom of the brass bush was made up with a smooth finish and contacts the bottom surface of the jar and inserted the hole of the brass bush was through the stainless-steel power

transmission shaft. The top surface of the brass bush was kept in contact with the nylon cap. It is 2.5 inches in diameter and the bore for the SS shaft was 1 inch in diameter. To insert the brass bush to the nylon cap the 2-inch diameter engraved hole was placed with 0.78 inches. Both the brass bush and the nylon cap were provided a sufficient clearance to rotate freely. Over the nylon cap, the mixing blade was fixed. Contacting the nylon cap and the blade was avoided by maintaining a gap.

Performance Evaluation of Agarwood-Induce Inoculum Mixing Machine

In the inoculum mixing process, time-saving and obtaining a consistent final product are the critical parameters to investigate. Therefore, two experiments were designed to assess the performance of the two distinct methods i.e., the novel agarwood-induce inoculum mixing machine and the existing hand mixing machine. One experiment was dedicated to assess the time taken to complete one batch of mixed and then, the other was to assess the consistency of the final mixed product from the two methods.

Mixing Time

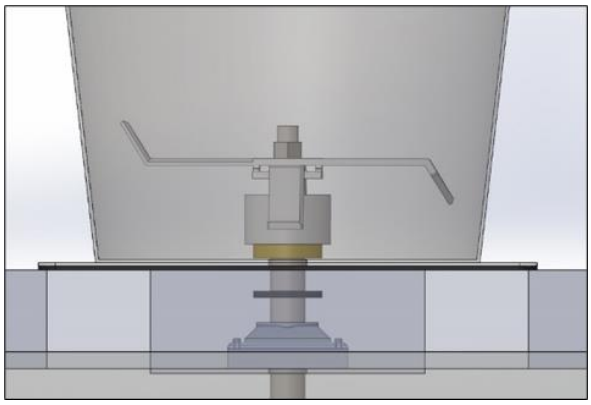

Figure 6: Design of installed mixing blade and the fluid sealing unit

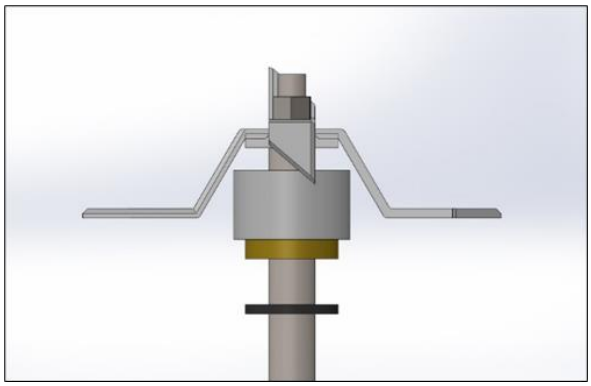

Figure 7: Design of isolated mixing blade and the fluid sealing unit. (A) SS mixing blade, (B) Nylon cap, (C) Brass bush, (D) SS power transmission shaft, (E) Flat rubber ring.

An experiment was conducted to assess the mixing efficiency of the two distinct methods using the time taken to complete one batch. For each method, a dedicated mixing station was established in a controlled environment to ensure equal grounds in the experimental conditions. The same amount of raw materials (10kg), including agar-based medium and fungal components, was used for both methods to facilitate a direct comparison.

Each mixing batch consisting of 10kg of raw materials was placed into the novel agarwood-inducing inoculum mixing machine. A stopwatch was initiated simultaneously with the activation of the machine. The mixing process was continuously monitored until the top surface of the dough became homogeneous and in full creamy foam. The stopwatch was stopped, and the recorded time was noted as the mixing time for the agarwood-inducing inoculum mixing machine.

An equivalent number of raw materials was mixed by an existing hand-mixing machine using skilled operators. The mixing was performed in a stainless-steel cylindrical container, simulating the standard procedure employed in the agarwood industry. A stopwatch was started as soon as the mixing process was commenced. It was continued until the materials mix was deemed thoroughly combined based on visual inspection as similarly appeared to be the same as in the novel method. This time spent was similar to the time taken in the usual agarwood inoculum mixing operation performed every day in the commercial scale. The stopwatch was stopped, and the recorded time was considered the mixing time for the conventional method.

Figure 8: Mixing process by hand held motor driven mixing machine

Figure 9: Mixing process by agarwood-inducing inoculum mixing machine

For each method, the mixing time was recorded for a total of 20 replicates to account for potential variations. The number of operators involved in both methods was noted for each replication. The operators were chosen for the experiments as those who are professionally trained for the inoculum preparation process and currently employed in the agarwood industry. The obtained data was subjected to statistical analysis using two sample T-tests to determine if there were significant differences in mixing time between the two methods.

Power consumption

The electric power consumption of the existing hand-held mixing machine and the novel mixing machine were evaluated by quantifying the power needed for a single batch of inoculum mix. Here the average time taken for each machine was taken into consideration to quantify the total electric energy units utilizing the standard kilowatt hour.

Assessment of Consistency

The second experiment was designed to evaluate the consistency of the final product from both operations to be recommended for practical use. Consistency, a key quality indicator, is essential for the uniform distribution of components within the inoculum.

A consistent batch size of raw materials, including agar-based medium and fungal components, was used for both methods. Upon completion of the mixing process in every batch, in both methods, 4 replicate samples each having the amount of 300g were collected representing the top middle and the bottom sections of the same inoculum batch and the same was continued for batches.

To assess the consistency of the final inoculum product, a sieving technique was used. A square-shaped plastic frame with 20 cm x 20 cm dimensions was obtained. A strainer mesh with the mesh number 60 (250 microns) was fixed to the bottom of the square frame for sieving. From each batch of inoculum four replicate samples each having 500g were gently pressed through the mesh by using a one-inch diameter PVC pipe with four strokes and the remaining mixed in the tray was measured by weight and visually observed for the ranking. Visual inspections were conducted on each sample to assess texture, uniformity, and distribution of components. Samples were rated on a subjective scale as excellent, good, fair, and poor to capture qualitative consistency assessments.

Figure 10: Sieving process of prepared agarwood-inducing inoculum

Similarly, after the conventional method using the hand mixing machine, 4 samples were obtained in the same manner. The remaining weight in the tray and the visual assessments were performed on each sample, focusing on the texture and distribution of components. Samples were again rated on a subjective scale to determine their qualitative consistency.

The collected data, including visual ratings for each sample, were compiled and the chi-squared test was utilized to determine if there were statistically significant differences in consistency between the two methods.

RESULTS AND DISCUSSION

Mixing Time

The hand-mixing machine was evaluated based on the time taken to mix raw materials. Table 1 displays the time taken for each of the 20 batches. There was a significant reduction in the operating time required for one batch of inoculum to be prepared up to the desired creamy foam.

Table 1: Mixing time for handheld motor-driven mixing machine

Batch No.	Time	Batch No.	Time
1	17 min 37 sec	11	17 min 37 sec
2	16 min 23 sec	12	18 min 08 sec
3	14 min 12 sec	13	17 min 12 sec
4	17 min 08 sec	14	17 min 34 sec
5	20 min 34 sec	15	21 min 03 sec
6	19 min 04 sec	16	16 min 55 sec
7	21 min 39 sec	17	21 min 39 sec
8	19 min 21 sec	18	20 min 43 sec
9	18 min 20 sec	19	19 min 20 sec
10	22 min 34 sec	20	17 min 50 sec

The average time taken by the existing hand-mixing machine for these 20 batches is 18 minutes and 26 seconds. The range of time taken varies from 16 minutes and 23 seconds to 22 minutes and 34 seconds.

The novel agarwood-inducing inoculum mixing machine was evaluated for its performance. Table 2 displays the time taken for each of the 20 batches.

The average time taken by the novel machine for these 20 batches is 3 minutes and 4.95 seconds (approximately). The range of time taken varies from 2 minutes and 3 seconds to 3 minutes and 37 seconds. As it demonstrated a remarkable reduction of operating time was observed when the mixing was performed by the newly developed novel inoculum mixing machine. Similarly, the statistical analysis conducted on the obtained results further strengthens the significance of the observed differences between the two methods. The conducted two sample T-tests indicated a statistically significant difference at the 5% significance level with a p-value that is very close to 0 ($p<0.001$) between the new agarwood-inducing inoculum mixing machine and the Hand-mixing

machine method. That, it could be concluded that the observed differences cannot be attributed by chance, thus confirming the superior performance of the novel machine.

Table 2: Mixing time for agarwood-induce inoculum mixing machine

Batch No.	Time	Batch No.	Time
1	3 min 24 sec	11	2 min 43 sec
2	2 min 55 sec	12	2 min 54 sec
3	3 min 10 sec	13	3 min 12 sec
4	2 min 48 sec	14	3 min 26 sec
5	3 min 5 sec	15	2 min 03 sec
6	3 min 8 sec	16	2 min 47 sec
7	3 min 37 sec	17	3 min 06 sec
8	3 min 14 sec	18	2 min 37 sec
9	3 min 12 sec	19	3 min 21 sec
10	3 min 16 sec	20	3 min 17 sec

This time-saving would bring a multitude of beneficial impacts to the agarwood production industry, potentially resulting in substantial cost savings by the reduced labour hour and increase in the capacity of inoculum production. This allows the producers to increase the efficiency of the entire process of inoculation as this was one of the limited factors in increasing the number of inoculation fields completed within a given time. The financial benefits attributed to labour saving and the extended capacity will have positive impacts on the agarwood producers to enhance their economic viability and sustainability in their business.

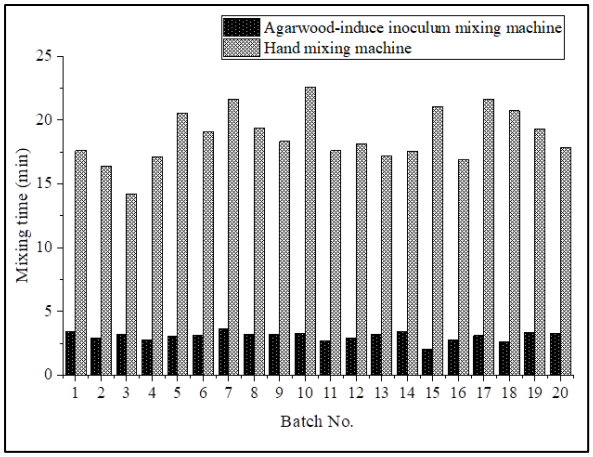

Figure 11: Consumed time to mix raw materials using the hand mixing machine and agarwood-induce inoculum mixing machine

Power consumption

The power calculation was based on the manufacturer's recommended rated input power needed for the operation of each machine. An attempt was taken to measure the voltage and ampere ratings to quantify the actual electric power consumed by the electric motors. However, it was not possible due to the ampere ratings was fluctuating in the manual mixing machine when the operator used it in placing the agitator element in different depths of the inoculum mix. The actual power acting upon in the inoculum mix can be calculated by considering the power factor of the two devices which is usually between 0.85 to 1. Accordingly, the shaft power for the single-phase device should be equal to $P = V \times I \times pf$, and for the three-phase motor $P = \sqrt{3} \times V \times I \times pf$. However, the parameter important in calculating the electric power consumption is not the actual power taken out from the motor shaft but the rated power consumed by the electric motor. Therefore, in this study, the power consumption of the two methods were compared using the manufacturer-rated power specification of the two machines. As it shown the total electric energy consumption was reduced from 0.48kWh down to 0.2kWh which the efficiency has increased more than double.

Table 3: Electric power specification of two mixing machines

Particular	Existing machine	Novel design
Model number	XZZ04-120	Y2-112M-2
Rated voltage	230V	420V
Mode	Single phase	Three phase
No load speed	800rpm	2885rpm
Rated input power	1.6kW	4kW
Power Mode	Single phase	Three phase
Shaft power equation	$P = V \times I \times pf$	$P = \sqrt{3} \times V \times I \times pf$
Time required one batch	18 min 26 sec	3min 5 sec
Approximate average	18 min	3min
Energy required for one batch	1.6(18/60) =0.48KWh	4 (3/60) = 0.2kWh

Consistency of the inoculum

The results revealed a significant improvement in the quality and the consistency of the final output of the inoculum from the novel agarwood-induce inoculum mixing machine to the output of the traditional hand-mixing machine. To get a quantitative measure of the consistency of the final inoculum mix an indexing platform was created. The indexing profile consists of the five most important priority indicators. The most important parameter would be the homogeneity of the mix which could blend all the agar and fungal inoculum particles into a single creamy foam. Therefore, the remaining weight of inoculum paste on the top of the tray with mesh No. 60 after five strokes was taken into consideration. If the amount exceeds more than 80g out of the 500g that is initially put on the mesh, the score is given as -20. Similarly, there were four other indications namely, the presence of solid agar particles, the presence of a watery mix, the presence of an unground fungal crest, presence of different color patches. Each of these quality indicators adds -20 marks if they were present in the sample. When ranking, each sample replicate was

Table 4: quality parameters and the score table for Consistency index

Indicator						Score
Remaining weight (g) in the sieve (Mesh No. 60)	Amount	0-40	40-60	60-80	80-100	>100
	Score	-0	-5	-10	-15	-20
Remaining solid agar particle						-20
Presence of a separated watery mix						-20
Presence of unground fungal crest						-20
Presence of different color patch						-20

Table 5: Quality ratings received by the inoculum mixed by hand-held mixing machine

Batch No.	Rank received				Batch No.	Rank received			
	R1	R2	R3	R4		R1	R2	R3	R4
1	G	G	G	E	11	G	F	G	G
2	F	G	G	F	12	F	P	G	G
3	P	G	G	P	13	P	F	G	P
4	F	G	G	P	14	G	G	F	G
5	G	G	G	F	15	F	P	G	G
6	G	G	G	F	16	P	F	P	G
7	G	G	E	G	17	F	F	F	G
8	G	G	F	F	18	F	F	G	F
9	G	F	F	G	19	F	G	G	F
10	G	F	F	G	20	G	G	G	E

P=Poor =9count, F=Fair=25count, G=Good =43count, E=Excellent=3count

Table 6: Qualitative ratings received by the inoculum mixed with the novel mixer

Batch No.	Rank received				Batch No.	Rank received			
	R1	R2	R3	R4		R1	R2	R3	R4
1	E	E	E	E	11	E	E	E	E
2	E	E	E	E	12	E	E	E	E
3	E	E	E	E	13	E	E	E	E
4	E	G	E	E	14	E	E	E	E
5	E	E	E	E	15	E	E	E	E
6	E	E	E	E	16	E	G	E	E
7	E	E	E	E	17	E	E	E	E
8	E	G	E	E	18	E	E	E	E
9	E	E	E	E	19	E	E	E	G
10	**E**	E	E	E	20	E	E	E	E

P=Poor =0count, F=Fair=0count, G=Good =3count, E=Excellent=77 count (96.25%)

given 100 marks at the beginning and added -20 marks at each observation only if the above-mentioned negative parameters were present in the observed sample.

The final rank of the consistency was indexed based on the total marks remaining after considering all five parameters. If the remaining score was >80 the excellent rank was given. From the total score 0-40, 40-60, 60-80, and 80-100 poor, fair, good, and excellent were given respectively. For instance, if there are not any of the four negative indicators in the observed sample and the remaining less than 40 g in the tray, an excellent category was given. If only one negative indicator present let us say there was only a watery fraction was found and 65g of inoculum paste was remaining in the tray: the rank was calculated as (100) - (20+10) = 70 the “better” grade was given.

For the newly developed machines, the majority of samples exhibited an excellent level of consistency. Out of 80 samples collected from 20 batches, 77 samples were rated as “excellent." Only 3 samples collected from 4 batches out of 80 were rated as “good” and those were also because of a remaining small amount of inoculum weight less than 60 grams in the tray. The results in Tables 5 and 6, has been demonstrated the capability of the new machine to consistently yield high-quality inoculum. More than 96% of the sample tested received an "excellent" rank

indicating a remarkable level of precision and reliability of the mixing operation. This indicates the capability of the machine to consistently produce high-quality inoculum, which is crucial for the uniform distribution of its all components. In contrast, the hand-mixing machine demonstrated a varied performance, with a substantial number of samples receiving "good" ratings. However, the presence of "poor" and "fair" ratings for a noteworthy proportion of samples belonging to the prevailing method discloses the shortcomings associated with it. Statistical analysis reassured the significance of the observed differences. The chi-squared test disclosed highly significant results between the two methods showing the respective p-value very close to zero ($p<0.001$), confirming that the quality difference between the output inoculum prepared by the two methods was statistically significant at the 5% level.

In summary, the newly invented Agarwood Induce Inoculum Mixing Machine has increased the process efficiency of the inoculation preparation by reducing the time required for the completion of a single batch of inoculum from 18 minutes to 3 minutes by 6 times. This improvement brings not only the reduction of labour costs but multitudes of other benefits. The ability to increase the capacity of inoculation fields allows the company to extend its business to another level. The increase in the capacity of a business brings the usual positive impacts to any business. Although the power requirement of the novel machine was increased from 1.6kW to 4kW the total amount of electricity energy requirement (kWh) has been drastically reduced to 2.4 times due to the quick operation time. This saving in electricity cost is huge when it is considered a large capacity business performing around 300 batches of inoculum per day as the electricity cost is calculated with the added rate for the increased consumption. This ensured the reduction of electricity costs by more than 2.4 times. The direct environmental benefits associated with the low electric energy consumption are also worth noting as we are still relying on a significant amount of fossil fuel-based electricity generation. Unlike the small hand-held 1.6kW machine, the novel machine is powered with a 4kW power 3-phase motor. This higher momentum force exerted a novel design into the inoculum could bring all the constituents in the inoculum smashed into a uniform creamy foam single-textured blend. This fine product has brought a convenient operation environment to the field inoculation teams preventing nozzle blocking in the inoculation applicators' guns. The authors of this work have already published their work on a novel approach of inoculation by newly invented Pneumatic Type Semi-Automated Agarwood Inoculum Injector (PSAII) elsewhere and conclude the suitability of inoculum mix for the field operation (Herath and Jinendra, 2023a). Usually, the inoculation gun is to be operated sitting in elevated branches in large trees via nozzle blocking bringing extremely difficult circumstances to the operator as it needs complete removal and refilling the machine with a new inoculum mix. When considering all these benefits, the newly invented machine has truly innovated the inoculation process in the agarwood industry to a new level.

CONCLUSIONS

The final blend of inoculum produced by the newly invented Agarwood-Induce Inoculum Mixing Machine had exceptional quality homogeneous texture and creamy foam which was ideal for providing a hassle-free convenient operation background during the inoculation process in field conditions. The newly developed machine has significantly reduced the processing time required for the completion of one batch of inoculum from 18 minutes to 3 minutes compared to the existing handheld device. The electric energy savings were reported as 2.4 times the processing of one batch as it has been reduced from 0.48 kWh to 0.2 kWh. Quality, assessed by a custom-formulated index, rated 96.25% of samples from the new machine as "excellent," surpassing results from existing hand-mixing machines. Besides the direct benefits, the innovation offers various other advantages, including increased business capacity and noticeable environmental benefits from reduced fossil fuel-based electric energy consumption.

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ENHANCING GERMINATION OF *Terminalia catappa* L. (TROPICAL ALMOND) SEEDS THROUGH DIFFERENT SEED TREATMENTS

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ABSTRACT

Terminalia catappa L. is a multipurpose species remained as an underutilized in Sri Lanka. The plant primarily spreads naturally and occasionally by cultivation. The natural regeneration of plants occurs through seed propagation of Terminalia catappa L. There are very few numbers of studies carried out on enhancement seed propagation. Therefore, present study aims to optimize seed germination of Terminalia catappa L. through various seed treatments. The present study was carried out at the University of Colombo Institute for Agro-technology and Rural Sciences in Weligatta, Hambantota from March 2021 to June 2021. The experiment was arranged in a Completely Randomized Design, with twenty replicates for each treatment. Seeds without any treatment (T1), seed clipping (T2), seed coat removal (T3), sun drying for 1 hour (T4), soaking in hot water (70 ^{o}C) for 10 minutes (T5), dip in 70% HCL solution for 5 minutes (T6), dip in 70% HCL solution for 10 minutes (T7), dip in 90% HCL solution for 5 minutes (T8), dip in 90% HCL solution for 10 minutes (T9), clipped seeds treated with gibberellic 200 ppm for 6 hours (T10), clipped seeds treated with gibberellic 400 ppm for 6 hours (T11), sundried for 1 hour followed by treated with gibberellic 200 ppm for 6 hours (T12), sun dried for 1 hour followed by treated gibberellic 400 ppm for 6 hours (T13) were applied as treatments. The pretreated seeds were established in small containers (2'' X 2'') filled with sand. The significantly (P≤0.05) highest germination percentage (80%) and lowest number of days (18 days) taken for sprouting were recorded from the seeds soaked in hot water (70 ^{o}C) for 5 minutes. The higher (P≥0.05) seedling height after 60 days of planting was recorded from T13 (sun dried for 1 hour followed by treated with GA3), T5 (soaking in hot water (70 ^{o}C) for 5 minutes) and T2 (seed clipping). Thus, soaking in hot water (70 ^{o}C) for 5 minutes was enhanced the germination of Terminalia catappa L. seeds. This research contributes valuable insights into optimizing seed propagation of Terminalia catappa L., offering a practical approach for enhancing germination percentage in cultivation practices.

Keywords: Germination, Pretreatments, Propagation, Seeds, Terminalia catappa L.

INTRODUCTION

Terminalia catappa L., is commonly known as Indian almond or tropical almond. This is a tropical tree species belonging to the family Combretaceae. Tropical almond is a versatile plant that gained global prominence due to its diverse applications in traditional medicine (Venkatalakshmi *et al*., 2016), agroforestry (Glencross *et al*., 2013), and landscaping (Thomson and Evans, 2006). *Terminalia catappa* L. has a diverse history of utilization in traditional medicine across various cultures. Different parts of the tree, including leaves, bark, and seeds, are often employed for their potential therapeutic properties (Venkatalakshmi *et al*., 2016). Tannins and other bioactive compounds in *Terminalia catappa* L. have exhibited pharmacological properties such as antioxidant, antimicrobial, anti-inflammatory, antidiabetic, *etc*. (Mohale *et al*., 2009; Anand *et al*., 2015; Saharan *et al*., 2022). *Terminalia catappa* L. plays a crucial role in agroforestry systems, contributing to sustainable land use and enhancing agricultural productivity due to its adaptability to a variety of soil types (Morton, 1985). The large, spreading canopy of *Terminalia catappa* L. provides excellent shade (Thomson and Evans, 2006), which can benefit crops by reducing evaporation, minimizing temperature extremes and providing more favorable microclimate. The tree's aesthetic appeal, coupled with its ability to thrive in diverse environments, makes it a desirable species for parks, gardens, and urban green spaces. *Terminalia catappa* L. can be managed for sustainable timber production, providing a valuable source of wood for construction, non-timber forest products and other purposes (Thomson and Evans, 2006). The seeds of *Terminalia catappa* L. are edible and consumed in certain regions in the form of roasted or raw (Manjusha *et al*., 2010). The seeds are also used in traditional cooking in some cultures. The leaves of the Indian almond tree can be used to produce a yellow dye. This dye has been used traditionally for coloring fabrics (Krisnawati *et al*.,

Table 1: Numbers of days for sprouting and germination percentage in different treatments of *Terminalia catappa* L seeds.

Terminalia catappa L. Seed treatment methods	Days taken for initial sprouting	Germination percentage (%)
T1-Without any treatment (Control)	22 [f]	50 [d]
T2- Seed coat clipping	21 [g]	70 [b]
T3- Seed coat removal	28 [d]	60 [c]
T4- Sun drying for 1 hour	24 [e]	50 [d]
T5- Soaking in hot water (70 ºC) for 5 minutes	18 [h]	80 [a]
T6- Dip in 70% HCL solution for 5 minutes	33 [b]	40 [e]
T7- Dip in 70% HCL solution for 10 minutes	34 [a]	50 [d]
T8- Dip in 90% HCL solution for 5 minutes	34 [a]	70 [b]
T9- Dip in 90% HCL solution for 10 minutes	30 [c]	70 [b]
T10- Clipped seeds treated with GA3 200 ppm for 6 hours	30 [c]	40 [e]
T11- Clipped seeds treated with GA3 400 ppm for 6 hours	21 [g]	30 [f]
T12- Sundried for 1 hour followed by treated with GA3 200 ppm for 6 hours	22 [f]	60 [c]
T13- Sundried for 1 hour followed by treated with GA3 400 ppm for 6 hours	21 [g]	60 [c]

Values in each column followed by the same letter are not significantly different at 0.05 probability level Duncan's Multiple Range Test.

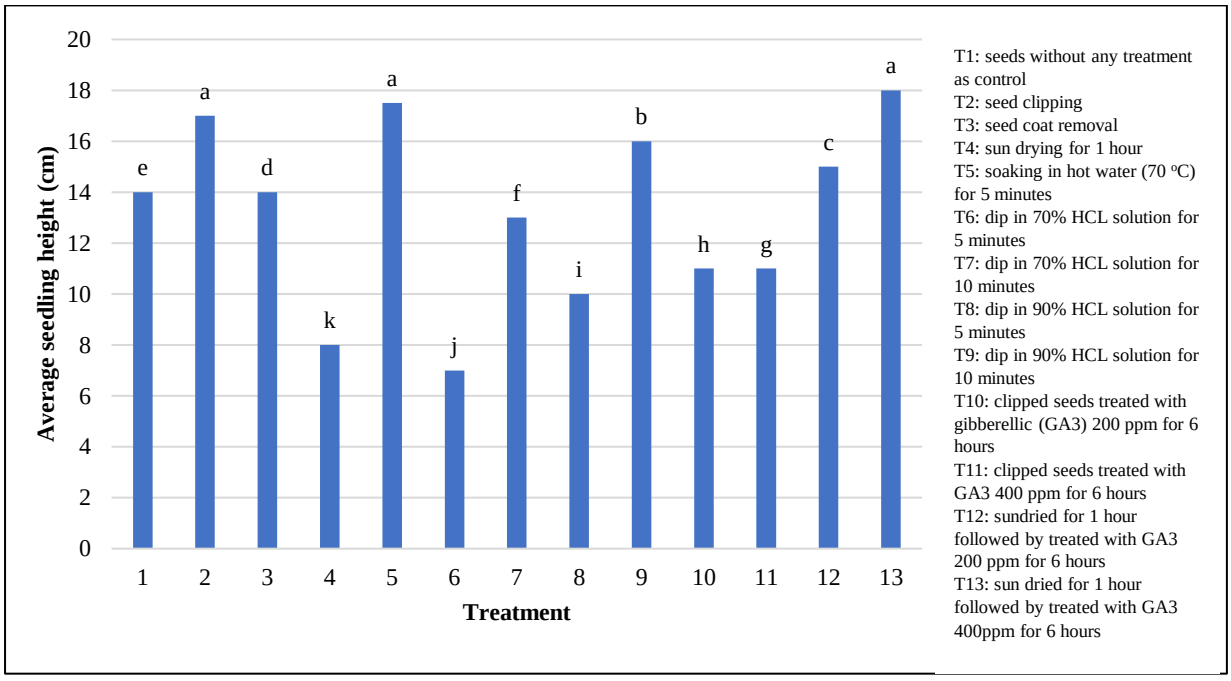

Figure 1 : Seedling height after 60 days of planting

2022). The dried leaves of *Terminalia catappa* are used in the aquarium industry. The tannin releasing from the leaves into the water, creating antifungal, antimicrobial and disease-free environment for ornamental fish (Perera, 2023). The propagation of this plant is mostly done through seeds. Lower germination rates hinder successful propagation, affecting agricultural practices and limiting the potential expansion of *Terminalia catappa* L. cultivation. The successful germination of seeds is a crucial aspect of plant propagation and growth. In the case of *Terminalia catappa* L., exploring effective pretreatment methods to optimize germination becomes paramount important to enhance its successful cultivation. Thus, pretreatment trials for *Terminalia catappa* seeds are essential to improve water absorption and create favorable conditions for germination. Therefore, this research was conducted to identify pretreatment techniques that maximize the germination percentage of *Terminalia catappa* L. seeds. By examining various pretreatment methods, the study aims to uncover the most efficient approach to facilitate the germination process of *Terminalia catappa* L. seeds, contributing to improved cultivation practices and broader agricultural advancements.

MATERIALS AND METHODS

The seed germination experiment of *Terminalia catappa* L. was carried out at the University of Colombo Institute for Agro-technology and Rural Sciences in Weligatta, Hambantota, Sri Lanka from March 2021 to June 2021. The study area is located within low country dry zone (DL5), characterized by an average annual rainfall from 600 mm to 1200 mm and temperature fluctuating between 29 °C to 32 °C.

The ripened fruits of *Terminalia catappa* L. were collected from mature healthy trees from Hambantota district. The uniform size (4-5 cm length and 18-20 g weight) fruits were selected. Fruit coat were removed manually before application of pretreatments. The Completely Randomized Design was applied for the experiment with twenty replicates for each treatment. Seeds without any treatment as control (T1), seed clipping using a sharp knife (T2), seed coat removal using a sharp knife (T3), sun drying for 1 hour (T4), soaking in hot water (70 ^{o}C) for 5 minutes (T5), dip in 70% HCL solution for 5 minutes (T6), dip in 70% HCL solution for 10 minutes (T7), dip in 90% HCL solution for 5 minutes (T8), dip in 90% HCL solution for 10 minutes (T9), clipped seeds treated with gibberellic (GA3) 200 ppm for 6 hours (T10), clipped seeds treated with GA3 400 ppm for 6 hours (T11), sundried for 1 hour followed by treated with GA3 200 ppm (T12), sun dried for 1 hour followed by treated with GA3 400ppm for 6 hours (T13) were applied as treatment. The analytical grade gibberellic acid was used for the study. Following to the treatments, the seeds were carefully established in small containers (2'' x 2'') filled with sand as one seed per container. The containers were placed inside the protected house according to the experimental layout. The watering and regular observations were done.

The germination process was monitored for each *Terminalia catappa* L. seed, and the number of days taken for initiation of sprouting in each treatment was recorded. Subsequently, the germination percentage was calculated at 60 days after planting based on the collected data. The seedling height was measured in each treatment after 60 days of planting. The data were analyzed statistically using SAS statistical software package. Mean values were compared through Duncan's Multiple Range Test ($P \leq 0.05$)

RESULTS AND DISCUSSION

Days taken for initial of sprouting

The *Terminalia catappa* L. seeds soaked in hot water (70 ^{o}C for 5 minutes) exhibited the significantly lowest number of days (18) for initial sprouting, with a significance level of $P \leq 0.05$ (Table 1). This implies that the application of hot water (70 ^{o}C) treatment accelerated the germination process compared to other treatments tested. This research findings were in closely align with a previous study conducted by Masilamani *et al*. (2013). According to the present study and Masilamani *et al*. (2013), the sprouting period for depulped fruits was around 21 days. Masilamani *et al*. (2013), reported that the sprouting duration for fruit without depulping was 24 days, highlighting that depulped fruits exhibited a shorter sprouting period in comparison. In present study, the seed coat clipping, clipped seeds treated with GA3 400 ppm for 6 hours, sundried for 1 hour followed by treated with GA3 400 ppm for 6 hours treatments reported significantly ($P \leq 0.05$) lower number of days (21 days) next to the hot water treated seeds for sprouting compared to the control.

Percentage of Germination

The *Terminalia catappa* L. seeds soaked in hot water (70 °C) for 5 minutes recorded the significantly ($P \leq 0.05$) highest germination percentage. The treatments of seed coat clipping, seed coat removal, dip in 90% HCL solution for 5 minutes, dip in 90% HCL solution for 10 minutes, sundried for 1 hour followed by treated with GA3 200 ppm for 6 hours and sundried for 1 hour followed by treated with GA3 400 ppm for 6 hours showed significantly ($P \leq 0.05$) higher germination percentage compared to control.

Masilamani *et al*. (2013), conducted a study on seed germination in *Terminalia catappa* L., with the entire fruit, including the pulp, serving as the control. The seeds were exposed to various sunlight conditions (open sunlight and partial shade) along with the application of different seed treatment methods. Notably, soaking the seeds in water and subsequently drying them for six days at 12 hours intervals, followed by a seven-day soaking in 2% $CaOCl_2$ for 12 hours, resulted in significantly enhanced germination, reaching a rate of 98% under open sunlight conditions. As mentioned in the study conducted by Mewded *et al*. (2019), subjecting *Terminalia laxiflora* seeds to high temperatures, specifically at 78°C for a duration of 10 minutes, resulted in a significant ($P \leq 0.05$) increased germination percentage (80%). The hot water (100 ^{o}C) treatment proved to be successful in promoting germination in *Bauhinia thonningii* seeds of varying sizes, resulting in germination rates of 40% for small seeds and 53.3% for large seeds (Mwase and Mvula, 2011). Prior studies on adaptable tree species such as *Balanites aegyptiaca* and *Balanites rotundifolia* indicated that the highest daily germination percentage was achieved by soaking seeds in hot water at 75°C for 10 minutes, followed by cooling for 12 hours (Seid *et al*., 2023). According to Azad *et al*. (2011), the highest germination success rate of *Acacia auriculiformis* was observed with hot water treatment at 83%, followed by scarification with sand paper at 78% and immersion in H_2SO_4 at 75%. The increased temperature contributes to breaking seed dormancy by hindering the activity of elongated palisade cells in

the outer layer of the seed coat which aids in the inhibition of imbibition (Geneve, 2003).

Height of Seedling

The higher seedling height after 60 days of planting was recorded from T13 (sun dried for 1 hour followed by treated with GA3), T5 (soaking in hot water (70 ^{o}C) for 5 minutes) and T2 (seed clipping). There was no significant (P≤0.05) difference among T13, T5, and T2, but collectively they were significantly (P≤0.05) different from the other treatments (Figure 1). As the study on *Acacia auriculiformis* seed germination conducted by Azad *et al*. (2011), immersion of hot water (80 ^{o}C) for 10 minutes showed the significantly (P≤0.05) higher plant height. According to the past research on seed germination of *Acacia polyacantha*, the highest germination and growth of the seeds were recorded in nicking seeds followed by the seeds immersed in the hot water (100 $^{\circ}$C) for 5 minutes (Missanjo *et al*., 2014).

The different pre sowing treatments facilitate higher germination. The seed dormancy and germination are varied according to genetic factors and environmental factors. Thus, different seed treatments were differently affected. Therefore, immersing seeds in hot water, either alone or in combination with other treatments, proved to be effective for breakdown the dormancy in *Terminalia catappa* L. seeds.

CONCLUSIONS

Immersing *Terminalia catappa* L. seeds in hot water at 70°C for 5 minutes proved to be highly beneficial, exhibiting the highest germination percentage and the quickest sprouting time, with statistically significant variances (P≤ 0.05). The seedling height also get improved in seeds treated with hot water. This practice is recommended to facilitate seed germination effectively. Thus, the process of soaking seeds in hot water could be recommended as a pretreatment for *Terminalia catappa* L. seeds due to demonstrated effectiveness in promoting germination.

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ASSESSING UNDERGRADUATE ENTREPRENEURS' PROPENSITY TO ADOPT BLENDED LEARNING STRATEGIES; A CASE STUDY AT UNIVERSITY OF COLOMBO INSTITUTE FOR AGRO-TECHNOLOGY AND RURAL SCIENCES

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ABSTRACT

The student's likelihood of using an educational technology such as blended learning is heavily influenced by their level of satisfaction with that technology. However, it is not expressed clearly in certain extents. The University of Colombo Institute for Agro Technology and Rural Sciences plays an important role in undergraduate entrepreneurial education through blended learning in Sri Lanka. The purpose of this study is to investigate the relationship of undergraduate entrepreneur's intention to enroll in the blended learning degree programme and their level of satisfaction. The population is made up of agricultural entrepreneurs who want to pursue degrees in the field of agriculture. The entire population included and pretested questionnaire used for gathering primary data on a range of variables on satisfaction and intention of blended learning. The secondary data was also collected accordingly. Analysis was conducted utilizing the statistical software programme SPSS (version 26). Significant positive correlations were found between the likelihood to embrace blended learning in higher education and factors such as overall satisfaction ($p < 0.05$), the form of delivery of blended learning ($p < 0.05$), the decision to follow a blended learning degree ($p < 0.05$), and promotion of blended learning among undergraduates ($p < 0.05$). However, satisfaction with the amount of time spent on the degree programme did not show statistical significance in relation to the intention to use blended learning ($p > 0.05$). Considering that, satisfaction with blended learning is having an impact on intention to use blended learning by undergraduate entrepreneurs

Keywords: Blended learning, Educational technology, Intention, Satisfaction, Undergraduate entrepreneurs

INTRODUCTION

Learner satisfaction, an essential component of the successful implementation and adoption of novel teaching approaches like blended learning. Blended learning combines both in-person and online components (Gosh *et al*., 2022). Applications of blended learning in a variety of fields, including business and management (Truss and Anderson, 2023), information technology (Bachtiar *et al*., 2014), the creative arts (Hlatshwayo, 2023), engineering (Shehawy, 2017), hospitality and tourism (Meeprom and Fakfare, 2023), etc., show how adaptable blended learning is in a variety of contexts and how it can meet the specific learning goals and needs of each domain while utilizing the advantages of both in-person and online instruction. The success of educational innovations such as blended learning is heavily influenced by the level of satisfaction among learners. Students who are happy with a new strategy become more motivated and involved, taking an active role in assignments and maintaining their attention on their education (Sesmiyanti, 2016). Their fulfillment encourages regular application of the strategy, which is essential for its effective execution. Additionally, it promotes student's resilience in their studies, which lowers dropout rates and is associated with better learning results (Joo *et al*., 2013 and Suhre *et al*., 2007). Furthermore, satisfied students frequently welcome new developments in education, which promotes sensitivity to upcoming changes in the field of education (Matulich, 2008). In order to ensure student satisfaction in Sri Lanka, blended learning strategies must not only be in line with the cultural and educational framework in country, but also adapt content and delivery techniques to be respectful of and consistent with local standards. Learners are more likely to accept and use these approaches when they see that their beliefs are being supported. As a result, satisfied learners support for more developments in blended learning (Cheng *et al*., 2023), promoting its long-term acceptance and advancement, an attitude in the educational system that values inventions and advances (Maiyarni *et al*., 2022). Therefore, understanding student happiness as well as their intention to use blended learning is crucial for developing new teaching tactics, especially when it comes to encouraging its integration with entrepreneurial education. Recognizing these

components facilitates the successful dissemination and integration of blended learning approaches into entrepreneurship education frameworks in Sri Lanka. This study aims to assess the relationship between the degree of satisfaction of students have with this teaching methodology and their intention to encourage blended learning among Sri Lankan undergraduate entrepreneurs.

Theoretical framework

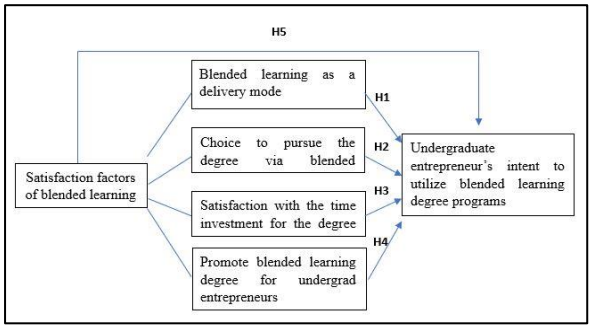

Figure 1: Satisfaction factors influence on blended learning adoption among undergraduate entrepreneurs

Undergraduate entrepreneur intention to use blended learning

The intention to employ blended learning indicates the willingness or readiness to interact with and adopt this method of education (George-Walker and Keeffe, 2010). The intention includes their views, reasons, and advantages they see from using blended learning into their academic path. (Radulović *et al*., 2023 and Samuel, 2023). The undergraduate entrepreneurs (individuals who are pursuing an undergraduate degree while also actively engaged in entrepreneurial activities) gave careful thought to how they intended to employ blended learning. Flexible scheduling and access to learning resources are made possible via blended learning, which can be quite helpful for students who combine their education with projects or business initiatives (Clark and Post, 2021). According to Mittal and Raghuvaran (2021), the abundance of information and resources that can be found online can supplement conventional classroom instruction and support the growth of entrepreneurial knowledge and skills. Additionally, online components often include interactive tools (Krishen *et al*., 2021), discussions (Schou *et al*., 2021), or simulations (Zulfiqar *et al*., 2021), encouraging participation and real-world application, which is advantageous for the development of entrepreneurial skills. Secondly, entrepreneurship frequently calls for flexibility and adaptability (Dabić *et al*., 21021). Blended learning may fit student's mindsets because of its flexibility and variety of learning approaches (Rahman *et al*., 2020) and needs in a constantly developing business environment. But more significantly, the power of blended learning might enable business owners to maximize their time by having access to lectures or course materials from a distance (Li *et al*., 2020), thus maximizing their productivity (Ma *et al*., 2022).

Blended learning as a delivery mode

When used as a delivery method, blended learning combines digital resources with physical instruction to provide a dynamic and adaptable learning environment (Dangwal, 2017). Examining the connection between the desire to employ blended learning as a delivery mode and its structure requires comprehending how its advantages and design affect people's choices and preferences (Li *et al*., 2020). It is important for instructors and educational institutions to recognize this relationship to create and execute blended learning programmes that effectively meet the demands and preferences of learners.

Hypothesis 1 (H1): Blended learning as a delivery mode is positively affect undergraduate entrepreneur's intent to utilize blended learning degree program

Choice to pursue the degree via blended learning

Decision to follow a degree through blended learning is a purposeful judgment that demonstrates a person's intention to adopt a modern teaching model (Ustun and Tracey, 2021). The choice indicates more than presence, Bai (2022) outlined how making a choice indicates a desire to use technology, interact with a variety of learning resources, and take an active role in both in-person and virtual learning. It reflects a person's deliberate attempt to customize their educational journey by making the most of the flexibility and variety of resources that blended learning offers (Osadcha *et al*., 2021).

Hypothesis 2 (H2): Choice to pursue the degree via blended learning is positively affect undergraduate entrepreneur's intent to utilize blended learning degree program

Satisfaction with the time investment for the degree program

An individual's intention to participate in blended learning is largely influenced by how satisfied they are with the time they have invested in a degree programme. People are more likely to stick with blended learning if they are happy with the time, they spend acquiring a degree through this kind of instruction (Gopinathan *et al*., 2020). The fulfillment may result from a number of things, including how effective the programme is considered to be (Xie and Li, 2020), the capability to balance studies with other assurances (Konstantinou and Miller, 2021), or the flexibility offered by blended learning in managing time efficiently (Li *et al*., 2020). In the end, having a

favourable opinion of the time spent on the degree programme helps to encourage a continuing desire to interact with and accept the blended learning model.

Hypothesis 3 (H3): Satisfaction with the time investment for the degree program is positively affect undergraduate entrepreneur's intent to utilize blended learning degree program.

Promote blended learning degree for undergraduate entrepreneurs

The way in which blended learning degree programmes are promoted is a significant factor in determining how people will choose to interact with this particular mode of instruction. Promotion spreads knowledge about the characteristics and advantages of blended learning (Posey and Pintz, 2017). People are made aware of this style due to the benefits, flexibility, and accessibility as well as how well it meets their requirements for education. An excellent promotion highlights how blended learning fits nicely with the intended audience's objectives and desires (Cheng *et al*., 2020), specifically entrepreneurs. Cheng went on to explain that it demonstrates how this strategy can support their goals by improving their abilities, providing useful knowledge, and working around their hectic schedules. Effective marketing techniques stimulate people's interest and curiosity (Wang, 2010). They display motivating stories of accomplishment (Nortvig et., 2018), testimonials (Marczok *et al*., 2015), or demonstrations (Alzer *et al*., 2023) of how blended learning might encourage people to think about and investigate this strategy by promoting development of skills, creativity, and entrepreneurial thinking. According to the Thorne (2003), by making a strong case for blended learning, promotion influences decisions. Throne went on to say that it shapes people's opinions, encouraging them to think about and plan to employ this approach for their education because it seems like a workable and promising solution.

Hypothesis 4 (H4): Promote blended learning degree for undergraduate entrepreneurs is positively affect undergrad entrepreneur's intent to utilize blended learning degree program.

Satisfaction factors of blended learning

The degree to which students are satisfied in a blended learning setting determines how likely they will continue with and participate in this type of instruction (Kuo *et al*., 2014). Their dedication is reinforced by positive experiences and a sense of satisfaction with the learning process, which encourages them to stick with blended learning as their favourite teaching approach (Gosh and Anwar, 2022). Moreover, Siriwardena *et al*. (2023) highlighted how undergraduate student's opinions are positively influenced and encouraged by their interactions with teachers, the resources in the modules, and the objectives of the courses.

Hypothesis 5 (H5): Satisfaction factors of blended learning is positively affecting undergraduate entrepreneur's intent to utilize blended learning degree program

MATERIALS AND METHODS

The University of Colombo Institute for Agro-Technology and Rural Sciences at Weligatta, Hambantota, Sri Lanka, was the location of the study. Every entrepreneur undergraduate who actively pursued a degree program at the institution using a blended learning technique participated in the survey. The entire population (204) was subject to data collecting. This method smoothly combines face-to-face interactions with online learning to produce a complete blended learning system. Data from both primary (from a questionnaire) and secondary sources (such as student registration details) were gathered for this investigation. A pre-tested Google Form survey administered via the Learning Management System was used to collect primary data. More than 80% responded for the Google form. Furthermore, secondary data from already-existing sources were obtained about the blended learning system. The constructed survey was designed to explore many aspects of blended learning satisfaction, covering subjects like blended learning delivery methods, the decision to follow a degree through this approach, satisfaction with the time spent in the degree program, and the promotion of blended learning degrees for undergraduate entrepreneurs. Also, it includes the dimensions to measure undergraduate entrepreneur's intention to use blended learning such as willingness, readiness, and inclination to engage with blended learning. From strongly agreed (+2) to strongly disagreed (-2) on a Likert scale, all the variables that were utilized for testing the hypotheses were evaluated. The statistical application SPSS was used to analyze the collected data (Statistics 26). The analysis included correlation analysis (selected variables on satisfaction and intention on blended learning) and frequency investigation, all of which were customized to the discovered associations between variables.

RESULTS AND DISCUSSION

Socio Economic Background of the Respondents

A population with 50.49% males and 49.51% females was included in the study, indicating gender equality. The age group of 21 to 30 years old comprised the majority of responders, or 61.27% of the total sample.

Table 1: Analysis of Mean, Standard Deviation, and Reliability for Dimensions in Undergraduate Entrepreneurs' Intention to Utilize Blended Learning Degree Programs

Dimension	Corresponding number of items	Cronbach's alpha values	Mean	St. Deviation
Blended learning as a delivery mode	1	0.831	1.86	1.13
Choice to follow the degree via blended learning	1	0.885	2.05	1.18
Satisfaction with the time investment for the degree program	1	0.910	1.39	1.19
Promote blended learning degree for undergrad entrepreneurs	1	0.902	1.91	1.14
Satisfaction factors of blended learning	4	0.803	3.61	1.95
Undergraduate entrepreneur's intent to utilize blended learning degree programs (Dependent variable)	3	0.812	2.08	2.12

Table 2: Correlation Coefficients and Significance Levels: Independent Variables vs. Dependent Variable

Attribute	[1]	[2]	[3]	[4]	[5]	[6]
[1] Blended learning as a delivery mode	1					
[2] Choice to pursue the degree via blended learning	[0.732**] (0.000)	1 (0.000)				
[3] Satisfaction with the time investment for the degree program	[0.321**] (0.000)	[0.399**] (0.000)	1 (0.000)			
[4] Promote blended learning degree for undergrad entrepreneurs	[0.561**] (0.000)	[0.624**] (0.000)	[0.399*] (0.000)	1		
[5] Satisfaction factors of blended learning	[0.822**] (0.000)	[0.869**] (0.000)	[0.672**] (0.000)	[0.811**] (0.000)	1	
[6] Undergrad entrepreneurs' intent to utilize blended learning degree programs (Dependent variable)	[0.367**] (0.000)	[0.364**] (0.000)	[0.108] (0.135)	[0.317**] (0.000)	[0.363**] (0.000)	1

"[ ]" indicates the correlation value, "( )" indicates the significant level

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

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

Independent variables – [1] to [5]; Dependent variable – [6]

It is noteworthy that a large percentage of the student entrepreneurs were experts in the area of agricultural consulting when compared with other fields such as training and education in agriculture, food industry and agricultural processing, livestock and crops. Thus, indicating a general trend among the participants in this area of focus.

Validating the instrument for assessing undergraduate entrepreneurs' intention to use blended learning degree programs

Table 1 shows that every dimension used in the research has acceptable Cronbach's alpha values, all of which are over 0.800. Furthermore, these dimensions demonstrate stable levels of reliability that correspond with the mean and standard deviation values. The information taken together indicates that the items measure the target construct consistently and efficiently.

Correlation analysis between variables

To investigate the associations between four different independent variables and one dependent variable, as indicated in table 2, an accurate correlation analysis was conducted. The dependent variable, which measures undergraduate entrepreneur's intention to enroll in blended learning degree programmes, shows a positive connection with all other independent factors, except for satisfaction with the amount of time spent on the programme.

Undergraduate Entrepreneurs' Adoption Intent for Blended Learning

Understanding the undergraduate entrepreneur's intention to employ a blended learning degree programme was the study's goal. A significant number of participants conveyed their contentment with the suggested pedagogical strategy.

According to figure 2, a significant proportion of participants (53.14%) expressed high levels of satisfaction on the willingness of the blended learning model. A majority of the respondents (54.85%) expressed strong satisfaction with the readiness of the blended learning programme. The overall positive readiness indicator among those surveyed suggests that the blended learning programme will be implemented successfully. A significant number of participants expressed their fulfilment with the suggested pedagogical strategy. In particular, 52.17% of the participants expressed great satisfaction with the concept of adopting a blended learning strategy. This clear inclination signal places the blended learning programme in a good position for its successful execution.

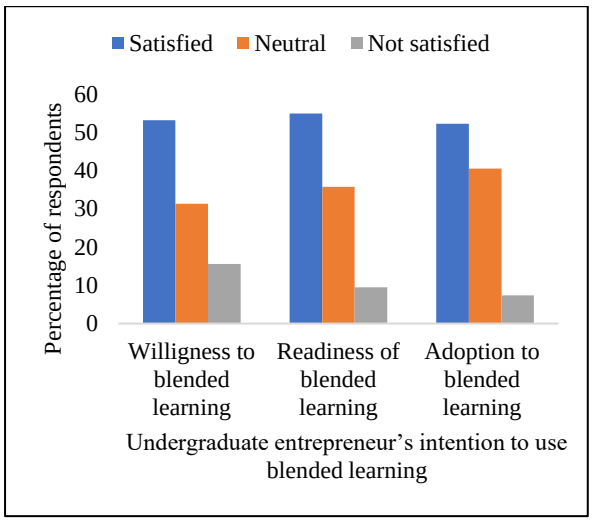

Figure 2: Undergraduate entrepreneur's intention to use blended learning

The Impact of Blended Learning Satisfaction on Intention to Utilize Blended Learning

When gathering all satisfaction dimensions, a statistically significant ($p < 0.05$) positive correlation ($r = 0.363$) is observed regarding the likelihood to use blended learning in their degree programme. Several variables, such as the ease of online material access, the degree of interaction with interactive resources, schedule flexibility, the standard of the instructional materials, or the general user experience in the blended learning environment, could be included in these satisfaction factors. According to the Lin and Wang (2012), learners generally view satisfaction features positively, which tends to support their commitment to staying with this strategy. For example, if students find the internet resources interesting, (Green *et al*., 2018), the flexibility adapting (Andrade and Alden-Rivers, 2019), and the overall experience performing (Ying and Yang, 2016), they're more likely to anticipate continuing employing blended learning for their learning. People are primarily motivated to select and participate in blended learning on a regular basis by these satisfying experiences. Thus, undergraduate entrepreneur's intention to use blended learning degree programs is significantly impacted by blended learning satisfaction variables (Hypothesis 5 is accepted).

The Influence of Blended Learning Delivery Mode on the Intention to Support Blended Learning

When looking at blended learning as a delivery method, there is a statistically significant (p value < 0.05) positive association ($r = 0.367$) between it with the intention to enroll in a blended learning degree programme. Baragash and Al-Samarraie (2018) examined the effects of using different learning delivery techniques, including web-based learning, learning management system-based learning, and in-person instruction. The results showed that these strategies had a favourable influence on students' academic achievement and educational perspectives in higher education. There is a positive correlation among the mode of delivery and intention meaning that learners are more likely to want to employ blended learning for their degree programmes when they believe the technique to be effective, available, and beneficial for providing educational information. (George-Walker and Keeffe, 2010). This could be recognized to the flexibility it approaches (Li *et al*., 2020), the range of resources offered (Snowball, 2014), or the individualized studying experiences (Zhang *et al*., 2020) contribute to a further positive perception and improved intention to continue employing this educational methodology. Taking all of this into consideration, it can be observed that using blended learning as a delivery method improves undergraduate entrepreneurs' intentions of attending blended learning degree programs (Hypothesis 1 is accepted).

The Choice to Practice the Degree via Blended Learning on Intention to Utilize Blended Learning

The intention to implement blended learning in higher education is significantly (p value < 0.05) positively correlated ($r = 0.364$) with the decision to pursue a degree programme through blended learning. This association emphasizes the importance of this purposeful selection on establishing a tendency towards accepting blended learning as a preferred educational style. This result emphasizes how crucial the decisions people make about their educational directions (Green *et al*., 2018). Students' intention to continue using blended learning techniques in higher education is favourably aligned when they actively decide to use a blended learning strategy as a satisfaction factor in their degree programme (Kuo *et al*., 2014). As a result, the decision to obtain the degree through blended learning has a beneficial impact on undergraduate entrepreneur's desire to use the blended learning degree program (Hypothesis 2 is accepted).

The Satisfaction with the Time Investment for the Degree Program on Intention to Utilize Blended Learning

There was not statistically significant (p value > 0.05) correlation found between the amount of time spent on the degree programme and the intention to use blended learning. This implies that their inclination to participate in blended learning may not be immediately impacted by the program's typical length or time commitment. Factors like the accessibility of resources (Almulla, 2022), support structures (Chiu, 2021), technological infrastructure (Ibrahim and Nat, 2019) or personal commitments (Turner and Gianiodis, 2018) may have a greater influence on people's intentions regarding blended learning than the amount of time spent on a degree programme. Therefore, contentment with the time investment for the degree program had no beneficial effect on student entrepreneur's willingness to use blended learning degree program (Hypothesis 3 is rejected).

Impact of Promoting Blended Learning Degrees for Undergraduate Entrepreneurs on Their Intentions to Adopt Blended Learning

Examining how undergraduate entrepreneurs promote blended learning degree programmes showed a strong (p value < 0.05) positive association (r = 0.317) with their intention to use such programmes. This implies that such entrepreneurs are more likely to think about and use blended learning as an educational technique when they come across advertising efforts that emphasize the relevance, advantages, and tailored benefits of blended learning. Thus, this association underlines how powerful the personal recommendations (Turner and Gianiodis, 2018) or suggestions for convincing and motivating aspiring college students to choose blended learning (Glazer, 2023), and demonstrating the impact that personal encouragement has on influencing student's educational decisions. Because of these factors, promoting blended learning degrees for undergraduate entrepreneurs has a good impact on their intention to use the blended learning degree program (Hypothesis 4 is accepted).

CONCLUSIONS

Several dimensions such as blended learning as a delivery mode, choice to follow the degree via blended learning, satisfaction with the time investment for the degree program, promote blended learning degree for undergraduate entrepreneurs were assessed to comprehend the undergraduate entrepreneur's intention to use blended learning. All the chosen components showed good internal consistency through reliability analysis, as indicated by Cronbach alpha values ranging from 0.803 to 0.910. The intention to adopt blended learning for higher education was significantly positively correlated with factors including overall happiness, the blended learning delivery style, the decision to pursue a blended learning degree, and promoting blended learning among undergraduates. However, in terms of the intention to use blended learning, the component pertaining to satisfaction with the amount of time spent in the degree programme did not show statistical significance. Entrepreneur undergraduates are satisfied with the existing blended learning program in different disciplines while they are more concerned on the time consuming the program which could use some improvement. Additionally, satisfaction significantly contributes to the intention to utilize blended learning program at the institute.

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EXPLORING ECOLOGICAL FUNCTIONS OF RICE-FISH INTEGRATION IN THE AGRICULTURAL LANDSCAPE: A REVIEW TO INVESTIGATE FEASIBILITY OF IMPLEMENTING RICE-FISH INTEGRATION IN SRI LANKA

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ABSTRACT

Rice-fish integration is, a symbiotic farming system where fish are reared in rice fields. Although this farming method widespread in many Asian countries, it is relatively new to Sri Lanka, and consequently information on its ecological functions under Sri Lankan context is scarce. Therefore, detailed investigation on the ecological function of rice fish integration would provide necessary information to establish rice-fish integration in Sri Lanka. This study followed a qualitative case study approach, including literature review and extensive document analysis. The results highlighted the rice-fish integration approach presents an array of ecological functions, underscoring its potential as a sustainable agricultural practice. Ecologically, the presence of fish in the system contributes to increase nutrient availability for rice plants, and biologically control weed and pest. Further, rice-fish integration promotes soil fertility of rice fields which improves growth and nutrient uptake of rice plants. The rice plants, in turn, play a pivotal role to maintain biodiversity in rice fields through water purification, establishing optimal water temperature conditions, and providing an array of micro habitats for a diverse aquatic fauna and flora. On the other hand, rice fish integration promotes water use efficiency, higher economic return and animal protein requirement of local farming communities. Considering ecological, economical and health benefits, integration of tilapia fish with suitable rice varieties available in Sri Lanka is proposed. In conclusion, the rice-fish integration is an ecologically balanced farming system which has a potential to enhance the sustainability of rice field farming systems in Sri Lanka.

Keywords: Ecological benefits, Rice-fish integration, Symbiotic farming, Tilapia

INTRODUCTION

\Rice-fish integration (RFI), an innovative and symbiotic agricultural practice that integrates agriculture and aquaculture within the same landscape has garnered considerable attention as it secures the main staple food for a large portion of the world's human population especially in Asia (Frei and Becker, 2005), together with high-quality animal protein. Further, this farming system has also been identified as ecologically sound, low cost approach to produce both fish and rice in a sustainable manner (Ahmed and Garnett, 2011). This multifunctional farming system presents an opportunity to address the challenges associated with traditional monoculture practices by creating a resilient landscape that simultaneously enhances agricultural productivity and promotes environmental conservation (Frei and Becker, 2005).

Conventional agriculture practices largely depend upon inorganic fertilizers, and the average fertilizer usage in Sri Lankan during the period between 2002-2016 was approximately 131.9 kg/ha (Jisna *et al.*, 2021). The majority of imported agrochemicals in Sri Lanka have been directed towards rice cultivation, with rice accounting for over 70% of the national fertilizer usage (Jayasumana *et al.*, 2013). Although the usage of inorganic fertilizers is necessary to obtain the target production to meet the growing need for food, the inherent environmental concerns of inorganic fertilizers are significant (Roy and Sathoria, 2022). Among them, eutrophication of aquatic ecosystems, biomagnification, and bioconcentration of certain pollutants specifically heavy metals, nitrate contamination of drinking water sources, and salinization of both soil and water have been highlighted in the literature (Camargo and Alonso, 2006; Savci, 2012). Under this context, RFI makes significant reduction of environmental impacts caused

by the excess use of inorganic fertilizers and other agro chemicals in paddy farming (Weimin 2010). In the context of RFI, the fish actively contribute to nutrient recycling through feeding, excretion, and the deposition of feces into the settled soil of the field bed. This process leads to an enhancement in the concentration of elements, including nitrogen (N) and phosphorus (P) (Noorhosseini and Bagherzadeh, 2013). Further, Li *et al.* (2022) recommended this integration for humid areas with low total nitrogen content (TN≤ 1.5 g/kg) in soil as the most promising strategy to simultaneously achieve the highest rice yield with good quality. The behaviors of fish promote mobility of nutrients in soil and consequently improve the fertility of soils. Specifically, nest making at the bottom of their habitat by cichlids, such as tilapia (*Oreochromis* sp.) not only improves the soil aeration, but also mobilizes soil nutrients (Inayat *et al.*, 2023). Further, fish excretions and metabolically excreted ammonia provides essential macro and micronutrients for paddy (Sathoria and Roy, 2022). Fish, by feeding and subsequently depositing their feces in the settled soil of the field bed, recycle essential nutrients, enhancing soil phosphorus and nitrogen levels and promoting the fertility of the soil beneath the plots (Frei and Becker, 2005). The biologic control of pests, diseases, and weeds is another significant benefit of fish culture in paddy fields, as it promotes a natural balance that minimizes the need for chemical applications (Fahad *et al.*, 2021; Kathiresan, 2007). The consumption of insects' larvae, leaf and stem feeding worms by fish like carp release to rice fields contributes to their growth and development, further biological control of rice pest population in the system (Noorhosseini and Bagherzadeh, 2013). Besides to rice and fish production that secure food security, RFI makes efficient use of land and water, maintain biodiversity, regulate water flows and water quality (Freed *et al.*, 2020)

While it has been proven success in various regions specially in the Asian continent, RFI is not popular or widely practiced in Sri Lanka. Therefore, a comprehensive study to scrutinize the effects and benefits of RFI in the Sri Lankan context is essential to signify its potential application in the country. Moreover, investigation of the effect of RFI on soil, water, and biodiversity is yet to be explored to promote RFI among farmers, specifically to adopt it as a sustainable and responsible agricultural practice. On the other hand, this information not only benefits in developing guidelines, and decision-making, but also to ensure their sustainability in terms of environmental, social, and economic aspects. Therefore, this paper discusses the potential ecological effects and benefits of RFI in the agricultural landscape of Sri Lanka with special emphasis on its feasibility of adopting in the Sri Lankan context.

MATERIALS AND METHODS

Literature search

The research employed a qualitative case study methodology, which encompassed an extensive literature review and document analysis. The study specifically investigated the importance of RFI as a sustainable agricultural practice in fostering the development of rural communities. The various research databases such as Google Scholar, PubMed, Scopus, and Science Direct were employed for exploring journal articles. In addition, references from retrieved articles and textbooks were also considered.

Data Extraction Process

Article titles were carefully selected, and documents considered 'irrelevant,' which did not provide information regarding the significance of RFI as a sustainable agricultural practice for the socioeconomic advancement of rural communities, were excluded. All studies offering qualitative or quantitative information related to the subject area were incorporated into the study. Initially, 105 papers were retrieved, reduced to 94 unique ones after removing duplicates using Zotero. The full articles corresponding to these 89 papers were retrieved and thoroughly examined. Ultimately, 86 papers met our inclusion criteria, and the information from these papers was included in this study.

The ecological functions of rice in rice-fish integration system

In RFI, rice plays an important role in providing a natural habitat and shelter for fish, particularly during the high-water temperature in the rice fields (Figure.1).

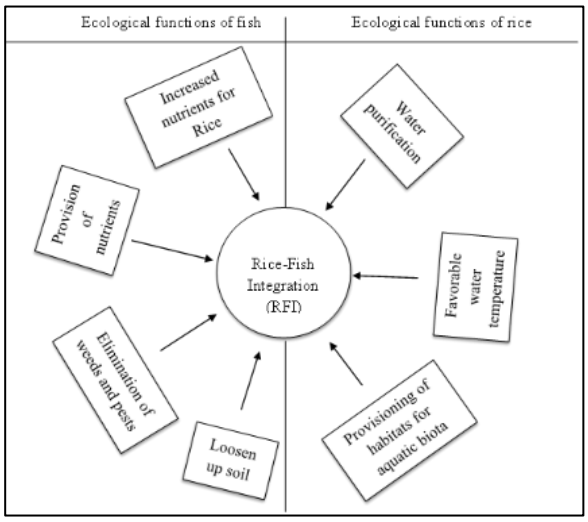

Figure 1: The functions of fish and rice in RFI

A network of interconnecting leaves of rice plants acts as a shelter, that minimizes the water temperature fluctuations benefiting fish especially in the summer season (Kunda *et al.*, 2008). Further, rice plants regulate the water quality in the rice field, by absorbing nutrients such as excess nitrogen and phosphorus from the soil. Availability of nutrients including nitrate, phosphate, potassium, and ammonia is being augmented by fish due to their direct and indirect behaviors (Chakraborty and Chakraborty, 1998, Zhang *et al.*, 1991). Nutrient retention in rice fields is comparatively low as those elements are easily absorbed by rice plants, and thus, there is less chance to develop harmful algal blooms that make severe detrimental problems for both fish and human beings. Additionally, the decaying leaves of rice offer favorable conditions for the multiplication of microorganisms, which are one of the natural feeds of fish (Lu and Li, 2006). These natural feeds improve growth and survival rates of fish. Compared to monocultures, RFI accelerates the overall production of the system (Kumara et al., 2023; Madhawa et al., 2023; Wang and Lei, 2000).

The ecological functions of fish in rice-fish integration

Fish in the RFI helps to loosen up soil surface, increase soil permeability, improve soil aeration, and enhance the vitality of soil microbes (Figure 1). Rice plants make it easy to absorb soil nutrients as the decomposition of nutrients in the soil is accelerated by microbes in the system. The occurrence of loach in rice fields has been demonstrated to enhance the proliferation of soil microorganisms, including nitrogen-fixing bacteria, cellulose-decomposing bacteria, nitrobacteria, sulfur bacteria, and ammonifying bacteria. This phenomenon contributes positively to augmenting the availability of soil nutrients (Wan *et al.*, 2010). Further, the behaviors of fish can induce soil aeration in rice fields (Mondol *et al.*, 2013), while they also control pests and parasites in the rice fields. Certain fish species feed on insects, snails, and other pests that destroy rice plants, reducing the need for chemical pesticides (Frei and Becker, 2005). Compared to monoculture rice fields, a significant reduction in pests and weeds has been reported in RFI with fresh water aquaculture species like tilapia, carps, etc. (Nayak *et al.*, 2020) and in rice-duck integration (Poonam *et al.*, 2019). Further, fish excreta serve as both a natural fertilizer for rice and enrichment for soil which can further enhance rice growth and yield (Lu and Li, 2006) while promoting the growth of phytoplankton and zooplankton, which are then consumed as feed by fish for their growth and development (Sha *et al.*, 2017; Wongkiew *et al.*, 2018). The phosphorous and nitrogen contains in the fecal matter of fish improves soil fertility, nutrient recycling (Nayak *et al.*, 2018) and reduction of fertilizer usage (Xie *et al.*, 2011). Fish contribute to the nutrient cycling process in the rice field ecosystem specially to nitrate cycle via the excretion of ammonia through their gills during their respiration. In addition, fish excreta are rich in nitrogen and phosphorus, essential nutrients for plant growth (Noorhosseini-Niyaki and Bagherzadeh-Lakani, 2011). The movement of fish help to enhance soil porosity and stir up sediments in the rice field, which helps to increase oxygen levels and reduce the buildup of toxic gases as convert an anaerobic system to an aerobic system (Bashir *et al.*, 2020). Fish, as they move through the water, disturb the sediment at the bottom of rice fields. This action helps to prevent sedimentation, which can otherwise lead to the formation of anaerobic (oxygen-deprived) pockets in the soil (Inayat *et al.*, 2023). Moreover, as fish move through the water, they create disturbances that lead to the formation of channels and pockets within the soil. These channels increase soil porosity, and the higher soil porosity allows for better air and water movement, facilitating gas exchange and nutrient uptake by rice plants. Further the rice plants have some special adaptations to breathe under inundated conditions (Mitin, 2009). Rice plants possess specialized tissues called aerenchyma, which are hollow, air-filled channels that allow for the exchange of gases between the roots and the above-ground parts of the plant. In addition, rice plants develop adventitious roots, known as "pneumatophores," which protrude above the water surface in flooded conditions (Rich, 2011). These roots help to facilitate gas exchange by allowing oxygen to enter the root system and carbon dioxide to exit, despite the inundated environment. By combining the natural adaptations of rice plants with the beneficial effects of fish movement in rice fields, RFI creates synergistic relationships that enhance soil health, promote better oxygenation, and ultimately contribute to improved crop yields.

Effects of rice-fish integration on soil fertility of rice field systems in Sri Lanka

Rice paddies are unique, artificial wetland ecosystems rich habitat for an array of aquatic flora and fauna. In Sri Lanka, paddy soils face challenges of overexploitation, with nutrient depletion emerging as a prevalent issue across the entire island. The extensive use of agrochemicals has led to soil pollution, particularly with toxic trace elements, contributing to a decline in soil fertility over recent decades (Rubasinghe *et al.*, 2021). Paddy soils, especially those integrated with fish cultivation, serve as favored habitats for numerous soil microorganisms. These microorganisms, including nitrogen-fixing bacteria, cellulose-decomposing bacteria, nitrobacteria, sulfur bacteria, and ammonifying bacteria, play a crucial role in sustaining nutrient cycles and soil fertility (Wan *et al.*, 2019).

The intensive application of agrochemicals in Sri Lankan paddy farming has exerted severe impacts on both the biotic and abiotic environments within these fields (Noorhosseini-Niyaki and Bagherzadeh-Lakani, 2011). Furthermore, the current levels of pesticide use in rice production are deemed unsustainable from both economic and ecological perspectives (Noorhosseini-Niyaki and Bagherzadeh-Lakani, 2011). Addressing these challenges calls for the adoption of eco-friendly farming technologies aimed at minimizing inorganic fertilizer usage while ensuring adequate productivity and enhancing soil fertility.

Therefore, the implementation of RFI in potential paddy fields as an eco-friendly farming technology would facilitate improving soil fertility and quality in an environmentally friendly manner in Sri Lanka.

According to Cagauan (1995), fish integration improves nutrient composition of floodwater, the oxidized surface of paddy soil, and the growth of rice plants, and there were four mechanism behind these actions, viz (i) fish contribute nutrients to the rice field through their feces excretion and the decomposition of deceased fish, (ii) fish behavior including swim and reproduction disturb the soil-water interface, while facilitating to release fixed nutrients from the soil into the water and disperse soil particles, (iii) fish make the soil more porous, enhancing nutrient uptake by rice, and (iv) nutrient recycling by grazing on the photosynthetic biomass and other components of the ecosystem.

The excrement produced by fish serves as a nutrient-rich organic fertilizer for rice, thereby decreasing the reliance on inorganic fertilizers for rice cultivation. The fish feces can provide nutrients equivalent to chemical fertilizers. For example, the amount of fish feces produced by 375 kg/ha of fish was comparable to the application of 93.8 kg/ha of ammonium sulfate and 33.8 kg/ha of calcium superphosphate (Weimin, 2010). According to Lu and Li (2006), the nitrogen-fixing function of the system has the potential to elevate the organic matter content, total nitrogen, and total phosphorus in the soil by 15.6-38.5%. Additionally, Madhawa et al. (2023) found notable enhancements in electrical conductivity, organic matter content, soil phosphate, and potassium levels in plots integrated with Tilapia compared to those without fish.

Effects of rice-fish integration on biodiversity of the rice field system in Sri Lanka

The rice field ecosystems are rich in biodiversity, as there is an array of habitats for both fauna and flora. Dynamics of rice field biodiversity largely influence by several factors such as inundation level and its frequency, irrigation mechanisms and systems, elevations, soil conditions, and various management interventions (Jayasiri *et al.,* 2022). According to Bambaradeniya *et al.* (2004), there were 494 invertebrate species, 103 vertebrate species, 89 macrophyte species, and three macro fungi species in rice field ecosystem at Bathalagoda, in the Kurunegala district, belonging to the Intermediate Zone of Sri Lanka. Among them, arthropods were particularly dominant accounting for 405 species. Additionally, a broad spectrum of freshwater invertebrates and a high density of aquatic birds have also been reported in Sri Lankan rice ecosystems (Bambaradeniya *et al.*, 2004; Bellio *et al.,* 2009).

Although the Sri Lankan government prioritizes rice production through rice intensification, an expansion of paddy lands in Sri Lanka face practical difficulties due to paddy land scarcity. Thus, alternative options including the usage of agrochemicals have been employed to increase rice production. However, this approach is not an environmentally friendly technique due to its inherent environmental consequences such as biomagnification, bio concentrations. Further, direct, and indirect impacts on non-target aquatic flora and fauna are also significant (Weerakoon *et al.,* 2018). In spite of the nation's prohibition on numerous pesticides and the adoption of guidelines from the World Health Organization (WHO) advocating restrictions, the persistent issue of excessive pesticide application and insufficient enforcement of policies has resulted in significant environmental pollution in Sri Lanka (Jayasiri *et al.,* 2022). However, the utilization of agricultural pesticides in Sri Lanka experienced a substantial increase of 43% from 1991 to 2018 (Jayasiri *et al.,* 2022).

Pesticide contamination in irrigation water can have adverse impacts on biodiversity within rice field ecosystems (Pandey *et al.,* 2020). The direct exposure to pesticides poses risks to non-target species, soils, and water bodies (Barbieri *et al.,* 2021; Weerakoon *et al.,* 2018). Detrimental effects encompass enzyme function inhibition, bioaccumulation, and tissue damage in fish (Clasen *et al.,* 2018; Gao *et al.,* 2020; Rossi *et al.,* 2020), disruptions in the swimming behaviors of fish and amphibians (Shuman-Goodier *et al.,* 2017), hormonal disruption in frogs (Shuman-Goodier *et al.,* 2017), developmental and biological activity restrictions in beetles (Khan *et al.,* 2018), mortality and altered feeding behavior in spiders, mortality of bees and wasps (Cheng *et al.,* 2018; Yasuda *et al.,* 2017), weight loss, and shifts in enzymatic activity of earthworms (Rico *et al.,* 2016), as well as a reduction in soil microbe populations (Nicomrat *et al.,* 2016). By actively consuming pests and weed propagules, the presence of fish in rice fields contributes to natural pest and weed control, reducing the need for chemical pesticides and herbicides. Consequently, it can help to mitigate the bio magnification of certain substances, such as toxins or pollutants, in food webs.

Moreover, RFI, recognized as an eco-friendly method, often minimizes the need for agrochemicals in pest and weed control, thereby preserving a diverse rice field biota (Weimin 2010) of the country. Madhawa *et al.* (2023) reported a higher biodiversity index (Shannon diversity index (H) of 3.09) in the RFI compared to rice monoculture, indicating greater aquatic biodiversity. Lu and Li, (2006) found that pesticide application can be reduced by 50% compared to modern high-input rice production, and sometimes, very minimum pesticide application is needed when rice is cultivated alongside fish. Therefore, the RFI actively contributes to the preservation of biodiversity of rice field ecosystems (Madhawa *et al.*, 2023).

Rice fish integration and efficient use of water in agriculture practices of Sri Lanka

Paddy cultivation in Sri Lanka follows diverse agricultural practices, with rainfed cultivation predominant in the lowlands wet zone and irrigated practices in the dry and intermediate zones. Notably, over 65% of paddy cultivation relies on major and medium irrigation schemes, with around 20% under minor irrigation schemes and 10% being rainfed (Salman *et al.,* 2022). Despite the country's self-sufficiency in paddy production, Sri Lanka exhibits relatively low levels of water productivity and efficient usage (Salman *et al.,* 2022).

Paddy cultivation, characterized by the continuous inundation of fields during the growing season, is inherently water-intensive. Studies suggest that for rice cultivation, a minimum of 1,000 to 1,500 mm of water is required, with 34% of the total cultivated area dedicated to high water-intensive paddy, consuming over 70% of the total water allocation for food production in Sri Lanka (Shantha & Alli, 2014). Notably, if a hectare of rice field produces 10 metric tons of rice, it still requires 1 to 1.5 m^3 of water to yield 1 kg of paddy (Sevilleja *et al.,* 1992).

In drier areas, irrigated agriculture, primarily focused on paddy production, accounts for 96% of water withdrawals. Despite this substantial water usage, the overall irrigation efficiency in the country stands at a mere 30%, significantly below its potential (Salman et al., 2022).

Recognizing this challenge, the promotion of RFI emerges as a timely and important holistic approach to enhance water use efficiency in Sri Lanka's rice fields. This RFI, where the same water is utilized for both rice and fish production simultaneously, facilitates the coupling of returns from a single paddy field and it also significantly improves irrigation water use efficiency when compared to traditional rice monoculture (Frei and Becker, 2005).

Effects of rice-fish integration on sustainability of rice field systems in Sri Lanka

Wet rice cultivation, with a history spanning at least 4,000 years, suggests that traditional rice farming is fundamentally sustainable. However, uncertainties arise regarding the sustainability of the substantial increases in rice production facilitated by the 'green revolution' (Greenland, 1997). Factors such as global warming, sea level rise, increased ultraviolet radiation, and water availability pose potential threats to rice production. The cultivation of fish in rice fields emerges as a potential enhancer of the sustainability of rice farming, contributing to a more balanced and stable ecosystem. This natural approach not only fosters a healthier environment but also minimizes the necessity for chemical interventions (Wan *et al.,* 2019). Additionally, by actively participating in the regulation of the rice field ecosystem, fish contribute to mitigating the risks of water and soil contamination. Weed removal by fish like tilapia, common carp, silver carp prevents the degradation of water and soil quality attributed to agrochemicals, thereby promoting a more sustainable and resilient farming system (Fahad *et al.,* 2021; Kathiresan, 2007).

Consequently, the integrated cultivation of fish alongside rice holds the potential to mitigate the adverse environmental impacts associated with traditional rice farming practices. By leveraging the inherent behaviors of fish, such as weed consumption and pest control, this approach aligns with the principles of ecological balance and sustainability. Ultimately, the system efficiently utilizes any fertilizers or feeds employed, converting them effectively into food production while minimizing nutrient discharge into the natural environment. Furthermore, RFI has been shown to decrease CH_4 emissions by approximately 30% in comparison to conventional rice farming (Lu and Li, 2006).

Potential rice varieties and fish species to enhance the ecological and economical functions in the RFI

Rice verities

Prior to the introduction of improved rice varieties in Sri Lanka, farmers predominantly cultivated traditional rice varieties (Rambukwella and Priyankara, 2016). However, in recent times, improved rice varieties are grown the majority of rice farmers all over the country (Paddy statistics 2022). Most of popular rice verities cultivate in all over the country is listed in Table 1. With the development of improved rice, several concern affecting rice-fish integration have emerged. The reduced growing period may be of greater concern, as many new varieties mature within approximately 105 days or less (Halwart and Gupta, 2004). With such a short

culture period for fish there is a need to either stock large fingerlings or use of refuge pond to facilitate to reach reasonable fish size in fish integration with improved popular rice varieties in Sri Lanka. A fish refuge is a deeper area where it can provide a space for the fish within a rice field to facilitate to contain fish for further grow whilst the rice is harvested (Halwart 1998). Farmers could also introduce larger size fingerlings with short culture period rice because of their high survival rate, as well as their high growth rate (Haque *et al.,* 2014). This is also agreed with study conducted in Bangladesh with rice-fish farmers, where in general all rice-fish farmers in Bangladesh use a slightly larger size of fingerling in a RFI, believing that fingerlings that start out a bit bigger will grow faster than those that start out smaller (Islam, 2016).

Consumers today (both locally and globally) are more health conscious and more interested in consuming traditional rice, as opposed to improved verities (Ginigaddara and Disanayake, 2018; Rodrigo, 2013). Therefore, at the moment there is a motivation and incentives for farmers to engage in traditional paddy cultivation. A study conducted in Anuradhapura district revealed that 67% of male farmers were willing to cultivate traditional rice varieties over improved verities (Ginigaddara and Disanayake, 2018). There are only handful of traditional rice varieties in existence today. These are: Suwadel, Kuruluthuda, Kalu Heenati, Madathawalu etc. (Table 1). These traditional verities have strong .characteristics which suited for RFI specifically tall and strong stems along with a long cultivation period, enabling them to withstand heavy rains, winds, and floods (Rodrigo, 2013). Therefore, traditional rice varieties could be better suited for RFI in Sri Lanka even with floods and heavy rains especially in low-lying areas.

Table 1 : The most popular rice varieties (improved and traditional) in Sri Lanka – 2016

Improved rice varieties			Traditional rice varieties		
Name	Age (Month)	Distribution (%)	Name	Age (Month)	Distribution (%)
BG 352	3.5	16.4	Suwadel	3.5	0.075
AT 362	3.5	15.4	Kuruluthuda	4 – 4.5	0.022
BG 360	3.5	13.3	Kalu Heenati	3.5	0.012
BG 358	3.5	8.0	Madathawalu	3.5	0.007

Source: *Department of Agriculture, Sri Lanka*

Potential fish species

The key to success of this RFI in Sri Lanka may lie in the use of the right fish. The fish to be stocked in rice fields should be capable of tolerating a harsh environment characterized by: shallow water, high (up to 40°C) and variable temperatures (range of 10°C in one day), low oxygen levels and high turbidity (Khoo and Tan 1980). Fast growth is also mentioned as a desirable characteristic so that the fish could attain marketable size when the rice is ready for harvest (Halwart and Gupta, 2004). Potential inland fish species that could be tried in rice fields for integration with paddy listed in Table 2.

Among the many species available for raising in rice fields, the choice is based on availability, marketability or desirability as food fish (Halwart and Gupta, 2004). In Sri Lanka, tilapia, snakehead murrel, catfishes, barbs and eels are the most demanded freshwater fish varieties and consumers have favorable attitudes towards freshwater fish consumption despite of its smell (Samarasinghe and Dushani, 2012).

Table 2: Potential inland fish species that could be tried in rice fields of Sri Lanka for integration with paddy

Scientific Name	Common Name(s)
Oreochromis niloticus	Nile tilapia
Cyprinus barbus	Barbs
Anguilliformes	Eels
Channa striata	Snakehead murrel
Heteropneustes fossilis	Sting catfish
Clarias batrachus	Walking catfish

(Samarasinghe and Dushani, 2012)

Preferable fish species over inland fish consumption

Tilapia stands out as the primary choice among inland fish species consumed in Sri Lanka, representing a significant portion of dietary intake. A study conducted across six villages in the Northwest province revealed that 60% of respondents included fresh inland fish in their meals, with tilapia accounting for 75–85% of these meals (Murray and Little, 2022). Among university students, tilapia consumption dominates at 64.79%, followed by a preference for Chinese and Indian carps at 19.72% (HMTNB and Radampola, 2016). Additionally, other inland fish, including native species, hold a preference

value of 15.49% (HMTNB and Radampola, 2016). The consistent demand for tilapia can be attributed to its delicate taste, mild flavor, and tender flakes when cooked, making it a favored choice for daily consumption (Suresh and Bhujel, 2012).

Ecological, economical and health benefits of tilapia fish in rice-fish integration

Ecologically, tilapia contribute to nutrient cycling within the system by consuming organic matter, detritus, and excess algae (Lowe-McConnell, 2000). Their excretion and waste products serve as natural fertilizers for rice plants, enhancing soil fertility and productivity (HAQUE, 2019). Tilapia feed on various aquatic organisms, including insect larvae, snails, and weeds, helping to control populations of pests and unwanted vegetation in the rice fields (Halwart *et al.*, 2012). Tilapia actively stir up the water column through their feeding, reproduction and swimming activities, which increases oxygen levels in the water and this helps to prevent oxygen depletion, particularly in areas with dense vegetation or organic matter decomposition, thereby improving overall water quality and supporting other aquatic life (Bashir *et al.*, 2020). Tilapia exhibit resistance to certain diseases and parasites, and their presence in rice fields can help to regulate populations of harmful pathogens by preying on them or competing for resources (Halwart and Gupta 2004).

Economically, tilapia contribute to increased overall productivity of the RFI by providing an additional source of protein and income through fish sales (Cai *et al.*, 2017). Tilapia excrete waste that serves as natural fertilizer (HAQUE, 2019). This reduces the need for chemical fertilizers, thereby cutting down on input costs for farmers. Tilapia feed on pests and insects that may harm rice crops (Halwart *et al.*, 2012). This reduces the need for chemical pesticides, leading to cost savings for farmers. Integrating tilapia into rice farming provides farmers with an additional source of income diversification (Cai *et al.*, 2017). This helps to stabilize farm income and reduce the risk associated with relying solely on rice cultivation (Pollock, 2005). Tilapia farming in rice fields can help mitigate risks associated with fluctuating rice prices or crop failure. The dual-purpose system provides farmers with alternative income sources, reducing vulnerability to market fluctuations or unforeseen events (Islam *et al.* 2015). The consumption of tilapia offers numerous health benefits, including weight reduction, increased metabolism, strengthened bones, and a reduced risk of chronic diseases, owing to the high nutritional content of its flesh (Alam *et al.*, 2016).

Characteristics of tilapia that make them well-suited for rice-fish integration

Tilapia possess several characteristics that make them well-suited for aquaculture and integration. Tilapia has high growth rates, adaptability to a wide range of environmental conditions and ease in rearing (El-Sayed, 2006; Kumara *et al.*, 2023). They can thrive in shallow and turbid waters, have high market value, adapt to various culture systems, exhibit high resistance to diseases and parasites, and are easily bred and maintained in captive environments (Pullin, 1983; Gupta and Acosta, 2001a; Ng and Romano, 2013). Moreover, tilapia demonstrate remarkable tolerance to crowding and can endure relatively stressful and unfavorable conditions, such as low dissolved oxygen levels (<2mg/l) and high ammonia levels (~50 mg/l), for longer durations compared to many other cultured fish species (Suresh and Bhujel, 2012). Additionally, tilapia display versatility in their diet, being able to consume various types of food and thrive on low-cost diets sourced from terrestrial sources (Ng and Romano, 2013).

Integrated farming of tilapia is practiced extensively worldwide. In Southeast Asia, especially Indonesia, Thailand, Vietnam, Cambodia and Myanmar, tilapia culture is widely integrated with agriculture & animal farming (Dey *et al.*, 2000; Little 2000; Gupta & Acosta 2004). Tilapia integrated with crop farming e.g., vegetables, rice and other field crops, was economically attractive and environmentally friendly compared to non-integrated ponds (Jamu 2001). A study conducted in Bangladesh indicated that the hardy fish like tilapia performed better in terms of production and economics than that of others fish species (*Puntius gonionotus* and *Cyprinus carpio*) in RFI. And same study recommended that tilapia can be a good option while selecting aquaculture species for rice field of Bangladesh (Jewel *et al.*, 2018).

Hence, tilapia emerges as an excellent choice for aquaculture species in RFI initiatives in Sri Lanka. This selection not only promote ecological balance within rice fields but also enhances economic viability and promotes better health outcomes among rural rice farmers in the region.

CONCLUSIONS

The findings of the present study clearly highlight that RFI significantly changes the ecological functions of rice fields through their intervention in water, soil nutrients and biodiversity. Further results reveal the usage of chemical inputs like chemical fertilizers, herbicides and pesticide applications are reduced by the biological control of weeds and pests in RFI forming an environmentally friendly farming system and minimize bioaccumulation of toxic substances. Irrigation water use efficiency of RFI is

comparatively higher than that of rice monoculture systems, due to dual usage of same water for fish and rice plants. Considering ecological, economical and health benefits, integration of tilapia fish with suitable rice varieties available in Sri Lanka is proposed.

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DESIGN, DEVELOPMENT AND PERFORMANCE EVALUATION OF PNEUMATIC TYPE AGARWOOD INOCULUM INJECTOR (PAII)

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ABSTRACT

Agarwood, a fragrant resin, is produced by certain tree species in the Thymalaeaceae family as a defense mechanism against stress. In commercial plantations, artificial inoculation of the fungal mix is used to induce the said stress, which is crucial for a fruitful harvest. The paste, containing viscous agar to be applied into drilled holes in the tree trunks and branches. Yet, an efficient tool to deliver this paste is lacking. Currently, inadequate industrial caulking guns are being used, proving time-consuming and ergonomically subpar design. To overcome these limitations, a Pneumatic type Agarwood Inoculum Injector was developed. A 6L capacity cast iron chamber was used as the core pneumatic body of the injector. An HCFE 3/8" non-return valve served as the air inlet. The delivered inoculum passed through a 1mm stainless steel strainer to prevent nozzle blockage. A pressure safety valve, set at 15 bars, released excess pressure. Inoculum compression relied on ambient air, filling up to 5L. A comparison of performance between the new device with the existing caulking gun was done for the inoculum filling rate, time taken to complete a single inoculation point, and the prevented volume of inoculum wastage. With the new device, the average filling volume of inoculum inside the drill holes was increased up to 85.35% and reduced the inoculum wastage from 1.325ml to 0.47ml per drill hole and both improvements were significantly different at the 5% probability level ($p<0.05$). The results concluded that the developed device is capable of delivering a smooth flow of inoculum paste to the target when the impending pressure thrust range is within 5 to 15 bars. Moreover, within this pressure range, the total volume of 5L was delivered at a fairly consistent rate. The invented new device was found to be highly successful in assisting the critical process of inoculation in the commercial-level agarwood industry.

Keywords: Agarwood, Fungal Inoculum Paste, Inoculation, Oud, Pneumatic Injector

INTRODUCTION

Agarwood, a prized and opulent forest product, holds a position of unparalleled prestige in the realm of plant-based aromatics, commanding unparalleled market demand and value (Kanazawa, 2017; López-Sampson & Page, 2018). Its alluring fragrance arises as a result of a self-defense mechanism observed predominantly in the genera Aquilaria and Gyrinops within the Thymalaeaceae family. This captivating phenomenon, however, is not universal across all species, emphasizing the intricacies of agarwood formation and its association with tree species, environmental factors, and genetic variations (Ngadiran *et al*., 2023).

The inception of agarwood formation is intrinsically linked to the stress and adversity that the trees endure. Natural occurrences like wildfires, grazing, and insect attacks inflict wounds upon the trees, setting in motion the self-defense response responsible for the production of this extraordinary resinous material (Liu *et al*., 2019; Fitriasari *et al*., 2021). In the wild, only a modest fraction of Aquilaria trees around 10% undergo this transformative process, underscoring the rarity and unpredictability of natural agarwood formation (Chowdhury *et al*., 2016).

Acknowledging the challenges posed by the erratic nature of natural formation and the pressing demand for agarwood, artificial inoculation methods have emerged as a pivotal means to stimulate resin production in a controlled and deliberate manner (Liu *et al*., 2013).

In commercial-scale production, various stress-inducing methods are practiced to generate agarwood inside trees other than the natural inducing. Considering these artificial methods Nailing, Drilling, Aeration, Agar-wit, partially-trunk pruning, burning-chisel drilling, and fungal inoculation are common techniques among farmers (Liu *et al*., 2013). Among these techniques, fungal inoculation has risen to prominence as a dominant method within the agarwood industry, offering a reliable and effective means of inducing resinous development (Chowdhury *et al*., 2016).

The fungal inoculation technique, at the heart of this study, represents a sophisticated and targeted approach to agarwood induction. It harnesses the interaction between the tree's self-defense mechanism and fungi to provoke the resinous response (Turjaman *et al*., 2016). This technique involves the introduction of beneficial fungal species into strategically drilled holes in the tree trunk (Rasool & Mohamed, 2016).

The fungi, thriving within these microenvironments, trigger the defense mechanism and promote the biochemical reactions inside the tree, culminating in the development of the coveted agarwood resin (Rohlfs and Churchill, 2011).

The choice of fungal species and the intricacies of inoculation significantly influence the quality and yield of the resin produced (Zhang *et al*., 2012). Researchers have explored variations in fungal strains, combinations, and culture conditions to optimize the process and maximize resin output (Justin *et al*., 2020; Ma *et al*., 2021). As such, fungal inoculation stands at the forefront of modern agarwood production, offering a nuanced and sophisticated means to replicate and enhance the resinous properties found in nature.

One of the common methods for practicing fungal inoculation is the agar-based fungal inoculum injected into 10mm (diameter) holes 4 cm (deep) and drilled holes in the tree trunk by caulking guns that are using in the construction field as a temporary basis.

The bores in the tree trunk will begin 50 cm above ground level. Holes should be 20 cm apart in the vertical distance, with about 2-3 holes in a horizontal line around the perimeter (Liu *et al*., 2013). After the holes have been drilled, the inoculation can be carried out using the culture medium used for fungi growth. After inserting the culture into the hole, it should be wrapped in a rubberized fabric or clay (Chowdhury *et al*., 2016).

The Agarwood industry is facing numerous challenges in the above-mentioned inoculation operation. The inoculation process should often be carried out staying either in a ladder or in a twigs often 10-20m above the ground. The inoculation paste should be with high viscosity and thicker enough to avoid the paste discharging back from the hole opening. Therefore, an efficient and effective device for performing this inoculation task is one of the priorities in the agarwood production industry.

As a solution, a Pneumatic type agarwood inoculum injector was developed and tested for its performance in contrary to the existing method to increase the productivity of a critically important inoculation process in the agarwood industry.

MATERIALS AND METHODS

Design and Construction of the Pneumatic Type Agarwood Inoculum Injector

The pneumatic type agarwood inoculum injector was designed and constructed with the primary goal of enhancing the efficiency of the inoculation process by injecting the inoculum paste into drill holes. The device consists of two main components: a pressure-regulated pneumatic storing tank and an inoculum injecting gun, connected by a conveying hose.

A cast iron chamber with a 6 L capacity was chosen as the foundation for the pneumatic tank. The tank's design incorporated a standard HCFE 3/8 non-return valve as the air inlet. The outlet for delivering the inoculum was fitted with a 1mm stainless steel strainer to prevent nozzle blockage. The delivery line from the strainer filter was connected to the inoculum injector gun.

The inoculum-injecting gun, an integral part of the device, featured a fixed needle at its end. This needle possessed a diameter of 5mm and a length of 80mm. The pressure safety valve was an essential addition, designed to release excess pressure when it reached a limit of 15 bar. Compressed ambient air was utilized to compress the inoculum inside the tank, which was filled up to a loading capacity of 4.5L.

The overarching objectives of the device's design were to enhance the inoculum filling rate, improve labor efficiency, and minimize inoculum wastage.

Performance Evaluations

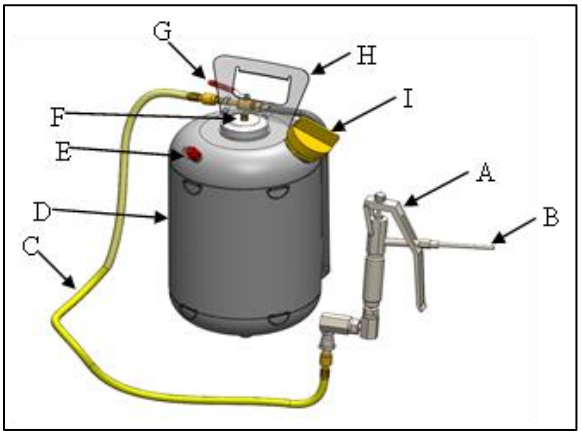

Figure 1: Design model of Pneumatic type Agarwood Inoculum Injector (PAII). (A) Inoculation gun, (B) Needle, (C) Rubber hose, (D) Storing tank, (E) Pressure relief valve, (F) Non-return air inlet valve, (G) Bowl valve, (H) Handle, (I) Airtight lid

Inoculum Paste Discharge Testing with Different Pressure Levels

A laboratory trial was conducted at the Department of Agricultural Engineering, Faculty of Agriculture, University of Ruhuna, Sri Lanka, to assess the discharge characteristics of the inoculum paste at various pressure levels using the pneumatic type agarwood inoculum injector. The tested pressure range spanned from 0.5 to 15 bar, and each pressure level was subjected to four replicate trials. The resulting average discharge values were recorded.

From the collected data, a relatively stable rate of inoculum discharge was identified, aiding in determining the optimal pressure range for the device's operation.

Figure 2: Discharge Testing with Different Pressure Levels

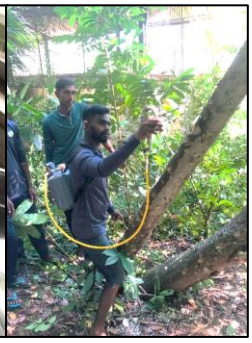

Figure 3: Practicing inoculation by PAII

Inoculum Paste Injecting Performance Evaluation

The performance evaluation of the inoculum injecting process was conducted within the maintained pressure range of the device (5-15 bars) in a commercial agarwood plantation located in Galle, Southern Province, Sri Lanka. The evaluation parameters included the time taken to complete a 10-drill hole operation in seconds, the average volume of inoculum injected per drill hole by collecting them back using a spatula, and the average volume of wasted inoculum due to overflow per drill hole by collecting them.

For the evaluation, twenty *Aquilaria crassna* plants were selected at the appropriate inoculation stage. Drill holes, created near breast height, were introduced using an electric hand drill equipped with a 10mm drill bit, maintaining a depth of 4cm in each hole. A total of 20 inoculation points were established per tree using the specified method. Ten of the selected plants were inoculated using the novel pneumatic type agarwood inoculum injector, while the remaining ten were inoculated using the conventional caulking gun method.

These measurements were then subjected to the paired t-test to determine if there were statistically significant differences in these parameters between the two inoculation methods.

This experimental setup aimed to provide comprehensive insights into the efficiency and effectiveness of the pneumatic type agarwood inoculum injector in comparison to the conventional caulking gun method.

Figure 4: Practicing inoculation process by conventional caulking gun

RESULTS AND DISCUSSION

Selection of optimum pressure range for the inoculum discharge

Laboratory trials were conducted to assess the impact of different pressure levels on the discharge of inoculum using the Pneumatic type agarwood inoculum injector. The objective was to identify the optimum pressure range for achieving consistent and efficient inoculum delivery. The findings offer valuable insights into the influence of pneumatic pressure on the discharge process and contribute to the refinement of the injector's operational parameters.

It was observed that there exists an optimal pressure range within which the inoculum delivery is both consistent and smooth. Specifically, this optimal pressure range was identified as lying between 5 to 15 bars. Within this range, the inoculum discharge exhibited a balanced and effective performance, ensuring reliable delivery without wastage or inefficiencies. When the pressure falls below this threshold, it indicates inadequate inoculum discharge due to insufficient force to elevate the highly viscous inoculum paste against the frictional resistance of the tubes and the inoculum itself.

At pressure levels below 5 bars, the inoculum discharge was characterized by a lower volume, which was insufficient to fully fill the delivery hose up to the discharge nozzle. This indicated a limitation in the effectiveness of the injection process at lower pressures. On the other hand, when the pneumatic pressure exceeded 15 bars, the discharge level increased, but an undesirable consequence emerged: excess inoculum paste was spilled away from the drill holes, leading to wastage. This highlights the importance of maintaining pressure within the optimal range to achieve optimal results.

The pressure discharge curve, constructed based on the experimental data, demonstrated a consistent upward trend. This positive correlation between pressure and average inoculum discharge reaffirms the direct influence of pressure on the injection process. The results indicate that as pressure increases within the optimal range, the average inoculum discharge also increases. For instance, the average inoculum discharge was measured at 839.5 ml/min at 5 bars pressure and improved to 983.5 ml/min at 15

bars pressure. This indicates that the injector maintains a fairly consistent and efficient inoculum delivery rate within this pressure range.

Importantly, the laboratory trials successfully demonstrated that a total volume of 5L could be delivered at a reliable and consistent rate within the identified optimal pressure range of 5 to 15 bars. This substantiates the suitability of this pressure range for practical applications of the device. Consequently, based on these results, it can be confidently concluded that the optimal working pressure range for the Pneumatic type agarwood inoculum injector lies within this range.

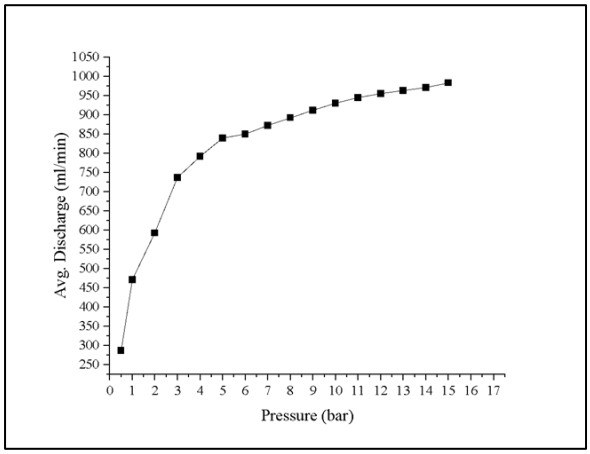

Figure 5: Average inoculum discharge for different pressure levels

Percentage of inoculum filling

The study focused on the comparison between a newly developed pneumatic type agarwood inoculum injector and the traditional caulking gun method for the inoculation of tree trunks. The objective was to assess the efficiency of the new injector in filling the drill holes with agarwood inoculum and to determine whether it outperforms the existing method in terms of filling volume. The results of this investigation provide insights into the efficacy of the new injector and its potential implications for agarwood cultivation.

In the conventional inoculation process, cylindrical holes with a diameter of 10mm and a length of 4cm were created in the tree trunk, resulting in an approximate internal volume of 3.14ml per hole. However, due to the presence of potential fibrous tissues within the hole (Idroes, 2019) , it was hypothesized that the actual filling volume would range between 2.5ml and 3.00ml. The initial assessment revealed that the new pneumatic injector exhibited a substantial enhancement in terms of inoculum filling volume per drill hole compared to the traditional caulking gun method.

The data analysis demonstrated a noteworthy increase in the average inoculum filling volume per drill hole when using the new injector. Specifically, the average filling volume achieved with the new injector was determined to be 2.68ml per hole. In contrast, the average filling volume attained with the traditional caulking gun method was found to be 2.19ml per hole. This discrepancy in average filling volumes between the two methods is of significant importance.

The observed improvement in the filling volume of the drill holes with the new injector can be attributed to its pneumatic mechanism, which allows for a more controlled and consistent injection process. The enhanced precision of the new injector likely contributes to a more efficient use of the available space within the drill hole, resulting in a closer approximation to the total volume of the hole. Consequently, the new injector facilitates a filling process that is more aligned with the theoretical capacity of the drill hole (~3.14ml) compared to the caulking gun.

The statistical analysis conducted on the obtained results further strengthens the significance of the observed differences between the two methods. The paired T-test indicated a statistically significant difference at the 5% significance level ($p<0.05$) between the new pneumatic injector and the traditional caulking gun method. This finding underscores the robustness of the evidence supporting the superiority of the new injector in achieving higher inoculum filling volumes per drill hole.

Labour and time saving

In the context of time efficiency, the performance evaluation demonstrated a significant improvement in the time taken to fill a set of 10 drill holes using the novel device as compared to the caulking gun. Specifically, the average time required to fill 10 drill holes using the novel method was 37.55 seconds, whereas the caulking gun exhibited an average time of 40.65 seconds for the same task. The statistical analysis, utilizing a paired T-test, substantiated these findings by revealing a significant difference at the 5% significance level ($p<0.05$) between the two methods in terms of consumed time.

This reduction in time taken for the inoculation process when using the novel device can be attributed to its pneumatic mechanism, which offers enhanced precision and speed in the injection process. The consistent and controlled injection facilitated by the Pneumatic Type Agarwood Inoculum Injector likely contributes to the observed time savings. The shorter duration required for injecting a similar number of drill holes implies that the Pneumatic Type Agarwood Inoculum Injector can streamline the inoculation

operation, potentially leading to increased efficiency and productivity in agarwood cultivation practices.

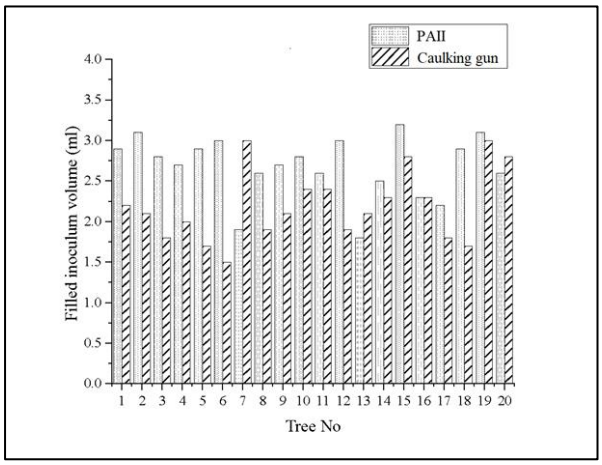

Figure 6: Average volume of inoculum filled in drill holes using PSAII and caulking gun

Figure 7: A segment of an inoculated *A.crassna* branch

Furthermore, the study also considered practical aspects of nozzle congestion and blocking during the inoculation process. The results indicated that neither the Pneumatic Type Agarwood Inoculum Injector nor the caulking gun experienced inoculum paste congestion or nozzle blocking when injecting into a total of 20 trees. However, in real-world field operations, the caulking gun exhibited a notable issue of nozzle blocking, occurring up to five to six times per day. This recurrent problem necessitates frequent nozzle cleaning and refilling time, contributing to increased operational downtime.

The Pneumatic Type Agarwood Inoculum Injector addresses this concern by incorporating a stainless-steel strainer, which effectively prevents nozzle blocking and congestion issues. This design feature enhances the operational reliability of the injector and contributes to its efficiency, particularly in scenarios involving prolonged or continuous use. The absence of a similar provision in the caulking gun's design leaves it susceptible to nozzle-related challenges, further highlighting the advantages of the novel device in real-world applications.

Reduction of inoculum waste volume

The focus of this investigation was to evaluate the wastage of inoculum during the agarwood inoculation process using a Pneumatic type agarwood inoculum injector in comparison to the conventional caulking gun method. The study aimed to quantify and compare the amount of wasted inoculum due to overflow between the two methods, and to ascertain the potential benefits of the newly developed injector in terms of inoculum utilization efficiency and cost-effectiveness.

The analysis of wastage revealed noteworthy differences in the amount of inoculum overflow between the Pneumatic type agarwood inoculum injector and the caulking gun. The results indicate that the Pneumatic Type Agarwood Inoculum Injector exhibited a substantially lower average wasted inoculum volume of 0.86ml per drill hole due to overflow. In contrast, the caulking gun method was associated with an average wasted inoculum volume of 1.325ml per drill hole. This discrepancy in wasted inoculum volumes is of considerable significance.

The observed reduction in wasted inoculum volume when using the Pneumatic Type Agarwood Inoculum Injector can be attributed to its pneumatic mechanism, which facilitates a more controlled and precise injection process. The enhanced accuracy of the injector likely minimizes the occurrence of excessive overflow, resulting in more efficient utilization of the inoculum. As a result, It demonstrates a notable advantage, with approximately 0.47ml less wasted inoculum volume per drill hole compared to the caulking gun.

Furthermore, the statistical analysis using a paired T-test reaffirmed the significance of the differences in wasted inoculum volumes between the two methods. The test revealed a significant difference ($p<0.05$) between the Pneumatic Type Agarwood Inoculum Injector and the caulking gun in terms of wasted inoculum volume due to overflow. This statistical evidence supports the contention that the Pneumatic Type Agarwood Inoculum Injector is more effective in terms of inoculum usage, resulting in reduced wastage and potential cost savings. Nevertheless, operators require some training in operating the new device, as mishandling may lead to the wastage of inoculum. In this experiment, we observed instances of such wastage, particularly in trees numbered 12, 14, and 15, where the new device resulted in greater wastage compared to the existing one.

Table 1: Pneumatic pressure Vs. Inoculum discharge

Pressure (bar)	Replicates R1 (ml/min)	R2 (ml/min)	R3 (ml/min)	R4 (ml/min)	Avg. Discharge (ml/min)
0.5	270	256	260	360	286.5
1	470	469	471	474	471
2	592	590	593	596	592.75
3	739	737	735	734	736.25
4	791	788	795	792	791.5
5	839	837	840	842	839.5
6	848	852	847	854	850.25
7	874	876	868	870	872
8	896	892	894	889	892.75
9	916	912	909	910	911.75
10	932	933	928	927	930
11	951	945	942	940	944.5
12	957	954	952	956	954.75
13	964	967	959	962	963
14	972	974	968	970	971
15	982	988	979	985	983.5

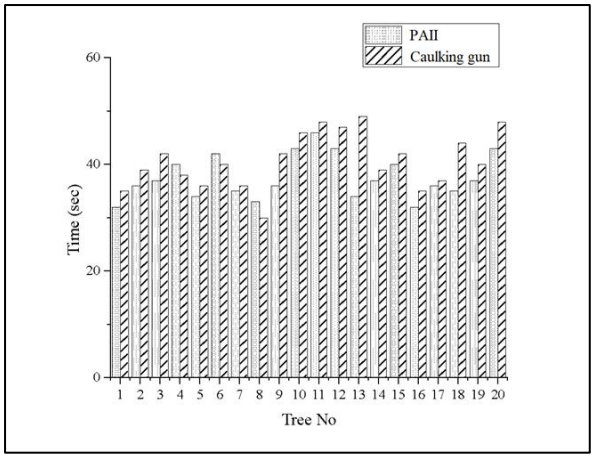

Figure 8: Consumed time to fill a set of 10 drill holes using the PAII and Caulking gun

Figure 9: External view after inoculation process by caulking gun

Figure 10: External view after inoculation process by PAII

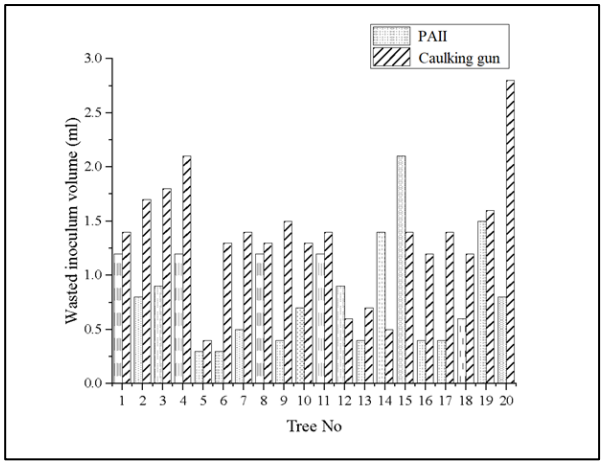

Figure 11: Average wasted inoculum per drill hole by caulking gun and PAII

The implications of these findings are important for agarwood cultivation practices. Minimizing the wastage of inoculum is not only environmentally responsible but also economically advantageous. The reduced wastage associated with the Pneumatic Type Agarwood Inoculum Injector can contribute to cost savings and improved resource utilization, making the inoculation process more economically viable. Moreover, the more efficient inoculum utilization provided by the Pneumatic Type Agarwood Inoculum Injector could potentially lead to better results in terms of inoculation success rates and agarwood production.

CONCLUSIONS

The invented new inoculum injector Pneumatic Type Agarwood Inoculum Injector was successfully operated under the internal pressure range between 5 to 15 bars while achieving smooth and continuous

flow of the inoculum delivery. The performance evaluation has concluded the capabilities of the novel approach with a significant increment of inoculum filling volume and at the same time significantly reducing the wasted inoculum volume and time taken to complete single-hole inoculation. The inoculum filling performance of the Pneumatic Type Agarwood Inoculum Injector was with significantly ($p<0.05$) high rate (2.68ml per drill hole) to the rate of the caulking gun method (2.19ml per drill hole) which the previous one is closer to the theoretical drill hole capacity of ~3.14ml. The time taken to complete single hole inoculation of the Pneumatic Type Agarwood Inoculum Injector device was with significantly ($p<0.05$) low (3.75s/ drill hole) to the time taken to complete it by the caulking gun method (4.06s/per drill hole) highlighting the inoculum delivery efficiency and the possibility of speeding up the inoculation process. The Pneumatic Type Agarwood Inoculum Injector was capable of maintaining a significant reduction of average wasted inoculum volume of (0.86ml per drill hole) to the caulking gun (1.325ml per drill hole). The wastage reduction was a critical consideration in designing the Pneumatic Type Agarwood Inoculum Injector to ensure maximum resource utilization. Moreover, the new device was having with five times more capacity than the existing approach ensuring the reduction of refilling time. Weightless backpack-type design and freehand agronomy were among the other advantages of the device. As such, the newly invented device demonstrated excellent capabilities in fulfilling the task associated with the inoculation process in commercial level Agarwood plantations as a practically viable solution to bring the inoculation process to a new level of business instead of inefficient and ineffective existing caulking gun-based operation environment.

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Acknowledgement: this enable you to thank all those who have helped in carrying out the research. Careful thought needs to be given concerning those whose help should be acknowledged and in what order and to avoid strong emotive language

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