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Improving the Monitoring and Control of Egg Vitality of *Lymantria dispar* Linnaeus 1758 Using an Innovative Device and Procedure for Removing Egg Hairs

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Abstract: Spongy moth (*Lymantria dispar* Linnaeus 1758) populations have the potential to reach outbreak levels, causing disruptions to forest ecosystems across Eurasia and North America. Continuous monitoring of the size and health of the spongy moth population in the egg stage is important for managing population outbreaks. Current methods include counting eggs within egg masses using manual methods. This study introduces an innovative solution aimed at optimizing the prediction of biotic disturbances and preventing the potential risks associated with spongy moth population outbreaks. The challenges and constraints related to the process of hair removal from spongy moth eggs have been effectively addressed through the development of a device powered by a torque-generating unit. This study aims to (1) introduce a novel device designed for the removal of hairs from spongy moth (*L. dispar*) eggs; (2) introduce a new hair removal procedure; and (3) empirically demonstrate the benefits of the introduced innovations. The introduced device and the procedure enable a significantly expedited diagnosis of the potential for a population outbreak in the current year, with the potential for widespread utilization. This invention enhances our understanding of predicting biotic disorders and facilitates the rapid assessment of the risk of their occurrence.

Keywords: *Lymantria dispar*; egg hair removal procedure and device; forest disturbances; methods of detecting insect outbreaks; integrated pest management

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1. Introduction

In recent decades, disturbances in forest ecosystems worldwide have witnessed a significant surge. Their causes are both biotic and abiotic, including factors such as wind, drought, fire, insects, and pathogens, alongside direct human activities [1]. Disturbances play a pivotal role in the dynamics of natural forests, and a profound understanding of these phenomena enables insights into the ongoing changes within forest ecosystems. The paramount challenge for sustainable forest management lies in integrating knowledge about the escalating frequency of disturbances into effective forest management strategies.

While there are a growing number of inventions focusing on the control or prevention of damage in the field of entomology, a predominant proportion is associated with the use of insecticides, mixtures, and formulations for pest control [2]. In contrast, inventions aimed at enhancing monitoring methods in pest control have remained relatively underrepresented. Given the heightened levels of ecosystem disturbances, ongoing climate changes, introduction patterns, and shifting ranges of invasive pests globally, there exists a universal need for improving methods for studying and monitoring pest populations.

The spongy moth (*Lymantria dispar* Linnaeus 1758, Lepidoptera: Erebidae) stands out as a polyphagous species and is considered one of the most globally significant forest pests [3–7]. Widely distributed throughout the Northern Hemisphere, *L. dispar* is an impactful Lepidoptera species. Caterpillars of this species exhibit a broad polyphagy, defoliating crowns of various forest tree species during outbreak periods (gradation) [8–11].

The population outbreaks of the spongy moth can induce substantial disruptions in forest ecosystems across Europe, Asia, and North America [12,13]. Historically, the spongy moth has been the most significant pest of deciduous forests in Serbia [14,15], with 18 documented population outbreak events from 1862 to present. The most recent outbreak in the Republic of Serbia, spanning from 2010 to 2013, underscored the importance of this pest, necessitating the mobilization of numerous professionals and material resources for effective control [16]. Serbia's extended latency time or erratic occurrences of severe outbreaks have been challenging for capturing by forecasting models [17]. In Europe, cyclical outbreaks of spongy moth populations are documented every 8–13 years [13], while in North America, outbreaks exhibit fluctuations with a dominant period of 10 years and a subdominant period of 4–5 years [18].

Given the cyclic population dynamics of the spongy moth, characterized by occasional surges in large numbers, consistent monitoring and population control measures are imperative on an annual basis. Counting eggs in egg masses stands out as the most practical method for determining the spongy moth population in forests [19]. These eggs are easily visible, facilitating counting and sampling from trees over an extended period of nearly nine months [20].

The annual determination of the presence and quantity of spongy moths in forests is crucial. This approach allows for the observation of changes in the movement of the spongy moth population, enabling the detection of gradation 2–3 years before its culmination. Ongoing monitoring of the population's level and vitality at the egg stage is paramount for effective spongy moth control.

The systematic study of spongy moth egg masses and their parasites is a well-established practice in the Republic of Serbia. The presence of egg parasites, their distribution, and their role in reducing the spongy moth population have been extensively analyzed through various studies [21–31]. The Institute of Lowland Forestry and Environment at the University of Novi Sad is a prominent diagnostic and prognostic center for forest protection in the Republic of Serbia [32–34]. The Institute has been conducting laboratory analyses of spongy moth egg masses since 2004.

When monitoring the spongy moth, maintaining permanent control over its population size and vitality is crucial. The assessment of parasitism in the egg stage through laboratory processing of the eggs plays a vital role in accessing the vitality of the spongy moth population. This assessment aims to determine essential parameters such as the average size of the eggs, the number of fertilized eggs, the percentage of parasitism, and the percentage of hatching. To achieve these objectives efficiently, it is imperative to successfully separate hairs from the eggs. Manual dehairing of egg masses or alternative methods are employed for this purpose [1,10,11,19]. These hairs, originating from the abdomen of female spongy moths, consistently trigger irritation and various dermatological reactions upon contact with the skin or eyes or upon inhalation [35]. Therefore, the conventional (manual) method for removing hairs from spongy moth eggs is characterized by its slow pace, inefficiency, and potential risks for analysts. Furthermore, this procedure lacks standardization and is impractical for application in laboratory settings due to the risk of contamination. The introduction of the current invention aims to address these shortcomings, providing a standardized and considerably accelerated process for hair removal and establishing a feasible procedure applicable in laboratory conditions.

The study aims to achieve the following objectives: (1) Presenting a new device—introducing a novel device designed for the removal of hairs from spongy moth (*L. dispar*) eggs; (2) introducing a new procedure—proposing and outlining a fresh approach to the process of hair removal from spongy moth eggs; and (3) empirical evidence of benefits—

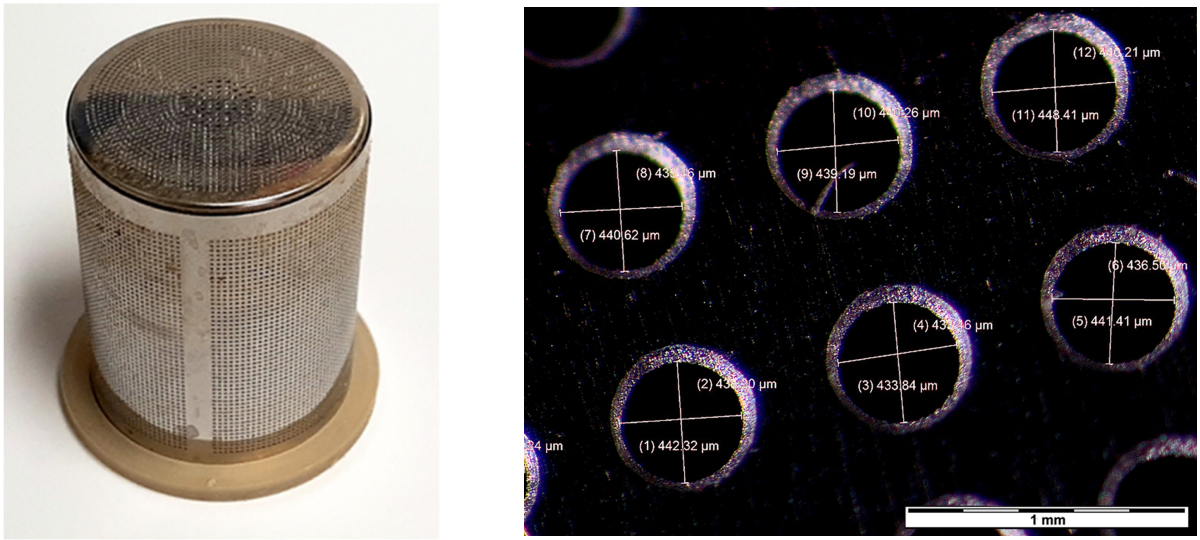
providing empirical evidence demonstrating the advantages of the new hair removal procedure, with a specific focus on reduced operational time.

By addressing these objectives, the study contributes to advancements in the methodology of handling spongy moth eggs, emphasizing the efficiency and effectiveness of the introduced device and procedure, as evidenced by tangible reductions in operational time. The presented method significantly improves the monitoring of population dynamics by advancing the insight into the content, number, and vitality of the separated eggs of the spongy moth. The population abundance and potential for outbreaks is more successfully controlled, thus minimizing the economic losses and improving pest management programs.

2. Materials and Methods

This study introduces a newly discovered procedure and device designed for the meticulous removal of hairs from *L. dispar* eggs. Monitoring of the separation process is facilitated by the design of a transparent glass cylindrical tube. The materials of all other parts are easily replaceable due to wear and tear. Their manufacturing methods are in accordance with the highest standards to meet tolerance constraints.

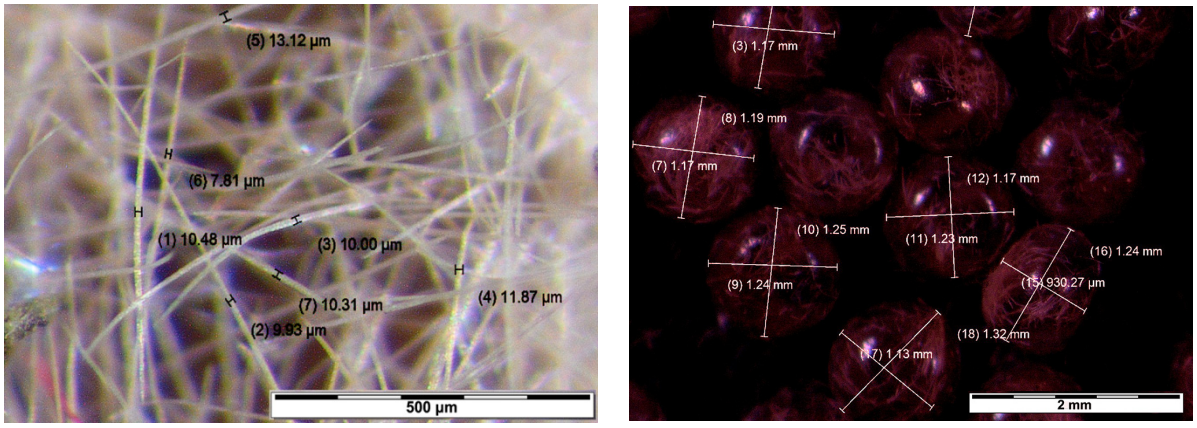
In designing the removable cylindrical insert with mesh (Figure 1a) incorporating a sieve with openings (Figure 1a), a key principle was adhered to. The opening size was deliberately chosen to be optimally larger than the hairs, facilitating the smooth passage of as many hairs as possible through the maximum number of sieve openings to the suction device. Additionally, careful consideration was given to ensuring that all eggs remain contained within the insert by designing the opening to be smaller than the smallest eggs. The size of the sieve opening (Figure 1b) ranges from 400 to 450 µm. The hair width (Figure 2a) ranges from 5 to 15 µm, while the dimensions of the egg diameter (Figure 2b) range from 1 to 1.5 mm. The dimensions of the sieve openings, as well as the hair width and egg diameter, are visually depicted in Figures 1 and 2, respectively.



(**a**) (**b**)

Figure 1. (**a**) Sieve for depositing separated spongy moth egg mass and openings for hairs sieving; (**b**) the dimensions of the sieve openings, enlarged.

The size of the cylindrical insert with mesh (5) in Figure 3 is specifically tailored to accommodate the largest egg masses from the tested series. This thoughtful design ensures that the device can effectively handle a range of egg mass sizes encountered during testing.



(**a**) (**b**)

Figure 2. (**a**) Dimensions of hairs from a spongy moth egg mass. (**b**) Dimensions of eggs from a spongy moth egg mass.

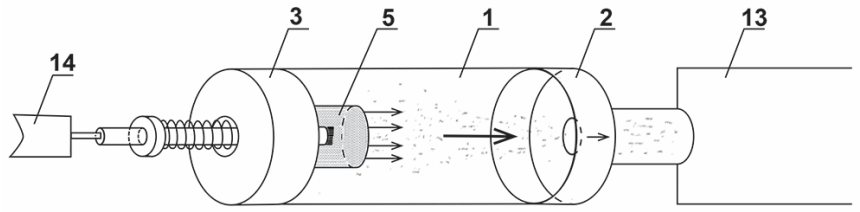


Figure 3. Device with basic parts (1—cylindrical tube, 2—cap, 3—cap with thread, 5—cylindrical insert with mesh, 13—suction unit, 14—torque transmission device).

The device itself is composed of a cylindrical tube (1) (Figure 3) designed to receive the cylindrical insert with mesh (5) (Figures 1a and 3). Additionally, it features a cap (3) (Figure 3) that can be threaded onto the cylindrical tube, forming a cohesive and functional unit (Figure 4). This design choice ensures ease of use and promotes functionality throughout the operation of the device. The threaded cap provides stability and security, enhancing the overall performance and usability of the device in the removal of hairs from spongy moth egg masses.

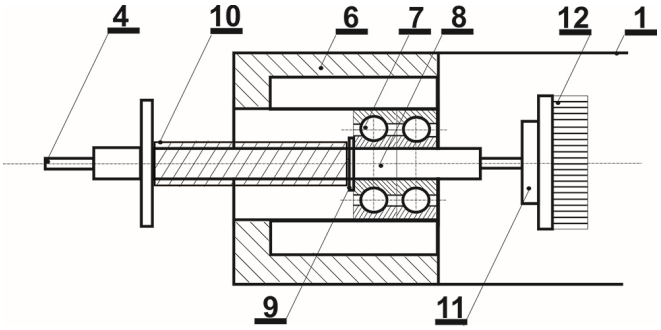


Figure 4. Cap with thread (3, Figure 5) as part of the complex hair removal mechanism (1—cylindrical tube, 4—gripper, 6—bushing, 7—ball bearing, 8—shaft, 9—ball bearing stop, 10—spring, 11—brush holder, 12—brushes).

The device for removing hairs from *L. dispar* eggs comprises several components (Figures 3 and 4), including a cylindrical tube (1) (Figures 3 and 4) with slotted threads on the sides of the cap (2) (Figure 3). The cap has threads and a slot through which the suction tube of the suction device (13) (Figure 3) is inserted. Additionally, there is a cap (3) (Figure 3) that is part of the complex mechanism for hair removal. It is wound on the opposite side of the cylindrical tube and serves to connect to the device (14) (Figure 3), which transmits the

torque (electric motor). Another integral part is the removable cylindrical insert with mesh (5) (Figure 3). The threaded cap (3) (Figure 4) and the complex hair removal mechanism (Figure 4) consist of the following components: bushing (6) (Figure 4), shutter opening, ball bearing (7) (Figure 4), shaft (8) (Figure 4), ball bearing stop (9) (Figure 4), spring (10) (Figure 4), brush holder (11) (Figure 4), and brushes (12) (Figure 4).

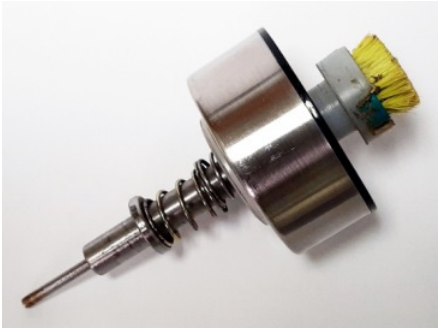


Figure 5. Cap with hair removal mechanism of the device prototype.

The procedure for removing hair from spongy moth eggs is centered on the use of the device designed for this purpose (Figure 3). The process initiates by connecting the suction tube of the suction device (13) (Figure 3) to one side of the cylindrical tube (1) of the device (Figure 3). Simultaneously, on the other side, the cap (3) (Figure 3) is opened, allowing the separate insertion of the cylindrical insert (5) (Figure 3) with the mesh, placing it carefully on a distinct spongy moth mass containing eggs.

After introducing the egg mass into the insert (5) (Figure 3), the cap (3) (Figure 3) with a thread and the hair removal mechanism is closed tightly onto the cylindrical tube (1) of the device (Figure 3). The suction device (13) (Figure 3) is activated, followed by the torque device (14) (Figure 3), which rotates the shaft of the hair removal mechanism (3) (Figure 3). The torque device (14) (Figure 3) can be a milling head or another device equipped with a mechanism for transmitting torque to the shaft, with the option to adjust the number of revolutions in steps.

The fine adjustment is facilitated by the pressure exerted by the device with torque securely connected to the device via the spring (10) (Figure 4) on the shaft of the device (Figure 4). Consequently, the brush (12) (Figure 4), in controlled contact with the collected egg mass, effectively separates the hairs. The separated hairs are then drawn through the openings of the cylindrical insert (5) (Figure 3) with a mesh (Figures 1a and 3). Meanwhile, the larger eggs are retained within the insert (5) (Figure 3), dehaired, and prepared as a sample for laboratory analysis.

The gripper (4) (Figure 4) of the shaft is extended and modulated (Figure 5) to establish a connection with the gripper of the torque transmission device (14) (Figure 3). The brush (12) (Figure 4), serving as part of the threaded closure and hair removal mechanism (Figure 5), is attached to the holder (11) (Figure 4) on the shaft. This attachment involves regulated pressure (hand pressure) and simultaneous torque (from unit (14) with torque) (Figure 3). The brush actively participates in the process of separating adhesive hairs from spongy moth eggs.

During the hair removal and suction process, the action occurs through a transparent cylindrical tube from the opening of the cylindrical insert (6) (Figure 4) with a mesh towards the suction unit (13) of the device (Figure 3). Once a small cloud of hairs has passed through the cylindrical tube (1) (Figures 3 and 4), the torque transmission device (14) (Figure 3) and the suction device (13) (Figure 3) are switched off. This allows for the release of the shaft with the brush (12) (Figure 4) from pressure against the eggs, and the device can be opened.

Subsequently, the cap with thread and hair removal mechanism (Figure 3) is unscrewed, and the cleaned eggs are extracted from the cylindrical mesh insert (Figure 1a). In

a Petri dish or any other suitable container for laboratory analysis, the cleaned and dehaired eggs are shaken out for counting. This marks the completion of the procedure.

Description of the manual procedure for the removal of gypsy moth's hair:

1. The operator employs tweezers to extract the egg mass, transferring it to a Petri dish.
2. The stopwatch is initiated, and the egg mass is delicately crushed into the smallest possible pieces using the fingertips (Figure 6a).
3. Hairs separated from the eggs are eliminated through gentle blowing (Figure 6b).
4. The operator notes the duration of the operation.
5. Completely dehaired eggs are set aside for counting.

(**a**) (**b**)

Figure 6. (**a**) Separation of the eggs from the hairy mass with the cheekbones of the fingers. (**b**) Removing detached hairs from the eggs by gentle blowing.

This traditional procedure involves manual handling of the egg mass, physical crushing, and a process of gentle blowing to separate hairs. The total time taken for these steps is recorded, and the dehaired eggs are then prepared for counting.

Description of the new procedure for the removal of spongy moth's hair is as follows:

1. The operator activates the machine with torque by plugging it into the power source.
2. The operator switches on the suction unit.
3. Using tweezers, the operator extracts the egg mass and transfers it to a container equipped with a sieve.
4. The operator seals the container with the sieve, securing the spongy moth egg mass between the cylindrical tube of the device and the cap with the hair removal mechanism (Figure 3).
5. The operator activates the torque-generating unit by selecting the corresponding rotation speed and starts the stopwatch.
6. Applying gentle hand pressure and utilizing the torque generated by the machine, the operator, while stabilizing the cylindrical tube containing the egg mass, removes hair from the eggs.
7. Upon observing, through the transparent glass of the cylindrical tube, that the hairs from the egg mass have been suctioned into the unit, the operator turns off the device and stops the stopwatch.
8. The operator records the duration of the operation.
9. The dehaired eggs are arranged in a numbered Petri dish and are prepared for egg purity analysis.
10. The container containing waste from the suction unit is transferred to a numbered container for analysis of the purity of the discarded hairs.

This new procedure involves the use of machinery, specifically a torque-generating device and a suction unit, streamlining the process of hair removal from spongy moth eggs. The steps are systematically recorded, and the dehaired eggs, as well as waste, are prepared for further analysis.

An empirical analysis was conducted to compare the working parameter duration of the two procedures—old (manual) and new (mechanical). Additionally, for the new procedure, the influence of rotation speed (10,000 rpm vs. 15,000 rpm) and the effect of brush type (stiff bristles vs. soft bristles) on the duration were investigated by comparative analysis. To fulfill these specified objectives, 30 egg masses were selected (collected from The forest Holding "Sremska Mitrovica", Locality Džepuš, 45°02′39.8″ N 19°11′04.9″ E, north-western Serbia) and randomly divided into five groups:

1. Group 1, comprising 10 egg masses, was allocated for manual separation of eggs from hairs.
2. Group 2, consisting of five egg masses, was allocated for mechanical separation of eggs from hairs at a speed of 10,000 rpm using a brush with stiff bristles.
3. Group 3, consisting of five egg masses, was allocated for mechanical separation of eggs from hairs at a speed of 15,000 rpm using a brush with stiff bristles.
4. Group 4, comprising five egg masses, was allocated for mechanical separation of eggs from hairs at a speed of 10,000 rpm using a brush with soft bristles.
5. Group 5, consisting of five egg masses, was allocated for mechanical separation of eggs from hairs at a speed of 15,000 rpm using a brush with soft bristles.

To neutralize the effect of varying egg mass sizes, measured duration times were adjusted to represent seconds per 100 eggs: $t = (t_0/N) \times 100$, where t_0 represents the original measured time, N denotes the number of eggs in an egg mass, and t represents the standardized time. The time duration for both the traditional and innovative method was measured using a stopwatch. The flowchart of the egg dehairing methodology testing is represented in the Figure 7.

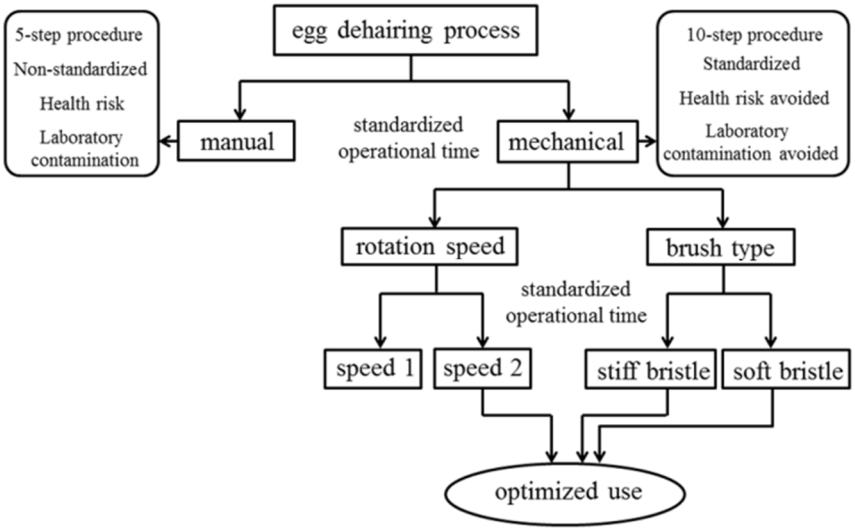


Figure 7. Methodological flowchart of egg dehairing testing process.

The original experimental design aimed to facilitate a simultaneous comparison of the standardized operational times across all five groups using the Kruskal–Wallis ANOVA by rank test. However, a complication arose when it was discovered that in four samples, subsequent to hair removal, no eggs were found. This absence of eggs precluded the calculation of standardized operational time, resulting in a reduction in sample size in two out of the five groups. Consequently, the analysis plan required modification.

To address this, the groups were amalgamated, and the individual impact of three variables was examined: the method of separation (manual vs. mechanical), rotational speed during mechanical separation (Speed 1—10,000 rpm vs. Speed 2—15,000 rpm), and the type of brush used in mechanical separation (soft bristles vs. stiff bristles). Due to the non-normal distribution of the dependent variable, the non-parametric Mann–Whitney U test was employed with a significance level set at 0.05. The outcomes of the statistical

analysis were further elucidated through box-and-whisker plots delineating extreme values, quartiles, and the median of the standardized operational time for each group. All statistical analyses were executed using Statistica 10.0 software (StatSoft Inc., Tulsa, OK, USA)

3. Results

In order to compare the standardized operational times of the procedures, we compared Group 1 (manual procedure, 10 egg masses) with combined Groups 2–5 (mechanical procedure, 16 egg masses). The decreased number of egg masses in Groups 2–5 is attributed to the fact that four egg masses subjected to mechanical hair removal contained zero eggs, making it impossible to calculate the standardized operational time (t). The results are presented in Table 1.

Table 1. Descriptive statistics for standardized duration time for two procedures.

Standardized Operational Time (s per 100 Eggs)	Old (Manual) Procedure	New (Mechanical) Procedure
Number of egg masses	10	16
Mean	61.88	5.89
95% CI for mean	(47.42, 76.34)	(3.59, 8.18)
Median	58.02	4.83
Minimum	39.47	1.35
Maximum	93.67	17.14
Standard Deviation	20.21	4.31
Coefficient of Variation	32.66%	73.23%

Table 1 shows that duration time for the manual procedure was from 39.47 to 93.67 s per 100 eggs and the average time was 61.88 ± 20.21 s, whereas the duration time for the mechanical procedure was from 1.35 to 17.14 s per 100 eggs and the average time was 5.89 ± 4.31 s. Furthermore, the mechanical procedure is significantly less variable (CV = 32.66%). The Mann–Whitney test was performed in order to compare duration times of two procedures. The results (U-statistics = 0.00, Z-value = 4.19, p-value = 0.0003) confirm that the duration time for the new procedure is statistically significantly shorter.

The second criterion of comparison was the rotation speed in the applied mechanical procedure. Therefore, we compared combined Groups 2 and 4 (rotation speed 1, 10,000 rotations per minute, eight egg masses) with combined Groups 3 and 5 (rotation speed 2, 15,000 rotations per minute, eight egg masses). The results are presented in Table 2.

Table 2. Descriptive statistics for standardized duration time for two rotation speeds.

Standardized Operational Time (s per 100 Eggs)	Speed 1 (10,000 rpm)	Speed 2 (15,000 rpm)
Number of egg masses	8	8
Mean	8.59	3.18
95% CI for mean	(4.73, 12.44)	(2.04, 4.33)
Median	6.90	3.05
Minimum	2.71	1.35
Maximum	17.14	5.77
Standard Deviation	4.61	1.37
Coefficient of Variation	53.71%	42.95%

Table 2 shows that duration time for the procedure speed 1 was from 2.71 to 17.14 s per 100 eggs and the average time was 8.59 ± 4.61 s, whereas the duration time for the procedure speed 2 was from 1.35 to 5.77 s per 100 eggs and the average time was 3.18 ± 1.37 s. The Mann–Whitney test was performed in order to compare duration times of the two rotation speeds. The results (U-statistics = 6.00, Z-value = 2.68, p-value = 0.007) confirm that the duration time for procedure speed 2 is statistically significantly shorter.

The final goal was to compare the duration times obtained by using different brush types in the applied mechanical procedure. Therefore, we compared combined Groups 2 and 3 (brush with stiff bristles, eight egg masses) with combined Groups 4 and 5 (brush with soft bristles, eight egg masses). The results are presented in Table 3.

Table 3. Descriptive statistics for standardized duration time for two brush types.

Standardized Operational Time (s per 100 Eggs)	Brush with Stiff Bristles	Brush with Soft Bristles
Number of egg masses	8	8
Mean	7.48	4.29
95% CI for mean	(3.03, 11.93)	(2.31, 6.27)
Median	4.92	4.15
Minimum	2.80	1.35
Maximum	17.14	7.06
Standard Deviation	5.33	2.37
Coefficient of Variation	71.21%	55.18%

Table 3 shows that duration time for the mechanical procedure which applied a brush with stiff bristles was from 2.80 to 17.14 s per 100 eggs and the average time was 7.48 ± 5.33 s, whereas the duration time for the mechanical procedure which applied a brush with soft bristles was from 1.35 to 7.06 s per 100 eggs and the average time was 4.29 ± 2.37 s. The Mann–Whitney test was performed in order to compare duration times with two applied brush types. The results (U-statistics = 19.00, Z-value = 1.31, p-value = 0.19) suggest that the differences between the two types are not statistically significant at the significance level 0.05.

Notably, the application of the mechanical hair removal procedure did not result in a significant number of cracked or crushed eggs, as the average percentages for all methods applied did not exceed 1%. Specifically, for the mechanical procedure, the average percentage of cracked eggs was 0.44 ± 0.82%, while the average percentage of crushed eggs was 0.34 ± 0.67%. In contrast, for the manual procedure, the average percentage of cracked eggs was 0.82 ± 0.74%, and the average percentage of crushed eggs was 0.74 ± 0.82%. Detailed results are presented in Table 4, which includes data for individual subgroups within the mechanical procedure, as well as aggregated results for all mechanically treated egg masses and the manually treated egg masses.

Table 4. Average percentage of cracked and crushed eggs.

Method	% Cracked Eggs (Mean ± SD)	% Crushed Eggs (Mean ± SD)
Mechanical Pr., Speed 1	0.10 ± 0.18	0.58 ± 0.89
Mechanical Pr., Speed 2	0.79 ± 1.07	0.10 ± 0.19
Mechanical Pr., Stiff Bristles	0.71 ± 1.08	0.60 ± 0.88
Mechanical Pr., Soft Bristles	0.12 ± 0.18	0.08 ± 0.17
Mechanical Pr., all groups	0.44 ± 0.82	0.34 ± 0.67
Manual Procedure	0.82 ± 0.74	0.74 ± 0.82

4. Discussion

The comparison between the old (manual) and new (mechanical) procedures reveals notable differences. In terms of the structure, the manual procedure comprises 5 stages, while the mechanical procedure involves 10 stages. In the new procedure, the initial two stages involve activating the suction unit and the torque machine. Subsequently, both procedures initiate the phase of separating the egg mass from the tree bark.

In the traditional procedure, the egg mass is transferred to a Petri dish, followed by gentle crushing into smaller pieces using the fingertips. Conversely, in the new procedure, the egg mass is placed into a container dish with a sieve. The container is then sealed, securing the gypsy moth egg mass between the cylindrical tube of the device and a cap with

a hair removal mechanism. The device, set to the desired transmission speed, is activated, and the stopwatch is initiated, marking the beginning of the separation process. As the hairs pass through the glass tube, the seventh phase is completed. The stopwatch is paused, the time is recorded, and the device is switched off. The operator notes the operation time.

In the traditional method, the crumbled material is meticulously separated from the eggs using fingertips (Figure 6a), and finer hairs are blown away (Figure 6b). The time is measured, and the eggs are prepared for counting and hatching, with subsequent monitoring of caterpillar hatching.

The new procedure includes two additional stages. In stage 9, the eggs are prepared for the analysis of egg purity, and in stage 10, waste from the suction unit is readied for the analysis of discarded hairs. The tenth stage in the new procedure allows for the analysis of hairs that could not be examined in the traditional procedure.

However, despite the increased number of operational steps, the required operational time and therefore the efficiency of the new procedure is significantly improved compared to the manual procedure, as demonstrated by the conducted empirical analysis. The average standardized time (calculated per 100 eggs in egg mass) is reduced by more than tenfold, while the standard deviation is decreased by approximately fivefold. Moreover, the results show further improvement when the mechanical procedure is optimized by utilizing a higher operational speed of 15,000 rotations per minute and employing a brush with soft bristles. The observed differences in standardized operational times with various brush types were not statistically significant with the current sample. We anticipate that in the continuation of the study, with larger samples of egg masses, we would be able to empirically demonstrate the advantages of employing a brush with soft bristles. Additionally, the percentage of damaged (crushed or cracked) eggs is not increased by the mechanical procedure, which could have been considered the main potential expected downside of semi-automation.

5. Conclusions

In this study, we introduced a novel method, along with a mechanical device designed for removing hairs from spongy moth eggs, and empirically demonstrated its significant efficiency enhancement compared to the traditional manual approach.

The device facilitates swift, effective, and controlled semi-automated hair removal from *L. dispar* eggs while mitigating the risk of environmental contamination in the laboratory setting. With this procedure, the integrity of the eggs is preserved, ensuring the vitality of the egg caterpillars within the chorions remains intact without disruption to their vital functions.

A key advantage of this invention lies in its potential for widespread application, notably reducing the time required for performing the conventional manual procedure while also contributing to the standardization of spongy moth egg hair removal process. The method is adaptable to laboratory conditions and can also be utilized in outdoor settings where power sources for the suction device and electric motor are available. Furthermore, this invention holds relevance for professionals engaged in forest conservation and protection efforts, serving as a valuable tool for identifying and managing the disruptive potential of spongy moth proliferation and facilitating timely responses from forestry management to disturbance events.

By advancing our understanding of biotic disorder prediction and expediting risk assessment, this innovative device and the procedure significantly improve methods for detecting spongy moth occurrence and potential proliferation, aiding in preventing catastrophic outbreaks. Improved accuracy in predicting forest disturbances and pest management is achieved, thereby enhancing monitoring and control of spongy moth egg vitality.

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