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A Mobile and Height-adjustable Smoker for Calming Giant Honeybees (*Apis dorsata*)

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ABSTRACT

The giant honeybees (*Apis dorsata*) plays an important role as pollinators, which are vital in plant reproduction. They help the forest and perennial crops by mediating speciation, promoting genetic diversity, and contributing to ecosystem stability. They live in large colonies with vertical comb and commonly make nests in natural sites and man-made structures. If disturb they may aggressive and attack the inhabitants in the area. Therefore, removal of their nest is a common practice especially when they are located in populated places. The removal of the nests can be harmful to the bees and destruction of colonies with fire is commonly reported. It would be more prudent to use mild smoke to disperse the bees and relocate the comb to a safer location. Unfortunately, there is currently no safe and reliable smoking device available to reach inaccessible combs. This study aims to introduce a new height-adjustable smoker as a solution for this problem. The smoker includes a combustion chamber and a pumping and delivery unit. The performance of the smoker was evaluated in Anuradhapura area using existing combs near human settlements. Different compaction levels of smoking fuel (a mixture of rice straw and guinea grass in a 1:1 ratio) were tested, and measurements were taken for firing time, smoke flow rate, total time, and smoke temperature. The data was then analyzed using ANOVA with a Complete randomized design at a significance level of $p<0.05$. The optimal compaction level for smoke generation was determined to be 67.5 g/ L. At this level, the firing time, smoke flow rate, and temperature were 21 minutes, 18.5 L/minute, and 37°C, respectively. It took only 8 mins to completely disperse giant honeybees from the colony. Therefore, the smoker can be recommended as an effective and safe method for dealing with giant honeybees.

1. Introduction

Honeybees play an admirable role in maintaining the balance of ecosystems and are of immense importance for both natural and agricultural environments. Honeybees are responsible for pollinating of numerous flowering plants, including fruit, vegetable, and nut crops ensuring the continued growth and productivity of the agricultural industry. In addition to that, honeybees also produce honey, beeswax, propolis, and royal jelly, which have several economic and medicinal uses (LiverTox, 2022). Hence, honey bees play a crucial role in promoting green development of agricultural. The present agricultural methods contribute significantly to environmental pollution due to their reliance on numerous harmful inputs, both directly and indirectly. Consequently, the adoption of green development in agriculture becomes imperative for ensuring sustainable agricultural production (Lei et al., 2022; Luo et al., 2022). The survival and conservation of honeybees are therefore crucial for maintaining a healthy and functional environment.

The majority of honey produced in many countries in Southeast Asia (around 70-80%) comes from the free-living giant honey bees, namely *Apis laboriosa* and *Apis dorsata* (Woyke et al., 2008). *Apis dorsata* (giant honeybee) has the largest natural colony size among all the honeybee species. They are also known as Rock bees and has a widespread distribution throughout the Asia, including Sri Lanka, India, Malaysia, Indonesia, and Philippines (Budagoda et al., 2010). In Sri Lanka, the giant honeybee is called *Bambara* in the local language (Sinhala). This species is native to tropical and subtropical Asia (Tan et al.,1997). These giant honeybees construct nests of various shapes and sizes, which can be found in trees, houses, caves, and overhead water reservoirs (Misra et al., 2017). Unlike other species in the genus, *A.dorsata* builds a single vertical comb, usually about 0.5 square meters in size, attached to the underside of a rock cliff, the cave of a building, or a tree branch (Punchihewa et al., 1985).

The coexistence of giant honeybees with human populations is not without challenges. Fear and misunderstanding of these bees often lead to destructive actions, such as hive destruction, posing a significant threat to the species' survival in certain areas. The nesting behavior of giant honey bees in human dwellings, such as buildings and houses, presents a significant issue. While these bees are crucial pollinators, their presence in close proximity to people can pose a threat, leading to the destruction of their colonies. Efforts have been made to remove these colonies from structures, but they often recolonize the same location after some time, exacerbating the human-bee conflicts. These conflicts are increasingly becoming a serious concern in various sectors of the country, including plantations and tourism.

Since the natural habitats of giant honeybees are destroyed for human settlements and development projects in the country, they have built their hives in many places in Sri Lanka, where humans are living, making a threat for human safety. Stinging incidents caused by giant honeybees in Sri Lanka are a frequent environmental danger, resulting in numerous hospital admissions. Honeybee stings can lead to various effects, ranging from irritation to a severe condition known as anaphylactic shock (Budagoda et al., 2010). According to a study by Witharana, et al., 2015, the Deniyaya hospital had a total of 11,254 patients admitted for emergency treatment due to insect attacks between 2011 and 2013. Out of these patients, 90.7% were stung by giant honeybees. Out of the total number of patients, 62% had experienced stings while working in tea plantations. Generally, in response to these attacks, people employ various measures such as setting fire to hives, using harmful chemicals, or employing different types of smoke to remove and drive away the bees ignoring the damage caused to bees.

Application of smokes before handling bees is important to calm down them and also preventing them to communicate each other by using pheromones (Salkeld, 2021). Considering this phenomenon, a small apparatus called smoker is used in bee keeping with domesticated bees such as *Apis mellifera* and *Apis cerana* for making smoke and directing a stream of it upon the bees to quit them. It is one of the essential tools of beekeeping to calm the bees when working with them. The most common smoker in the honey industry consists of a metal firepot with a funnel shape outlet and a leather bellow to inject air by pumping (YamadaBeeFarm, 2005). However, this smaller smoker is not appropriate for large honeybees because it has several deficiencies, including a short firing time, negative effects on bees, low emission of smoke, inability to control smoke, and the requirement to climb trees or tall buildings to reach the hives.

Therefore, to guarantee the safety of both humans and bees, this study aimed to develop a height-adjustable, mobile smoker capable of producing gentle smoke for a long duration. This device will be used to effectively repel giant honeybees residing in areas densely populated by humans. Most of the hives of giant honeybees are constructed at distances of 10 m or even 100 m above the ground, while only a few hives are built less than 1 m above the ground (Crane, 1999; Khan et al., 2007; Sattigi & Kulkarni, 2001). Therefore, adjustability of height is important to reach hives easily in a vast range of heights. The smoker's mobility is crucial to fully benefit from it, considering that giant honeybee hives can be found in diverse locations like buildings, trees, and large stones. Hence, this innovation will prove to be beneficial for numerous individuals who face the danger of being attacked by giant honeybees.

2. Methodology

2.1 Designing and fabrication of the smoker.

While designing a machine for specific tasks, it is crucial to consider the number of factors in order to enhance user friendliness and adaptability to local conditions (Perera et al., 2015; Piyathissa & Kahandage, 2016). As the smoker is supposed to be used for giant honeybees who make their hives on roofs of residential buildings and on the branches of trees near human living places, several factors such as height adjustability, portability, continuous supply of smoke for a long time, and lightness were considered especially in the designing process. In addition to these factors, safety for both operators and bees, easy maintenance and repairs, and the ability to use locally available smoking fuels were taken into consideration.

The designed smoker consists of several components such as the combustion chamber for smoking fuel, smoke blowing unit with an air blower, smoke delivering pipes, power source to operate air blower, and the frame with wheels. Figure 1 illustrates the components of the designed height-adjustable smoker for giant honeybees.

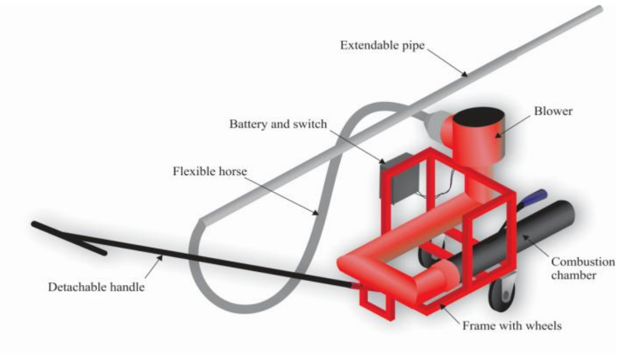

Figure 1. Components of the mobile and height-adjustable smoker for giant honeybees.

2.1.1 Combustion chamber for smoking fuels

The smoker fuel used to get smoke should be available readily and be able to provide a quality smoke that will not harm the honeybees (Civitts, 2022). Therefore, chopped guinea grass (*Panicum maximum*) and rice straw were considered as the smoking fuel of the designed smoker. Choosing seasonal crops as biomass for smoke generation can contribute to the mitigation of global warming by enabling the absorption of released carbon by the upcoming season (Kahandage et al., 2023). The combustion chamber was designed with a capacity of 4,000 cm-3 in order to accommodate the combustion of 275 g of a mixture consisting of guinea grass and dried rice straw with a 1:1 ratio, while maintaining normal bulk density. Figure 2 shows the components and major dimensions of the combustion chamber.

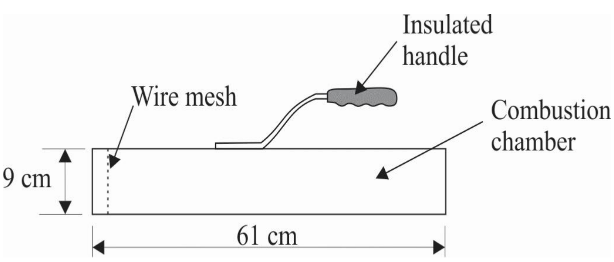

Figure 2. Components and major dimensions of the combustion chamber of the smoker.

The shape of the combustion chamber is cylindrical, and one end is open while the other end is fitted with a wire mesh to hold the smoking fuel. An insulated handle (with a rubber grip) is fitted to the combustion chamber to move it here and there safely and comfortably even when it is hot. A 61 cm length galvanized iron pipe with 9 cm diameter and 3 mm thickness was used to fabricate the combustion chamber. Galvanized steel was chosen for its strength, lightweight nature, and ability to withstand corrosion (Ranasingha et al., 2020). Enhancing user-friendliness at the village level is achieved by utilizing readily available materials in the local market, which facilitates easier repairs and maintenance. After filling the smoking fuel into the combustion chamber the end with wire mesh should be inserted into the open end of the smoke pumping system and the other end should be used to fire on. The combustion chamber can easily be disconnected from the smoke pumping system and another fuel-filled one can be connected easily and quickly to have a continuous smoke flow.

2.1.2 Smoke pumping and delivery system

Smoke pumping system consists of a blower, smoke intake pipe, the exhaust pipe that increases the speed of the smoke flow, the flexible pipe that directs the smoke, and a plastic tube that can be shortened or increased in length. Figure 3 demonstrate the arrangements of the smoke intake pipe and the exhaust pipe that increases the speed of the smoke flow to the blower.

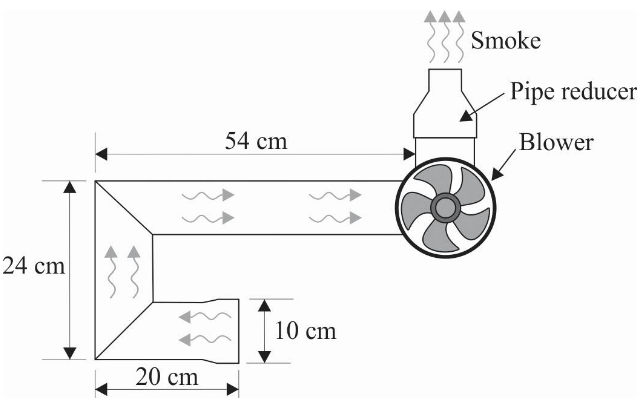

Figure 3. Arrangement of the smoke intake pipe, blower, and the exhaust pipe.

The smoke intake pipe is fabricated with galvanized iron pipe with 9 cm diameter. The pipe reducer connected to the exhaust end helps to increase the flow speed. The smoke intake pipe is designed with three 90^{o} bends and a total 112 cm length to reduce the temperature of the smoke to avoid damage to the blower and bees. The flexible rubber hose connected to the pipe reducer is 450 cm in length and the extendable pipe connected to the flexible rubber hose consists of two pipes inserted one into other and maximum extendable length is 450 cm. Therefore, the maximum achievable height is 900 cm (30 feet).

A blower of an automobile air circulatory system (Operating voltage-12 V) was used to intake air through the combustion chamber to direct smoke to the smoke delivery pipe. The maximum and minimum speed of blower is 272 and 92 rpm, respectively.

Power was supplied to the blower using a 12 V rechargeable lead acid battery. A regulator was used to control the smoke emission rate by regulating the voltage of blower.

The frame was designed to assemble all the components together as a single unit. Two caster wheels were fixed to the frame to make the smoker movable. A detachable handle was fixed to the frame to ease the pulling.

2.2 Testing the efficacy of the fabricated smoker

2.2.1 Ratio and compaction level of smoking fuel

The smoke released from fuel material should not cause any injury or death to the bees and does not toxic to the operator as well. As chopped guinea grass and rice straw were the smoking fuel of the smoker a preliminary test was conducted to realize the best suited ratio of rice straw and guinea grass in the mixture for smoking fuel. Rice straw (moisture content-16% on a wet basis) and airdried guinea grass (moisture content-67% on a wet basis) were chopped into pieces about 10 cm in length on average and several mixtures with different weight ratios of guinea grass to rice straw such as 1:0.5, 1:1.0, 1:1.5, and 1:2.0 was prepared. After selecting the best ratio (1:1), seven levels of compaction were used as 37.5g/L, 42.5g/L, 47.5g/L, 52.5g/L, 57.5g/L, 62.5g/L, and 67.5g /L to select the best compaction level. To select the best ratio and compaction level, the total smoking time, smoke flow rate, and temperature of smoke at exhaust pipe of the blower and at the main outlet of the delivery tube were measured and considered.

As per to the results of the preliminary test, the best weight ratio was 1:1 for rice straw and guinea grass. Therefore, as the smoking fuel for further evaluation, 1:1 ratio of rice straw and guinea grass was selected.

2.2.2 Performance and user satisfaction

After selecting the best ratio and the compaction level, the performance of the smoker was tested with three natural giant honeybee hives located in Faculty of Agriculture, Rajarata University of Sri Lanka. During each trail, the height to the hive from the floor, time taken to partially clear the comb, and time taken to completely clear the comb were recorded. User satisfaction levels were assessed through a questionnaire survey. A total of twenty operators participated in the test. Each operator was provided with instructions on how to use the smoker and given the opportunity to use it freely. The questionnaire focused on several aspects, including the ease of filling firing material, ignition, connecting the smoke generating unit, handling, adjusting the height, removing ash, and ensuring safety during operation.

Data were analyzed with ANOVA using SAS 9.0 software by Complete Randomized Design (CRD) and results were interpreted with 95% confidence interval.

3. Results and Discussion

3.1 Functional description of the smoker

Figure 4 illustrates the constructed height-adjustable smoker developed for giant honeybees, while Figure 5 showcases the smoker's combustion chamber. Table 1 gives some of the important specifications of the smoker.

Figure 4. The mobile and height-adjustable smoker for giant honeybees.

Figure 5. Fabricated combustion chamber of the smoker.

Table 1. Specifications of Smoker.

Parameter	Dimensions
Total weight	25 kg
Volume of the combustion chamber	4,000 cm^3
Adjustable height range of smoke delivery unit	0-900 cm
Height of machine with frame	84 cm
Total width of the machine	42 cm
Length of the operating handle	100 cm

3.2 Functional efficacy of the smoker

3.2.1 The preliminary test for best ratio for paddy straw and guinea grass in smoking fuel

The table provides a detailed summary of the experimental results pertaining to different straw-to-guinea grass ratios in the preliminary test. Each ratio was evaluated in terms of average filling time, average firing time, flow speed, and temperature. Table 2 summarizes the results.

Table 2. Average filling time, average firing time, flow speed and temperature at the outlet.

Straw: guinea grass Ratios	Average filling time (s)	Average firing time (s)	Flow speed (ms^{-1})	Temperature (°C)
1:0.5	41[a]	464[a]	0.7[a]	40
1:1.0	42[a]	486[b]	0.8[a]	40
1:1.5	42	Not burned properly	-	-
1:2.0	41	Not burned properly	-	-

Means with different superscripts are statistically significant (*p<0.05*), dependent variables were not statistically compared.

Different ratios of straw to guinea grass as 1:0.5, 1:1.0, 1:1.5, and 1:2.0 in the smoker fuel mixture were tested. The average filling time is the time taken to load the smoke generation unit with the specified fuel mixture and initiate the burning process. For the 1:0.5 and 1:1.0 ratios, it took approximately 41 and 42 seconds, respectively. Average firing time indicates the duration of time the smoker continued to produce smoke after ignition. For the 1:0.5 and 1:1 ratio, it lasted around 464 and 486 seconds, respectively. However, for the 1:1.5 and 1:2.0 ratios, the material did not burn properly, resulting in an indeterminate firing time. The combustion of straw typically progresses through three distinct stages, such as induction, flaming combustion, glowing combustion, and Smoldering. During the first phase, the biomass undergoes pyrolysis, releasing volatile compounds and smoke particles. In the second stage, the released volatiles ignite, producing a luminous flame as the temperature increases. Once the flaming combustion phase subsides, the residual char from the straw continues to burn, albeit without visible flames. This stage is marked by glowing combustion, and the straw smolders for some time. Smoke continues to be emitted throughout all three stages of the combustion process (Jenkins et al., 2003).

The flow speed is the parameter that measures the speed at which the smoke was generated and expelled from the smoker. It ranged from 0.7 ms^{-1} for the 1:0.5 ratio to 0.8 ms^{-1} for the 1:1 ratio. In summary, the results suggest that the 1:0.5 and 1:1 ratio provided successful and consistent burning of the fuel mixture, resulting in reasonable filling and firing times, adequate flow speed, and a constant temperature, making them viable options for use in the smoker. In contrast, the 1:1.5 and 1:2.0 ratios did not burn properly and, therefore, did not produce valid data for the parameters under consideration. Consequently, compaction ratio 1: 0.5 and 1 :1.0 were tested statistically using independent sample t -test and average firing time were significantly greater in 1:1.0 compaction level compared to the 1:0.5 compaction level (*p< 0.05*). Thus, based on the findings, a straw-to-guinea grass ratio of 1:1 has been chosen for further evaluation of the smoker as it gives a comparatively higher firing time. The smoking time of a smoker for honeybees is essential for creating a safe, controlled, and less stressful environment for both beekeepers and the bee colony. This ratio demonstrated consistent and effective performance in the experimental tests, making it the preferred fuel mixture for the ongoing assessment of the smoker's performance.

3.2.2 The best compaction level for the smoking fuel

Various compaction levels of smoking fuel were tested in the combustion chamber, ranging from 37.5 g/L to 67.5 g/L, to determine the optimal compaction level for the smoker. Several key parameters were assessed, including the time required for fuel filling into the combustion chamber, firing time, smoke flow rate, and the temperature of the smoke at the outlet. These tests were conducted to identify the most effective compaction level that would ensure efficient and consistent smoker performance. According to the dependent variables (time required for fuel filling, firing time, smoke flow rate, and the temperature of the smoke at the outlet) were statistically tested using CRD at *p<0.05*. The results are shown in Table 3 below.

Base on the results shown in Table 3, there were no significant differences in the dependent variables of average time consumed to fill smoke generation unit, flow speed of smoke emitted at outlet, and temperature of smoke emitted (*p<0.05*). However Significantly greater average firing time was observed with the compaction level of 67.5 g/L. Therefore, the maximum possible compaction level (67.5 g/L) was selected as the best suited compaction level for the smoker.

Smoke is comprised of a mixture of minute solid, liquid, and gaseous particles. While the composition of smoke can encompass hundreds of different chemicals and fumes, the visible component of smoke primarily consists of substances such as carbon (in the form of soot), tar, oils, and ash (bin Abas et al., 1995; H. Zhang et al., 2021). These elements combine to create the visible and often hazy appearance of smoke. Smoke is generated because of incomplete combustion due to absence of sufficient oxygen. The visible smoke is primarily composed of volatile organic compounds (hydrocarbons) evaporating from the burning biomasses (Saarnio et al., 2010). When the fire's temperature is sufficiently high, these hydrocarbons can ignite and burst into flames. Once they ignite, there is no visible smoke because the hydrocarbons are then transformed into water vapor and carbon dioxide through the combustion process (Pino, 2014; Y. Zhang et al., 2020). Indeed, a higher compaction level of fuel can promote incomplete combustion by restricting the contact between the fuel and enough air. Incomplete combustion often occurs

Table 3. Determination of the best compaction level for the smoking fuel.

Dependent variable	Level of Compaction						
	37.5 g/L	**42.5 g/L**	**47.5 g/L**	**52.5 g/L**	**57.5 g/L**	**62.5 g/L**	**67.5 g/L**
Average time consumed to fill smoke generation unit (s)	40 ^{a}	42 ^{a}	43 ^{a}	44 ^{a}	45 ^{a}	45 ^{a}	46 ^{a}
Average firing time (s)	480 ^{a}	760 ^{b}	783 ^{b}	960 ^{ab}	1045 ^{ab}	1146 ^{ab}	1232 ^{c}
Flow speed of smoke emitted at outlet (ms^{-1})	1.00 ^{a}	1.00 ^{a}	1.00 ^{a}	1.00 ^{a}	1.05 ^{a}	1.10 ^{a}	1.05 ^{a}
Temperature of smoke emitted (℃)	36^{a}	36 ^{a}	35 ^{a}	35 ^{a}	35 ^{a}	35 ^{a}	35 ^{a}

Means with different superscripts are statistically significant ($p<0.05$), dependent variables were not statistically compared.

when there isn't an optimal air-to-fuel ratio, and a higher compaction level can limit the available oxygen for combustion. This can lead to the generation of smoke and the release of unburned hydrocarbons, as the fuel doesn't have access to the necessary oxygen to facilitate complete combustion. This was the reason for the higher average firing time with a continuous smoke flow in the maximum compaction level (67.5 g/L) of smoking fuel.

Following the selection of the optimal straw-to-guinea grass ratio (1:1) and the ideal compaction level (67.5 g/L), the smoker's performance was assessed. During the evaluation, the average time required to completely clear selected giant honeybee combs was found to be 483.5 seconds. This information reflects the effectiveness and efficiency of the smoker in achieving its intended purpose.

3.2.3 Guidelines for operating on the smoker effectively.

The operational procedure begins with the preparation of the fuel mixture. Guinea grass and paddy straw are cut into approximately 2cm pieces and thoroughly blended in a 1:1 ratio to achieve a well-balanced fuel mixture. Following this preparation, 270g of the mixed fuel should be carefully loaded into the combustion chamber of the smoker. To ignite the fuel mixture, a box of matches or a lighter should be used. After ignition, switch on the power control to activate the air blowing, initiating the smoking process. A voltage regulator comes into play, allowing precise control of the smoke emission rate to align with specific requirements. This feature enables seamless adjustments as needed. Depending on the height requirements for your application, you can attach either the small or large delivery tubes to the smoker, ensuring secure and reliable connections. Once the combustion process is completed, it is crucial to diligently remove any residual ash particles from the smoke generation unit, preparing it for subsequent use. By meticulously following these steps, anyone can confidently and proficiently operate the smoker for its intended purpose.

3.3 Feedback from users

The engagement of users in the development of a functional machine or system isof paramount importance to meet the expectations of the end-users (Kujala, 2003; Ranasingha et al.,2020). The feedback collected from twenty operators is summarized in Table 4.

In accordance with the feedback summary, enhancements should be made to the device's portability, height adjustability, and safety features to align with user requirements. The relatively small size of the wheels has made it somewhat challenging to navigate on uneven, stony terrain. Notably, most users have expressed a greater concern for safety from giant honeybee stings rather than safety related to the device itself, despite the absence of any recorded stinging incidents during the experiments. Additionally, there is a notable request from some users to improve the height-adjusting mechanism. Since all the factors under consideration meet or exceed the satisfactory level, overall user satisfaction with the smoking device is deemed acceptable.

3.4 Potential uses, limitations and the future scope of improvements.

The mobile and height-adjustable smoker developed for giant honeybees, as illustrated in Figure 4, exhibits promising potential applications in beekeeping. With a total weight of 25 kg and an adjustable height range of 0-900 cm, the smoker aims to provide a versatile tool for calming giant honeybees. Its functional design, including the fabricated combustion chamber (Figure 5) and specifications listed in Table 1, suggests utility in controlling bee behavior during hive relocating and honey harvesting. The smoker's ability to generate and regulate smoke offers a practical solution for creating a safe and controlled environment, facilitating beekeeping activities.

Table 4. Feedback from users.

Factor	User satisfaction level (%)				
	Very good	Good	Satisfactory	Bad	Very bad
Easiness of filling smoking fuel	100	-	-	-	-
Easiness of igniting	-	80	20	-	-
Connecting and disconnecting of combustion chamber	80	20	-	-	-
Moving	-	-	100	-	-
Adjusting the height	-	70	30	-	-
Removing ash	10	70	20	-	-
Safety	-	60	40	-	-

Despite its potential, the smoker presents certain limitations. The results from the preliminary test on different straw-to-guinea grass ratios (Table 2) reveal that specific ratios, such as 1:1.5 and 1:2.0, resulted in incomplete combustion, indicating a limitation in fuel mixture optimization. Additionally, the feedback from users (Table 4) highlights concerns about the device's portability, especially on uneven terrain due to relatively small wheels. Users also express the need for improvements in the height-adjusting mechanism and safety features. These limitations suggest areas for refinement and optimization in future iterations of the smoker.

The smoker's potential for future development lies in addressing the identified limitations and enhancing its overall functionality. Further optimization of the straw-to -guinea grass ratio may improve combustion efficiency and provide consistent performance across a broader range of conditions. Enhancements in portability, possibly through the incorporation of larger wheels or additional features, could address user concerns about maneuverability on uneven terrain. Improving the height-adjusting mechanism and safety features in response to user feedback would contribute to the overall usability and safety of the device. Future iterations could also explore the integration of technological innovations for more precise control of smoke emission and advanced safety mechanisms. Collaborative efforts with beekeepers and continuous user feedback will be essential in refining the smoker for widespread adoption and ensuring its effectiveness in various beekeeping contexts.

4. Conclusion

In conclusion, we have successfully designed and developed a portable, height-adjustable, and safe smoker for the purpose of chasing giant honeybees. This smoker incorporates four major components: the smoke generation unit, smoker blowing unit, smoke delivery unit, and power supply unit. By utilizing a fuel mixture of paddy straw and guinea grass with a 1:1 ratio, we achieved optimal firing performance. The smoke generation unit's suitable compaction level of 67.5 g/L allowed for efficient operation. Remarkably, it took just 46 seconds to fill the 4 L smoke generation unit with 270 g of guinea grass and paddy straw in a 1:1 ratio. Moreover, this smoker proved highly effective, taking only 8 minutes to completely clear a hive positioned 24 feet above the ground. Based on the compelling data and results presented, we confidently recommend the newly constructed smoker for the effective management of Bambara bee colonies.

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