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Efficiency of place-based innovated briquettes making technologies for sustainable cooking energy in Tanzania

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Abstract

Globally, more than 2.8 billion people don't have access to electricity. Whereas about 550 million of them live in Africa. Hence, they opt to go for cheaply available sources like charcoal and firewood for their cooking and heating purposes in their daily domestic and industrial applications. More than 80% of sub-Saharan Africans and 90% of East Africans rely on biomass energy for their domestic and industrial heating purposes. In Tanzania, more than 85% of the population depends on wood-based energy for cooking. This dependency is directly linked to climate change as it promotes deforestation and has the potential to lead to desertification. Currently, a focus is on the use of renewable energies, especially recycled bio-waste (bio-briquettes) as an alternative to charcoal and firewood. Both government and private institutions have initiated and taken the lead in making sure that the effort is of high value; however, the available briquette-making machines are expensive, complex to use, and demand electricity which adds more costs to production, hence making the briquette production a non-economic business adventure within Tanzania. In addressing the problems, this study aimed at conducting an inventory study in order to come up with place-based briquette technologies suiting youth and female unemployed groups. A human-centered design concept was used in inventing two briquetting machines. One uses screw pressing mode (Peyam Screw Press), while the other one uses a hydraulic jerk system (the Briquetter). The machines were tested for; Type Test (compression method), user friendliness (gender sensitiveness approach), and acceptability (market validation method). Results revealed that the machines produce briquettes of high quality that passed both the Impact Resistance Index (IRI) and Water Absorption Resistance (WAR) tests at a threshold of >50%. Moreover, they offer reliable production and have passed social acceptability tests, hence they should be considered for adaptation.

Keywords: *Briquettes, briquetting technology, cooking and heating energy, innovations, sustainable energy, biomass waste*

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Introduction

Globally, over 2.8 billion people lack access to electricity, with about 780 million of them living in Africa. Hence, charcoal and firewood become their best and cheapest sources for meeting their domestic and industrial cooking and heating demands (Drechsel *et al.,* 2011; Nyamoga and Solberg, 2019). More than 80% of sub-Saharan Africans and 90% of East Africans rely on biomass energy for their domestic and industrial heating purposes (Hoffmann *et al.,* 2018). In Tanzania, in excess of 85% of the population depends on wood-based energy for cooking, and is considered the fifth-largest charcoal producer in Africa (Fløytrup *et al.,* 2022; Okoko *et al.,* 2018). Overdependence on these sources is directly linked to deforestation and desertification, hence a focus on recycling biomass waste to produce renewable energies like briquettes is thought to be the most adequate intervention in replacing firewood and charcoal consumption (Bär *et al.,* 2017; Fløytrup *et al.,* 2022).

It is feasible to trap resources from biomass waste, since the globe is generating, more than 140 billion metric tons of biomass waste on a daily basis (Drechsel *et al.,* 2011; UNEP, 2009). High proportion of these wastes are; residual stalks, leaves, husks, nuts, shells, waste wood and animal husbandry (Grover and Mishra, 1996; Nyamoga and Solberg, 2019). These wastes are insufficiently utilized, leaving most of it to rot at either farmlands, markets, processing zones, or domestic settings (Drechsel *et al.,* 2011; Grover and Mishra, 1996). However, these wastes have great potential for being utilized as feedstock material in production of renewable energies like briquettes and biogas (Akinbami *et al.,* 2021). In the Tanzanian context, about 15 million tons and 1.8 million tons of agricultural waste and forest residues, respectively, are generated on an annual basis. These wastes if utilized in the production of briquettes, would at least subsidize the 750,000 tons of charcoal that are used by the city of Dar es Salaam on an annual basis. As a result, about 250,000 to 350,000 hectares of forests utilized in producing the equivalent charcoal feeding the city would be saved every year (Nyamoga and Solberg, 2019; UN, 2023).

According to Bandara and Kowshayini, (2018) and Raju *et al.,* (2014), the availability of biomass waste and the chemistry of making briquettes is not an issue, but rather the technology of making them. Several studies have been done to develop machines to be used on a domestic and industrial scale. Nevertheless, the technologies are either expensive or not place-based for interested stakeholders who wish to join the briquette production business (Drechsel *et al.,* 2011; Heinimö and Junginger, 2009; Oladeji, 2015; Shuma and Madyira, 2017; UNEP, 2009). Making briquettes takes us back from raw material mobilization (biowaste), carbonization, and fabrication processes (Bandara and Kowshayini, 2018; Oladeji, 2015). Several carbonization (also referred to as pyrolysis) options that are place-based have been developed and proven to work effectively, whereby for both rural and urban settings the vertical slow pyrolysis using used oil drums has proven to be the most economical option (Bleuler *et al.,* 2021; Lohri *et al.,* 2015; Zabaleta *et al.,* 2018).

Briquettes fabrication machines are grouped into three groups: high-pressure compaction (without heating coils and binder), medium-pressure compaction (with heating coils), and low-pressure compaction (with a binder) (Oladeji, 2015). The first two groups are mostly used in producing uncarbonized briquettes, while the last one is used in producing carbonized briquettes. Moreover, the machines can be of the screw or piston type (Sengar *et al.,* 2012). Briquettes were invented after the first world war (WW1), with sawdust briquettes being the dominant biomass waste used as feedstock (Grover and Mishra, 1996; Oladeji, 2015). The quality of the briquettes produced by the briquette machine is determined by several factors, the key ones being the quality and nature of the feedstock material used (biomass waste), the binding material, the pressing power of the machine (compaction pressure), and the size and shape of the briquettes to be produced (Karunanithy *et al.,* 2012; Kers *et al.,* 2010; Oladeji, 2015; Rahman *et al.,* 1989; Sengar *et al.,* 2012). Therefore, all machines globally fall under either screw or piston press machines, hence innovations under this study considered this factor in coming up with one innovation model for each group.

The specific objectives for this innovation study were firstly; to design and manufacture one screw and one piston press user friendly briquettes fabrication machines, and secondly; to determine social acceptance of innovated technologies. The development of these machines was spearheaded by the limited escalation of the biobriquettes technologies in developing countries including Tanzania due to limited technologies including inappropriate briquetting machinery (Yustas *et al.,* 2022; Inegbedion, 2022). These machines were developed based on their effectiveness in fabricating high quality biobriquettes, suitability for small scale application (Kaur, 2017), their price compared (less than US$700) to other machines purchased from outside the country (US$4,513.00 - US$4,745.00) (Alibaba, 2023), easiest to use since they are coupled by wheels which simplifies the densification process and can be used by different groups including women, and they do not use electricity which add up to the cost of briquettes production. Apart from the goodness of these machines, they have some limitations namely their use require binder; When employing lignin-containing materials, they must be carbonized before being used in this machine to create biobriquettes since they are not coupled with heating systems which carbonize the feedstock automatically (Grover and Mishra, 1996; Wessapan *et al.,* 2010). So, this study explored the technical design efficiency of the innovations, this was done by type-testing experiments, thereafter the operation efficiencies of the respective machines were tested by determining the social acceptance by users.

Materials and methods

Study area

This innovation-based study was conducted in Tanzania, whereby the designing and fabrications of the innovated machines were done at Ardhi University and University of Dar es Salaam, which are located in Dar es Salaam. The type tests experiments that confirms the design specifications and the fabricated model were done by Tanzania Bureau of Standards (TBS), while the social acceptance was done at Ardhi University, in Dar es Salaam and Mbalari district located in Mbeya city, Tanzania. Figure 1 shows a map of Tanzania as a case study for this innovation-based research.

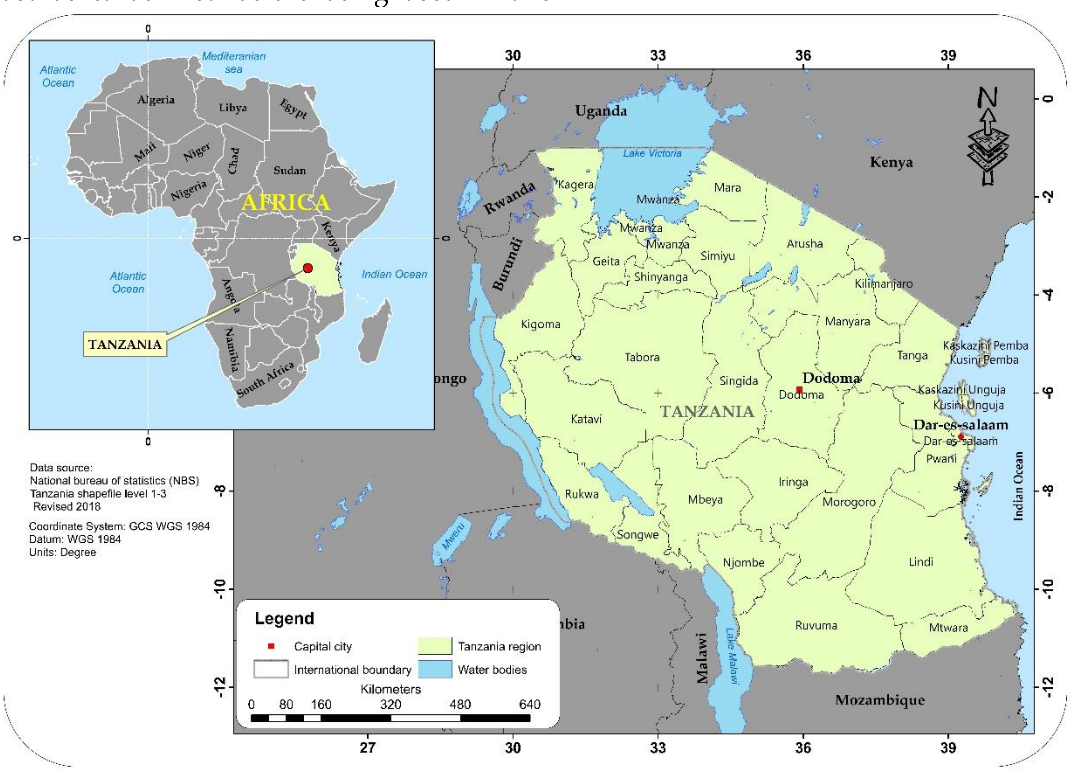


Figure 1. Location of the case study (Modified from Ramani Huria shapefiles 2012)

Design Concept

This study utilized the Human Centered Design (HCD) principle and theory in coming up with the innovative technologies. This principle is basically used in providing solutions that are technically feasible, socially desirable, and financially viable by focusing on the user experience (Gasson, 2003; Watson *et al.,* 2012). Existing briquette-making machines locally used in Tanzania were studied in order to identify the place-based gap. Thereafter, a document review was conducted to understand the briquette machine innovation trends from World War I to date so that the innovated machines would not be a repetition of the already-made model. Two manually operated machines were invented: the Peyam Screw Press (PSP), which operates using the screw model, and the Briquetter, which operates using the piston mode (hydraulic jerk). The adaptation of manually operated machines was due to the fact that many places with vast feedstock for making briquettes are off-grid (not connected to the national electric grid). Moreover, there was a need to cut down on the cost of purchasing and operating the machines

The innovated machines were conceptualized to be technically feasible, in the sense that they meet customers' and operators' demands. The operators/manufacturers need machine that is simple to operate, doesn't require electricity, can be handled by a variety of people, including women, and has minimal purchase and maintenance costs (Wessapan *et al.,* 2010; Joshi *et al.,* 2015). Apart from operators, customers require alternative energy to charcoal/firewood, biobriquettes with less smoke and high heating value, affordable and easily accessible (Nguyeni *et al.,* 2017). Hence, the designed machines are considered socially desirable if they are user-friendly to women and youth unemployed groups, and they are regarded as financially desirable if they are affordable and have the potential of returning the investment cost within six months of operation. However, in this publication, the technical feasibility of the innovated machines will be discussed in detail, along with a briefing on social acceptance.

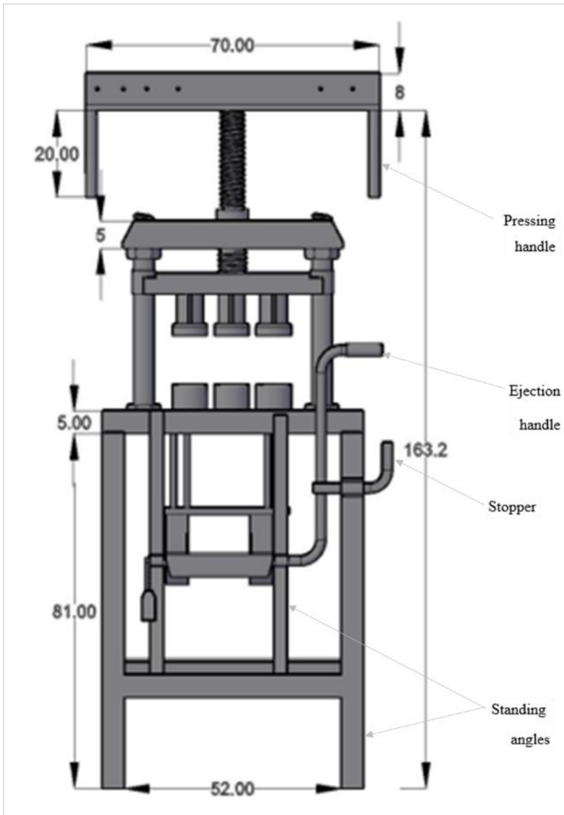
Technical feasibility tests

The technical feasibility tests were done in two stages, firstly; machines design and fabrication stage and secondly; the physical testing of both the fabricated machines and the produced briquettes from the machines.

Machine designs and fabrication process

The engineering drawings of the Peyam Screw Press (PSP) were done using AutoCAD 2019 version 23.0, while those of the Briquetter machines were done using AutoCAD 2020 version 23.1. Ideation stage prior to drawings was done using human centered design whereby, the simplicity in using the technology by both women and youth was considered as a key consideration. Simplicity in using the machine was essentially considering the pressing and ejection easiness and maximization of production per day. The outputs from this stage were feasible engineering drawings that called for either acceptance to fabrication stage or re-modifications after trial of the fabricated machine. This stage was not only done once, modifications were continuously done to the end of the final accepted models.

Each machine, the PSP and Briquetter, was designed to produce at least 500 kg per day when operated by at least two people, either women or men. More importantly to note is that the production rate is much more dependent on the working time and the motivation to produce by the production team. In this case, the machines were operated for eight hours with ready-made feedstock materials and binders. The designs of machines are as presented in Figures 2 (PSP machine) and 3 (Briquetter machine).



Front view

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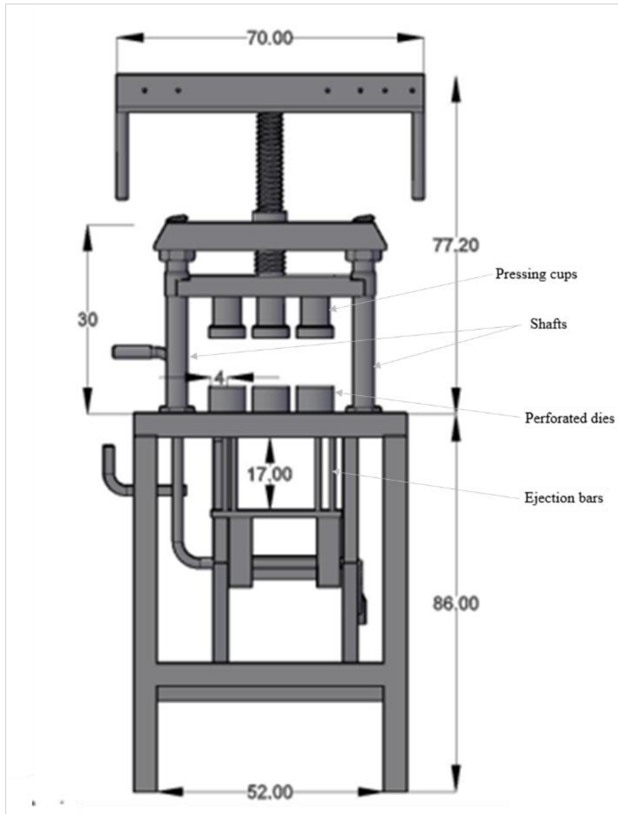

Back view

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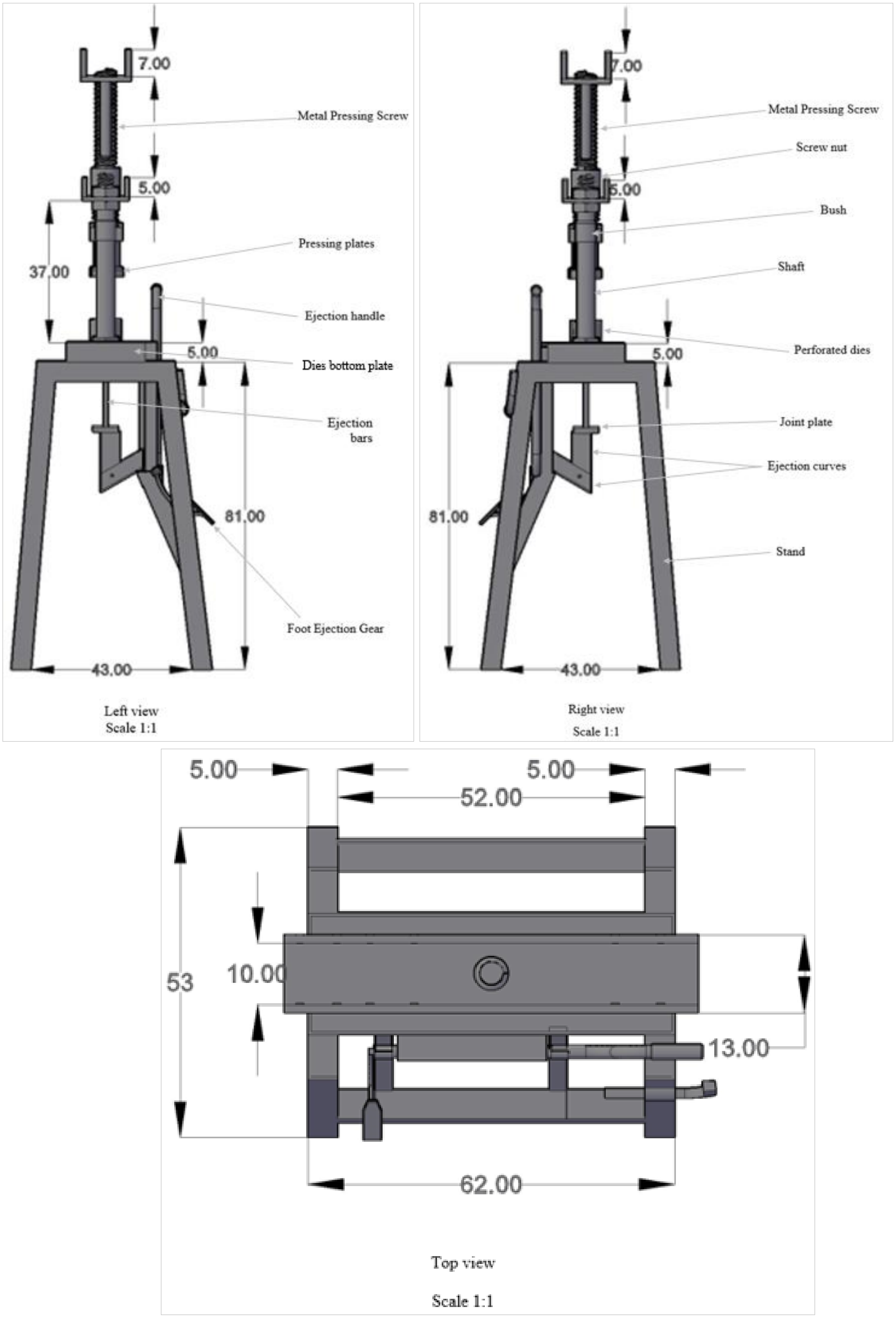
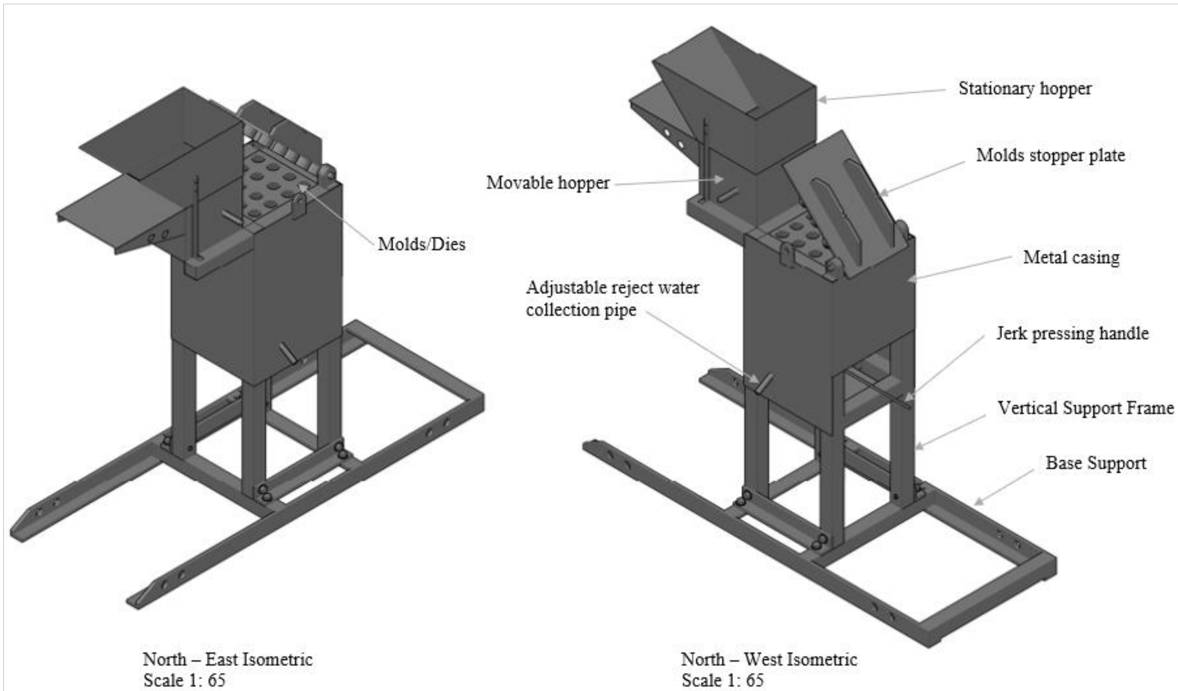


Figure 2. Design drawings of Peyam Screw Press (PSP)


Stationary hopper
Molds stopper plate
Movable hopper
Molds/Dies
Metal casing
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Jerk pressing handle
Vertical Support Frame
Base Support
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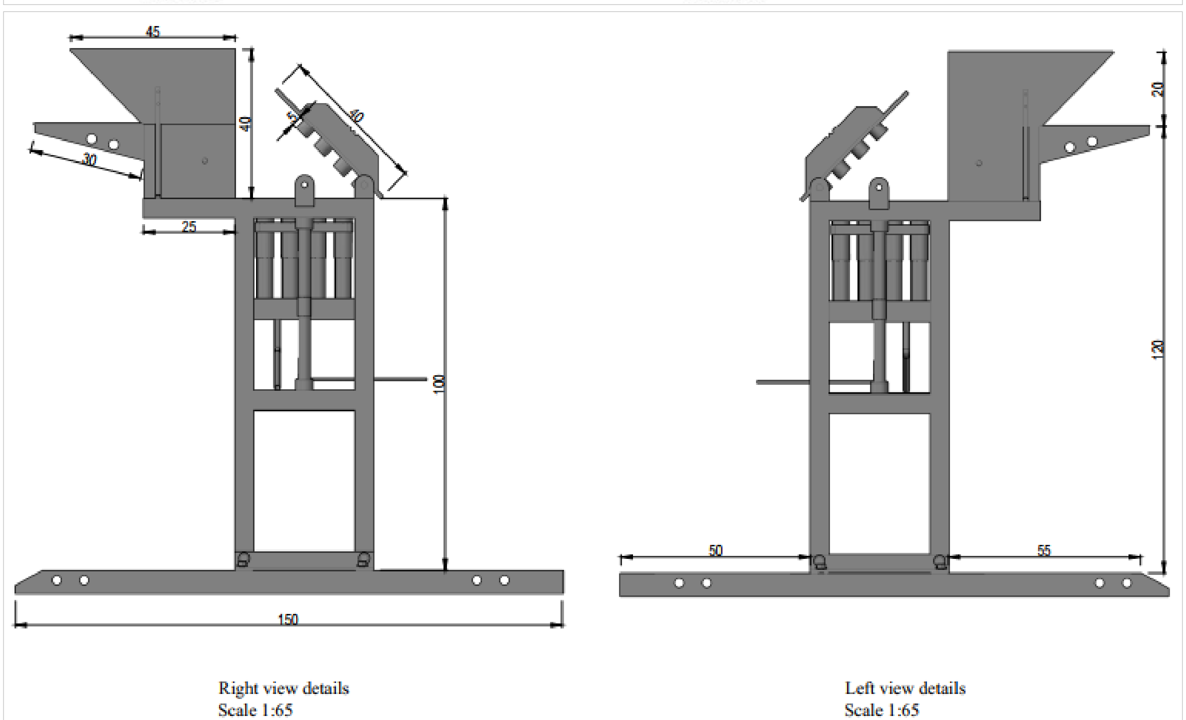
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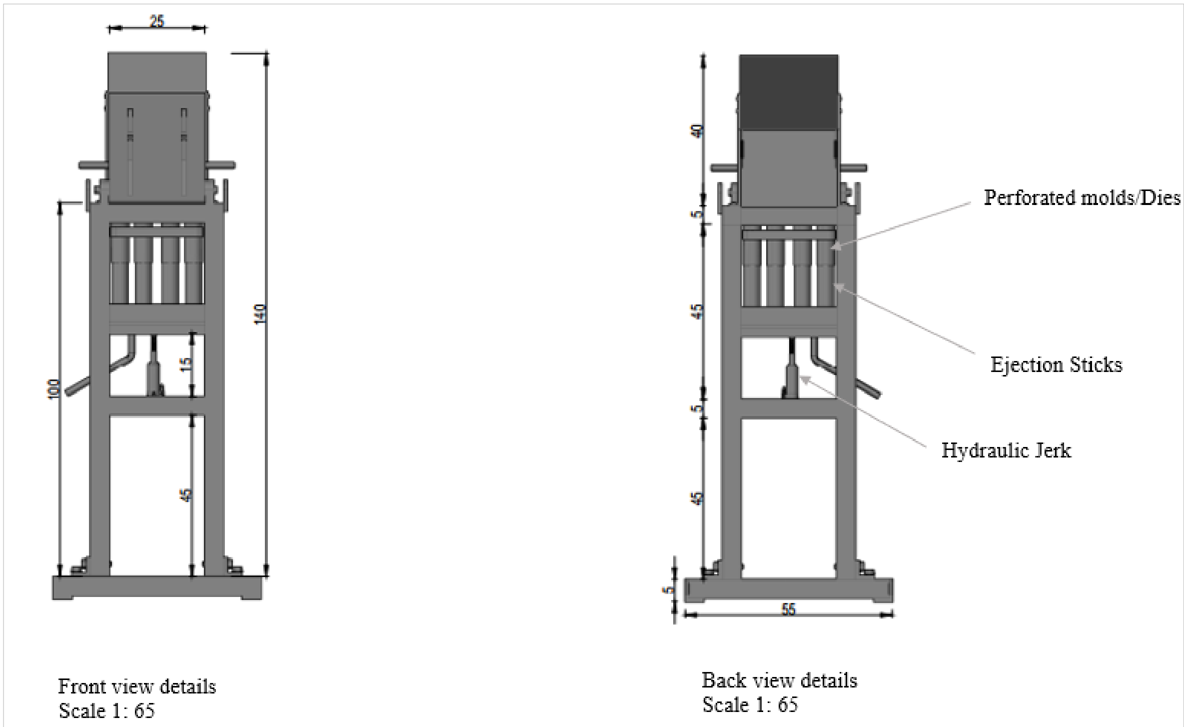

Figure 3. Design drawings of Briquetter Machine

The fabrication process was done at the Technology Development and Transfer Centre (TDTC) of the University of Dar es Salaam. The best suit modes were PSP, which used screw pressing mode, and Briquetter, which used piston mode, operating with the aid of a hydraulic jerk. The activity took one and a half years, from January 2018 to July 2019.

Physical testing of fabricated machines and briquettes

After the machines were ready for use, prior to distributing them for market validation (social acceptance), they were subjected to a type test (compression method) at the Tanzania Bureau of Standards (TBS). Moreover, the compression strength of the machines was tested by subjecting the fabricated briquettes to drop tests from a height of 2 m and a water absorption resistance test.

The drop test, also known as the impact resistance index (IRI) test, and the water absorption resistance (WAR) test were obtained by calculations. In order to obtain IRI or WAR value the weight of initially produced briquettes (W1) was subtracted from the final weight of the briquettes after either being dropped into or immersed in water (W2). The result was divided by the initial weight times 100 percent. The remaining percentage of useful briquettes was obtained by subtracting 100 percent from the answer (Equation 1).

$$IRI\ or\ WAR\ (\%) = 100 - \left((W1g - W2g)/_{W1g} \times 100\right) \text{……………….....Equation 1}$$

Whereby;

IRI = % Impact resistance index
WAR= % Water absorption resistance
W1= Original weight of the briquettes (g)
W2 = Weight of the briquettes after impact (g)

The final grades that exceeded 50% that is, IRI or WAR > 50%, then the test was considered to pass, otherwise it was considered as a failure. The weighed briquettes are only those pieces that can be burned to either heat or cook, so the reasonable sizes only were weighed after drop test or water immerse test to obtain W_2.

Social acceptance tests; The usability and acceptability were tested. In order to know the user friendliness of the machines, the machines were operated by women. The PSP was operated by female fourth-year (final-year) undergraduate students at Ardhi University, Dar es Salaam, Tanzania (Figure 4A). While the Briquetter was operated by the local rice farmer at Ubaruku ward in Mbarali district of Mbeya city, Tanzania (Figure 4B). On the other hand, the acceptability of the machines (market validation approach) was tested using key informant interviews with both students (30 students) and Mbarali farmers who operated the machines (30 farmers).

Figure 4. User friendliness (gender sensitivity) test of the innovated machines

The social acceptance of PSP and the Briquetter was determined by ranking the drivers (factors) dictating selection of a briquette's machines. The drivers for this case were; Simplicity of using the machines, user friendliness in terms of operation and maintenance, costs associated with operation, quality of product (produced briquettes) and quantity of products (produced briquettes). Simplicity factor was defined by the appearance of the machines being simple to move and operate, while user friendliness was defined by the machines being easy to operate by females and youth. The operational costs, is significant in determining the unit costing of the briquettes in cost/kilogram, whereby the unit costing of the machines can be calculated easily by estimating total material costs used for fabrication of briquettes plus the workmanship costs, utility costs and the margin percentage of profit (e.g. 15% of the total production costs). The good quality of the produced products by the machines was determined by observing the smooth and shape appearance of the produced briquettes, easiness to ignite the products and their well compaction strength by observations. Lastly, the quantity of the products fabricated by the machines was considered as among the key driver that predicts the choice, so the hypothesis was that the machine with high production per day would be more preferred than that with less production per day.

Data was collected using a checklist with box spaces for checking the drivers (factors) that made the participants select the produced machines. Each participant was allowed to choose more than one driver if applicable, so each was instructed to choose only the factors that they think were the factors that made them either accept or reject the use of PSP and the Briquetter. The collected data were presented using histogram plotted from Microsoft excel version 2019.

Results

Physical testing results of fabricated machines

The type test performed by Tanzania Bureau of Standards (TBS) showed that the Briquetter has a compression capacity of about 49,033 Newton meters (Nm), which is equivalent to 5 tons. Although the machine has high compression strength, yet it was challenged to be unstable during production due to it having mobile footing drums. Instead, it was recommended that the machine should have stable horizontal stands instead of mobile drums. Hence, the drums were replaced by the horizontal footing stands that extends on both sides of the machine in order to maximize its stability. Even though, the overall type test for the Briquetter was a pass, yet it was found not to be the exact measure of compression strength of the produced biobriquettes due to difference in weight of feedstock and energy capacity of the operator of the machine. So, differences in compression strength of biobriquettes produced with even for the same feedstock by two different people is expected.

On the other hand, the PSP was rated to have a compression strength of 29,419 Nm, which is equivalent to 3 tons. Similar to the Briquetter, this is not the actual compression strength of the produced biobriquettes but rather the capacity of the machine. The better the compression of the feedstock in producing briquettes have implication in the raise of calorific value of the briquettes. According to Kers et al. (2010), agricultural byproducts that are considered as waste have high potential of being utilized as feedstock in production of briquettes. Some potential feedstocks for making briquettes with these two machines are shown in Table 1. The materials have been presented with their respective ash contents to provide an overview of their quality, whereby the ones with a higher ash content have less energy efficiency than those with a lower ash content (Kers *et al.*, 2010).

Table 1

Potential feedstock materials to be used for briquettes production

S/N	Agro-waste	Ash (%)	S/N	Agro-waste	Ash (%)
1	Corn cob	1.2	6	Tobacco	19.1
2	Saw dust	1.3	7	Groundnut shell	6
3	Coffee husks	4.3	8	Bagasse	1.8
4	Coconut shells	1.9	9	Cotton shell	4.6
5	Rice husks	22.4	10	Tea waste	3.8

Source: Grover & Mishra (1996), Kers *et al.,* (2010) and Oladeji (2015)

Carbonization of the feedstocks presented in Table 1, prior to making biobriquettes with the innovated machines, was observed to improve the energy efficiencies. Moreover, the materials are different in weight in both forms before and after carbonization, some are heavier than others. So, it was observed that using weight approach to quantify the efficiency of the PSP and Briquetter in producing briquettes is not realistic, instead the count methods was observed to suit best for the purpose.

For instance, the PSP machine was found to have the capacity of producing three (3) pieces of briquettes for a single press and release process. However, the size of the briquettes produced are larger for existing charcoal stoves in Tanzania, hence reduction of briquettes size was of paramount importance which required introduction of separator plates. The separator plates were realized to reduce the size by increase the rate of production form 3 pieces per single press to 9 pieces per single press. Using a single plate for each of the three molds produced six briquettes while the use of two for each mold produced nine briquettes per single pressing. That is twice to thrice the original design number (3). In so doing the PSP machine is amplified to produce more numbers (pieces) of briquettes. For the case of the Briquetter, the machine has the fixed capacity of producing sixteen (16) pieces for a single press.

The PSP machine was favored by students from university as it has simple pressing approach of using screw road. However, the ejection process was observed to be challenging due to less power possessed by hands as compared to feet. Hence the modification of ejection to comprise both hand and feet ejection systems resolved the challenge. Feet gear introduced to the machine made the machine easy for use and a preference by females who used in producing briquettes as part of their academic career. On the other hand, the Briquetter was reported by users as an easy machine with one system for both pressing and ejection. A hydraulic jerk installed simplified work of pressing and ejecting the compressed feedstock (briquettes), hence it was considered more user friendly than the PSP. Moreover, cylindrical shape of the molds results to better compression strength of the feedstock than square or rectangular ones. This is due to the fact that, there is less friction during pressing and releasing of the feedstock from cylindrical molds than from square or rectangular one. Also, the smoothness of the briquettes from cylindrical molds was preferred by users than the square and the rectangular ones.

Physical testing results of produced briquettes

Results from impact resistance index tests (IRI tests) which is also known as drop test showed that compression of the carbonized sawdust, coffee husks, rice husks, and bagasse, with an equal ratio of waste paper slurry as binder (25% by weight of the feedstock composition), using both PSP and the Briquetter machines is strong enough to resist breaking after being dropped three times in raw from a height of 2 m. Table 2 shows the IRI tests results.

Table 2.
Drop test results of briquettes made by the PSP and Briquetter

Feedstock	$100-((W1-W2)/_{W1}\times 100)$ (%)			Average (%)	IRI	Target IRI > 50% = Pass IRI < 50% = Fail
	Test 1	Test 2	Test 3			
PSP test results						
Sawdust	99.68	94.44	90.77	94.96		Pass
Coffee husks	99.91	94.74	96.80	97.15		Pass
Rice husks	91.57	89.09	80.93	87.20		Pass
Bagasse	97.82	93.07	78.34	89.74		Pass
Briquetter test results						
Sawdust	99.96	99.83	94.01	97.93		Pass
Coffee husks	99.92	99.03	96.05	98.33		Pass
Rice husks	94.02	86.26	80.91	87.06		Pass
Bagasse	99.06	94.43	89.11	94.20		Pass

Whereby; W1 = Weight of briquettes before dropping (g), W2 = Remaining weight of useful briquettes to be burned after dropping (g), IRI = Impact Resistance Index (%)

The data in Table 2 implies that the machines produce briquettes with high compaction pressure. However, the differences in impact resistance imply that the compaction is not only dependent on the strength of the machine and the operator but also, on the materials being compacted as well. Moreover, it was observed that the compaction is not uniform for all people, as some might apply more strength than others. The results presented in Table 2 were for the briquettes manufactured by undergraduate female students at Ardhi University. Hence, these data can be applied as average threshold values for community adoption.

The water absorption resistance test results showed that the Briquetter have better compression strength than the PSP, as the briquettes produced by it didn't disintegrate in water after being dropped in. Moreover, difference materials were observed to have different water absorption resistance once pressed by either PSP or the Briquetter (Table 3).

Table 3.

WAR test results of briquettes produced by PSP and the Briquetter

Feed stock	30 sec in water $100-((W1-W2)/_{W1}\times 100)$ (%)	Target WAR > 50% = Pass WAR < 50% = Fail
PSP test results		
Sawdust	52.05	Pass

Feed stock	30 sec in water $100 - ((W1 - W2)/_{W1} \times 100)$ (%)	Target WAR > 50% = Pass WAR < 50% = Fail
Coffee husks	69.91	Pass
Rice husks	45.52	Fail
Bagasse	48.03	Fail
Briquetter test results		
Sawdust	68.79	Pass
Coffee husks	81.93	Pass
Rice husks	61.92	Pass
Bagasse	51.09	Pass

Where; W1 = Weight of 80% dry briquettes before immersed in water (g), W2 = Remaining weight of 80% TS dried briquettes after immersed in water for 30 seconds (g), WAR = Water Absorption Resistance index (%)

From Table 3, it is clear that the Briquetter have better compression strength than PSP, with briquettes that don't allow water to penetrate.

Social acceptance of the machines; Farmers in Mbarali district generate a massive amount of rice husks that have potential to be recycled into briquettes. The demonstrations and hands-on trainings on the use of innovative machines proved that the community is willing to use any briquette-making technology that is simple, user-friendly, and that ensures high production of briquettes. Although the machines can produce briquettes from rice husks bonded by waste paper or waste cassava flour, yet, blending the feedstock with other feedstocks with less ash content, like sawdust, falling leaves, and maize straws was observed to improve the quality of the produced briquettes. Operational costs and quality of briquettes were observed to be of less important, with ranking scores of 66.67% and 63.33, respectively (Figure 5).
On the other hand, student respondents at Ardhi University claimed that it is the quality (90%) and quantity (86%) of the products produced by the machine that highly trigger their selection/acceptance of the briquettes-making machine (Figure 5).

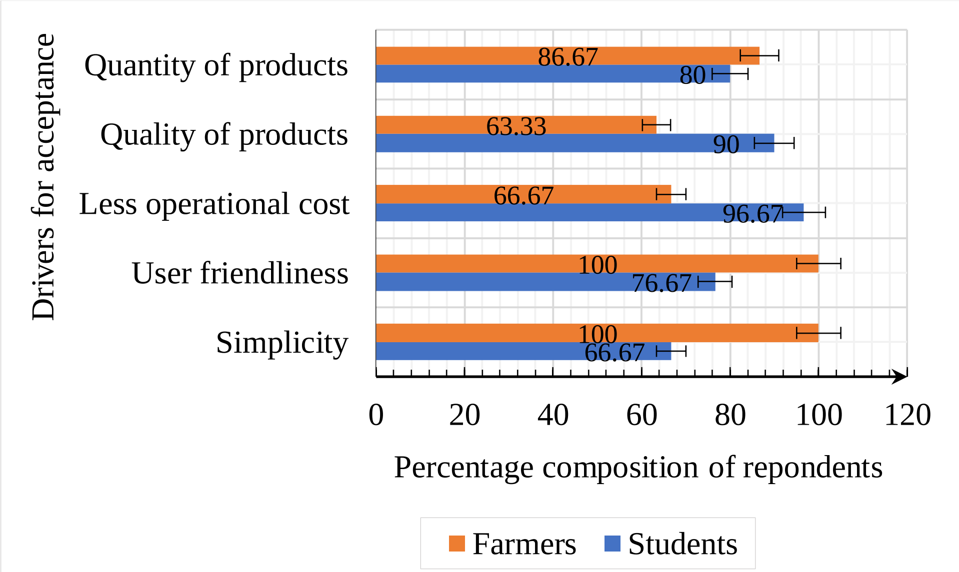

Figure 5. Ranking of drivers for social acceptance of the innovated machines

Results in Figure 5, shows that innovated machines scored high ranks in simplicity and user friendliness factors, so they have potential of being adopted for use by both youth and women unemployed groups. Moreover, the machines can be adopted by graduate students from colleges or universities who are inspired to join an entrepreneurial journey by making and selling briquettes. Majority women who tested the machines are the housewives, who have no other job except agriculture, which is done seasonally. Hence, they have too much time that can be utilized in the production of briquettes using these innovated machines. Although the cost of purchasing the machines was not mentioned as among the driving factor for selection of the machines yet, it is very important to consider it for upscaling purposes.

Apart from machines being adopted for commercial use, they proved to have positive impacts on improving training and teaching skills at the college and university levels. These innovated machines have been used by dissertation students at Ardhi University in performing experiments concerning briquette production as part of their academic qualifications. Moreover, the machines are demanded by other universities within Tanzania, including the University of Dar es Salaam and the University of Dodoma. Engineering and science students dedicating their academic careers to renewable energy, especially biomass briquettes, require these machines to alter chemistry or test their hypotheses in their research.

Discussion

The PSP and the Briquetter have reasonably good compressive strength, however production rate and quality is much dependent on the strength of the operator and the feedstock being used. Since feedstock materials used in producing briquettes are of different weight and quality (refer Table 1), then selection of feedstock materials should be based on the most available best quality and heavier materials. If the readily available feedstock is of either low quality or light weighted then blending with the best quality and denser is important.

Both machines have reasonable compression strength as they both passed the impact resistance index (IRI) tests. However, the failure of PSP in compressing briquettes made from rice husks and bagasse as they disintegrate after being dropped in water, suggests that the machine is not best suit in compressing light weight feedstock with less binder. Moreover, the failure is also due to the different in shape of the briquettes, whereby the briquettes made by PSP are doughnut (donut) shaped with a hole in between (Figure 6, A) while those of the Briquetter are solid without a hole (Figure 6, B). This being the case more surface area of the briquettes made by PSP are exposed to water than that of the Briquetter, hence weakening their inter molecular bonds created by the binding material.

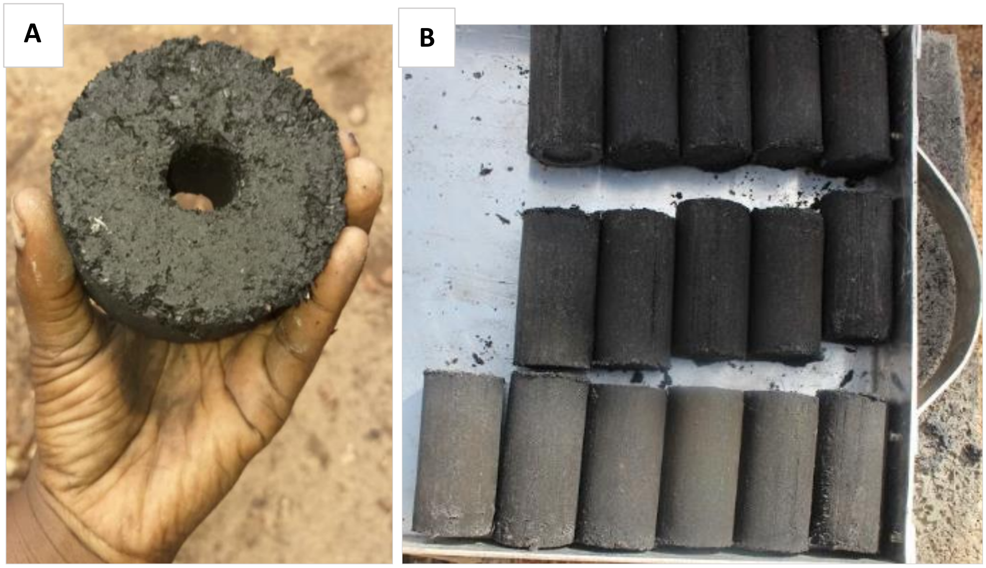

Figure 6. Shape difference of the briquettes made by A; PSP and B; Briquetter

Yet, the PSP machine can be adopted for use in producing briquettes from light weight feedstock since dropping of briquettes in water is a very rare case as compared to dropping them on bare land. Dropping briquettes in water can happen if accident occurs during transportation of briquettes over water bodies like rivers, lakes and seas which if happed it is very hard to save the product. So, if there is a risk of dropping in water the briquettes fabricated by PSP then a water resistance package should be used to cover them. In that case both the PSP and the Briquetter best suits for mass adoption within and outside Tanzania.

As long as the machines are simple in operation, user friendly and offers high production, they can be widely adopted by farmers. Moreover, they have potential of being adopted for academic purposes provided that they have less operation costs and can produce briquettes of high compression strength. This is due to the fact that, farmers are more concerned on making profit out of them while academicians (students) are more concerned on quality and serving costs in their researches. That being the case both the PSP and the Briquetter have potential of being adopted by both farmers and academicians (students).

Conclusion

The innovated briquette-making machines which are; the Peyam Screw Press (PSP) and the Briquetter, are efficient both technically and socially in attaining sustainable cooking and heating energy in Tanzania. They are simple and user-friendly for both women and youth unemployed groups from grid and off-grid communities. They produce briquettes that have high impact resistance after falling from a height of 2 m. However, the briquettes made by PSP proved to be useless once immersed in water for 30 seconds. Yet they are adequate and effective, because there are rare to no cases of briquettes being immersed in water. In that circumstance, the producer, supplier, or user is encouraged to take all the necessary precautions to ensure that the produced briquettes don't immerse in water. This should not be considered as a failure but rather as a property of the produced briquettes by PSP machine, just like that of glass, that is fragile once allowed to fall to the ground.

In order to have efficient and adequate sustainable clean cooking and heating energy in Tanzania and similar countries, it is highly recommended that place-based briquette-making machines like PSP and the Briquetter be promoted and widely adopted. Interventions for making sure that the machines are widely distributed to interested stakeholders, such as academic institutions (universities, colleges, and schools) and entrepreneurs, especially the youth and unemployed women groups should be created. Interventions might be made through calls for upscaling projects to innovator of these machines or entrepreneurs who wish to produce briquettes. With all that, yet, more studies, innovations, and developments are needed in order to develop more simplified, cost-effective, and place-based cooking and heating energy production technologies.

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