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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.

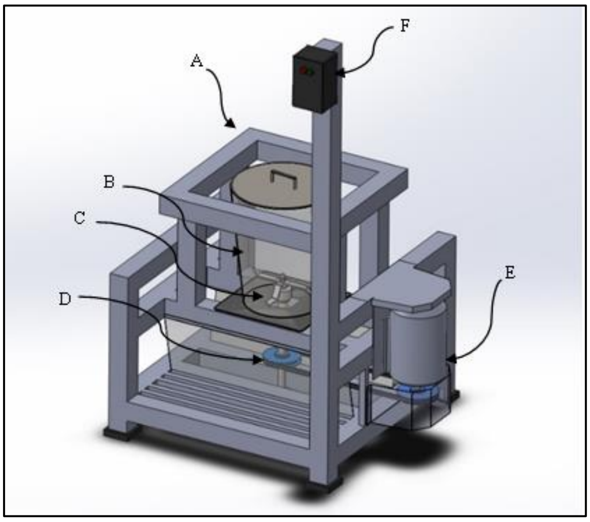

Figure 1: Design model of Agarwood induce inoculum mixing machine. (A) Heavy iron base, (B) Frustum-shaped stainless-steel jar, (C) Mixing blade, (D) Power transmission unit, (E) Induction motor, (F) Control panel.

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.

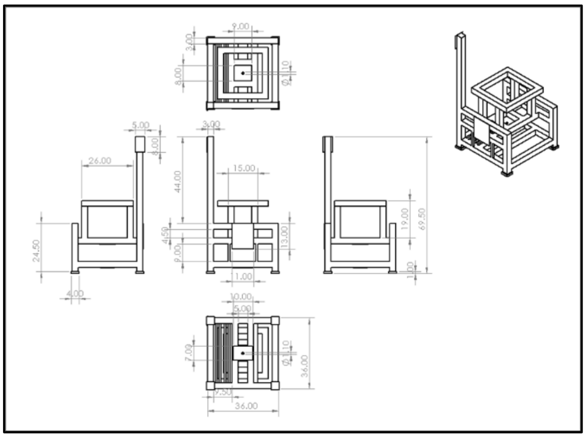

Figure 3: Design sketch of Heavy iron base (Note. all in inches to reduce no. of digits)

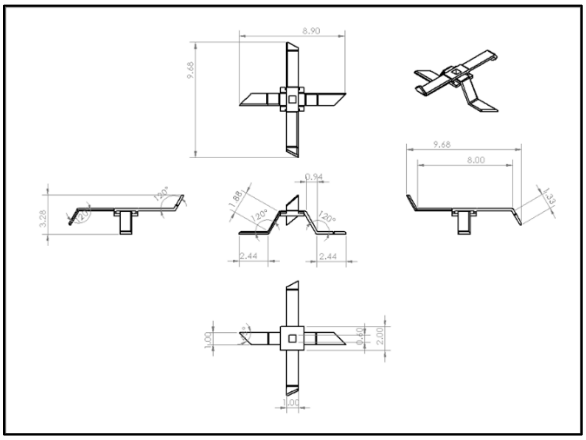

Figure 4: Design sketch of SS mixing blade

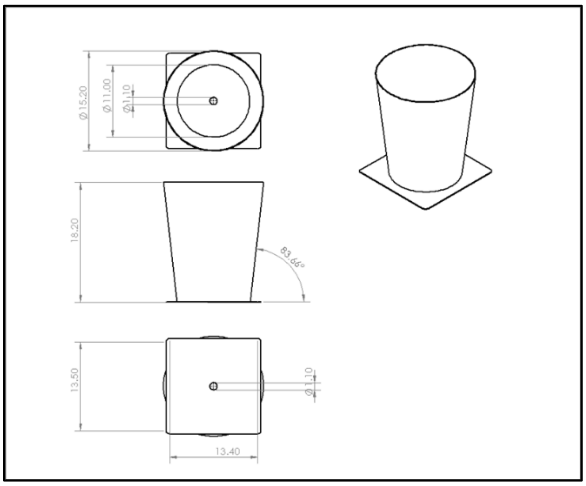

Figure 5: Design sketch of frustum-shaped SS jar

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

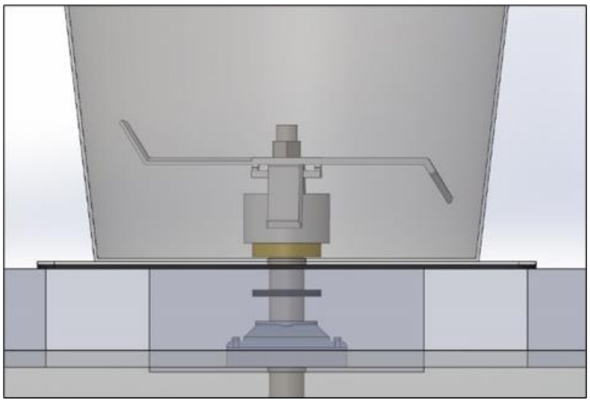

Figure 6: Design of installed mixing blade and the fluid sealing unit

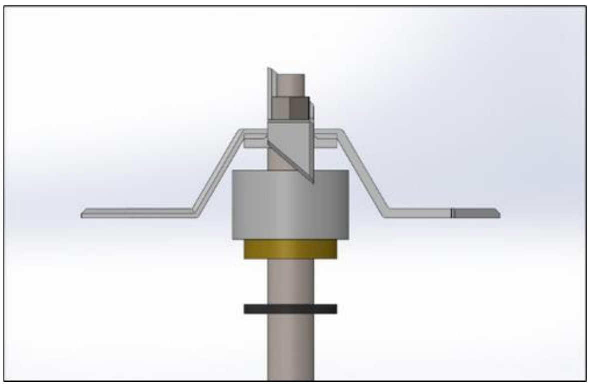

Figure 7: Design of isolated mixing blade and the fluid sealing unit. (A) SS mixing blade, (B) Nylon cap, (C) Brass bush, (D) SS power transmission shaft, (E) Flat rubber ring.

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.

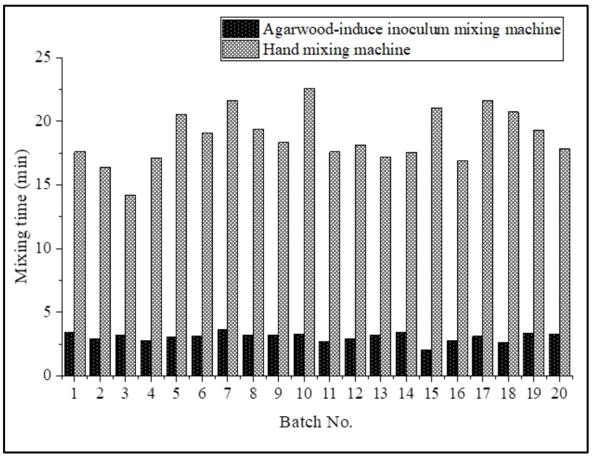

Figure 11: Consumed time to mix raw materials using the hand mixing machine and agarwood-induce inoculum mixing machine

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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REFERENCES

Akter, S., Islam, M. T., Zulkefeli, M. and Khan, S. I. 2013. Agarwood Production - A Multidisciplinary Field to be Explored in Bangladesh", *International Journal of Pharmaceutical and Life Sciences*, 2(1), pp. 22–32. DOI: https://doi.org/10.3329/ijpls.v2i1.15132

Azren, P.D., Lee, S.Y., Emang, D. and Mohamed, R. 2019. History and perspectives of induction technology for agarwood production from cultivated *Aquilaria* in Asia: a review. *Journal of Forestry Research*, *30*, pp.1-11. DOI: https://doi.org/10.1007/s11676-018-0627-4

Chowdhury, M., Hussain, M.D., Chung, S.O., Kabir, E. and Rahman, A. 2016. Agarwood manufacturing: a multidisciplinary opportunity for economy of Bangladesh-a review. *Agricultural Engineering International: CIGR Journal*, 18(3), pp.171-178.

Herath, H.M.W.A.I., and Jinendra, B.M.S. 2023a, Design, development and performance evaluation of Pneumatic Type Semi-Automated Agarwood

Inoculum Injector (PSAII). In *International Symposium on Agriculture and Environment (ISAE)*, (p. 111).

Herath, H.M.W.A.I. and Jinendra, B.M.S. 2023b. Recent Advancement in Agarwood Induction Technology: A Comprehensive Review for the Transformation of Artificial Agar Resin Induction Methods. *Journal of Agro-Technology and Rural Sciences*, 3(1), p.6-17. DOI: https://doi.org/10.4038/atrsj.v3i1.46

Lee, S.Y. and Mohamed, R. 2016. The origin and domestication of Aquilaria, an important agarwood-producing genus. *Agarwood: science behind the fragrance*, pp.1-20. DOI: https://doi.org/10.1007/978-981-10-0833-7_1

Li, W., Cai, C.H., Guo, Z.K., Wang, H., Zuo, W.J., Dong, W.H., Mei, W.L. and Dai, H.F. 2015. Five new eudesmane-type sesquiterpenoids from Chinese agarwood induced by artificial holing. *Fitoterapia*, 100, pp.44-49. DOI: https://doi.org/10.1016/j.fitote.2014.11.010

Persoon, G.A.. 2007. Agarwood: the life of a wounded tree. *IIAS Newsletter*, *45*, pp.24-25.

Turjaman, M., Hidayat, A. and Santoso, E. 2016. Development of agarwood induction technology using endophytic fungi. *Agarwood: science behind the fragrance*, pp.57-71. DOI: https://doi.org/10.1007/978-981-10-0833-7_4

Faizal, A., Esyanti, R.R., Aulianisa, E.N., Iriawati, Santoso, E. and Turjaman, M. 2017. Formation of agarwood from *Aquilaria malaccensis* in response to inoculation of local strains of *Fusarium solani*. *Trees*, *31*, pp.189-197. DOI: https://doi.org/10.1007/s00468-016-1471-9

Xu, Y., Zhang, Z., Wang, M., Wei, J., Chen, H., Gao, Z., Sui, C., Luo, H., Zhang, X., Yang,Y. and Meng, H. 2013. Identification of genes related to agarwood formation: transcriptome analysis of healthy and wounded tissues of *Aquilaria sinensis*. *BMC genomics*, 14(1), pp.1-16. DOI: https://doi.org/10.1186/1471-2164-14-227

Zhou, X., Huang, Y., Wu, S., Chen, X., Sun, W., Gao, Y., Zhang, W. and Gao, X. 2022. Characterization of agarwood by gas chromatography–mass spectrometry and a random forest model. *Analytical Letters*, *55*(9), pp.1364-1381. DOI: https://doi.org/10.1080/00032719.2021.2005081