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AMA

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EDITORIAL

Recently, I had the opportunity to visit Tanzania in Africa on the request of Japan International Cooperation Agency (JICA). This was my first visit to Tanzania.

I visited it during the end of July until the beginning of August. This year's summer in Japan was getting extremely hot, so I thought it would be hotter in Africa; speculating the discomfort of heat, at first I thought of avoiding the travel, but after I looked into it, I found that Tanzania is located in the southern hemisphere and theoretically it is winter now! The maximum temperature was 27°C, making it a very comfortable visit. Tanzania is 2.6 times the size of Japan and has a population of about 63 million.

First, we visited the paddy fields that were created under the guidance of JICA in the Kilimanjaro state. The state is a province near Mount Kilimanjaro, Africa's highest mountain. According to the director of the 'Kilimanjaro Agricultural Training Center' there, Tanzania's population is estimated to grow more than double in the next 30 years. So strengthening the food production system in Tanzania is obviously an essential task.

In the five paddy fields that were created with the aid of Japan, I found there are some combine harvesters and other machines provided by Japan, but 80% of them were broken and unusable. When the machines were installed, they were free of charge, but when the machine breaks down, the cost of spare parts and other repairing goods are chargeable. Moreover there are no local personnel who can fix it properly. Therefore, I thought it would be a waste to have a machine that could still be usable if repaired. When providing assistance for agricultural machinery, I think this kind of assistance model must include after-sales service costs for at least five years. Also, I thought that local people should be invited to Japan and trained to be able to repair agricultural machinery. Capacity building of local artisans and workshop personnel is as important as providing machinery to the farms.

Africa will become a densely populated region in the world, and it will be necessary to increase food production. Currently, this continent is still importing food, but they have to produce all food necessary for themselves. To achieve this food self-sustainability, the progress in agricultural mechanization is essential. I also felt that equally essential is the progress of total agricultural mechanization, including after-sales service, and continued assistance from developed countries in terms of technology and appropriate machinery.

Yoshisuke Kishida
Chief Editor
Oct, 2022

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AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

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The Greenhouse Industry in Russia: Current Status and State Policies for Industry Support and Education

by

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Abstract

The greenhouse industry in Russia has overcome a dramatic decline in the 1990s, but has not recovered completely. Greenhouse production in Russia is gathering momentum and becoming more stable every year. However, the industry faces various challenges, one of which is a severe lack of qualified personnel. In this paper, we describe the current situation in the industry, and the technological features of different types of greenhouses. We also present an overview of state support policies for the greenhouse industry. Finally, we describe the agricultural education system in Russia, with a focus on supplying skilled personnel for the greenhouse industry.

Keywords: Greenhouse industry, agricultural education, state support

Introduction

Development of Greenhouse Industry in Russia

The greenhouse horticulture sector in Russia mainly developed during the Soviet Union period (Union of Soviet Socialist Republics; USSR) with the peak in construction of facilities from the 1970s to 1986. During this period, greenhouses were built in all regional centers and around the major cities with populations of more than 100,000 people. During the Soviet Union period, the greenhouse industry (protected cultivation) was a productive industry that was able to supply vegetables to the population during the off-season period. The devastating reforms of the 1990s negatively affected Russian agriculture in general, but especially greenhouse production, which has still not recovered to its pre-reform level (Muravyev, 2011).

Greenhouse production in Russia has several specific features. At present, there are modern greenhouses that were built using foreign technologies and adapted for Russian climate conditions. The Netherlands is the main supplier of greenhouses; drip irrigation systems are made in Israel, and boilers for greenhouse heating are produced in Germany. The share of domestically produced raw materials and technological solutions for greenhouse construction has increased gradually up to 30% in recent years (Agricultural platform “Agroinvestor”, 2019).

According to the Greenhouses of Russia Association, which was founded in 1994, the pace of greenhouse construction has doubled since 2013, with 200-300 ha of greenhouses being built every year. State support for agricultural producers has played a significant role in the development of the greenhouse industry in Russia. Nowadays, the association plays a significant role in supporting domestic producers. The association represents and protects the interests of greenhouse enterprises, monitors modern technological achievements and helps to implement them in the greenhouse industry, and promotes cooperation between Russian and international greenhouse producers. More than 189 enterprises from all over Russia have joined this association. The largest proportions of greenhouse producers are from the Krasnodar and Stavropol regions, and the Republics of Bashkortostan, Karachay-Cherkessia, and Tatarstan (Federal Service for State Statistics, 2019; Greenhouses of Russia Association, 2019).

Current Challenges in Russian Greenhouse Industry

There are several issues mainly faced by the Russian greenhouse industry. High production costs continue to challenge the industry. Depreciation of fixed assets is approaching 80% (Chekmarev, 2015). Due to the long service life (20-35 years) of greenhouses, the obsolete design of older models prohibits the introduction of modern technologies, which in turn restricts increases in production because the greenhouse itself is the main component of production efficiency. Simultaneously, obsolete technologies entail significant costs resulting in low profitability of greenhouse production. The average profitability of only 10-12% prevents agricultural producers from investing in business development and technological improvement, and remains one of the primary factors hindering industrial development (Greenhouses of Russia Association, 2019).

Another problem that has remained unresolved for decades is the significant lack of qualified personnel with higher education in all agricultural spheres including agronomy and engineering. Agriculture is developing every year, and new diversified, technologically sophisticated agricultural farms are being created. However, according to the All-Russia Agricultural Census conducted in 2016-2017, 47.9% of male and 27.6% of female employees in the sector are aged above 30, and many specialists are approaching retirement age (**Fig. 1**).

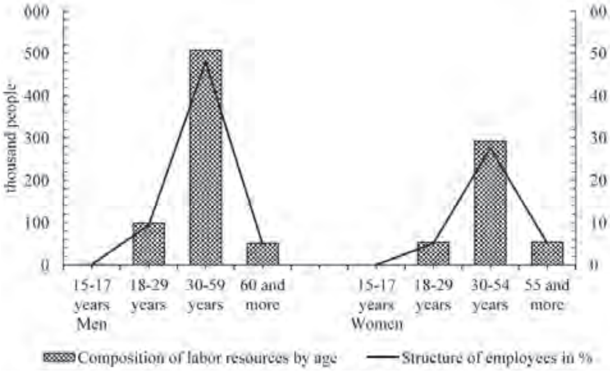
Agricultural employees with basic vocational education amount to 22.84%. Of the 21.22% of agricultural employees with secondary vocational education, almost half (9.8%) have specific agricultural qualifications. Only 12.38% of all employees in agriculture have attained higher education, and only 6.7% have professional agricultural degrees (All-Russia Agricultural Census, 2018).

Because the modern greenhouse industry is one of the most innovation-driven, technology-dependent industries, the disparity between technological progress and educational obsolescence is particularly large. This means that a lack of qualified personnel is another severe issue restricting the progress of the industry. In the program for the maintenance and development of greenhouses, the Ministry of Agriculture set an ambitious target of 4,700 ha of greenhouses by 2020, producing about 1.5 million tons of vegetables to meet 80% of the total demand of the population provided that the yield of vegetable crops is no less than 50 kg/m^2 (Greenhouses of Russia Association, 2019; Ministry of Agriculture of Russia, 2019). For sustainable greenhouse production to develop to that extent, there must be comprehensive state support and a new system of education and training to produce highly qualified personnel.

Study Objectives

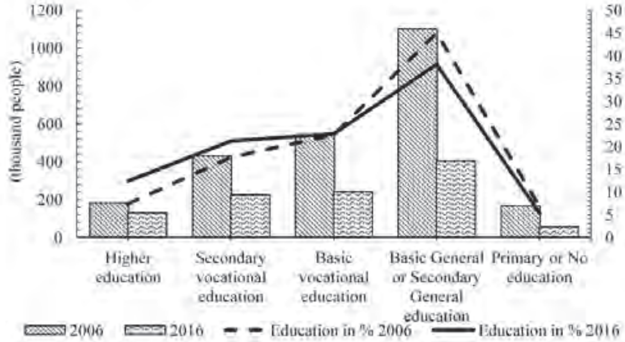
The primary aim of this study is to describe the characteristics of the agricultural education system focused on higher education for the greenhouse industry in Russia. To do this, we provide an overview of the current state and challenges of the industry, paying particular

Fig. 1 Distribution of population employed in agriculture by age groups



Source: All-Russia Agricultural Census, 2018.

Fig. 2 Educational attainment of population employed in agriculture



Source: All-Russia Agricultural Census, 2018.

attention to state support policies. We describe different technological types of greenhouses that must be staffed by personnel with particular qualifications. Despite significant changes in both the greenhouse industry and related sectors and the agricultural education system in Russia, relevant literature in English on these topics is scarce. Research on educational programs specifically for greenhouse professionals has not been conducted previously.

Data Sources and Methods

To gather information for this study, we examined official data of the Federal State Statistics Service, Ministry of Agriculture, and the Ministry of Science and Higher Education of the Russian Federation. To overview curriculums related to the greenhouse industry, we obtained state educational standards and relevant legal regulations, and checked official sites and publications of agricultural educational institutions. We also studied relevant literature and information from the Greenhouses of Russia Association.

Technological Types of Greenhouses in Russia

Greenhouse production includes engineering techniques such as construction technology, plant growth, environmental protection, and vegetable production. For this study, we gathered information on the technological types of greenhouses, and on the qualifications required for personnel to manage such facilities.

Greenhouse production in Russia began with primitive lean-to structures and has since developed to include modern high-tech facilities. The greenhouse industry stagnated for a long time after the collapse of the USSR, and consequently, many Russian greenhouses are outdated and inefficient (Bryzgalov, 1995). In 2018, out of the 2,600 ha of land occupied by operational greenhouses, 1,750 ha had old complexes with a service life of 30-40 years, and up to 50 ha of outdated greenhouses were being removed annually (Agricultural platform “Agroinvestor,” 2019). Currently, we can define five different types (generations) of greenhouses in Russia.

The first-generation of greenhouses is characterized mainly by one-slope construction with wooden frames and floors. The slope of the ramp faces the sun to intercept maximum solar radiation. These greenhouses are ventilated by vents on the ramp, and are stove-heated.

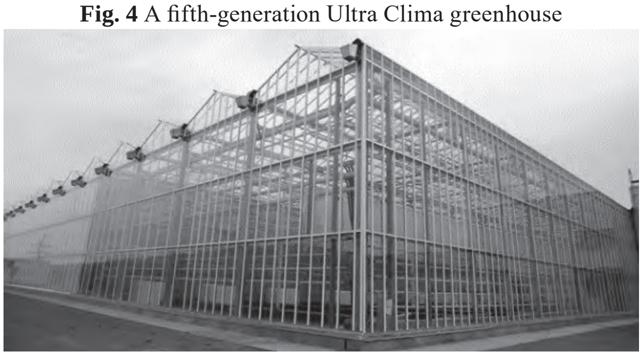
The second-generation greenhouses have a gable roof and are more progressive with water and air heating for year-round use. These greenhouses have metal or wooden frames and support posts arranged in two rows in the center, connected to the upper part by metal girders. They are double ventilated at the top and sides.

The third-generation greenhouses are the large-scale hangar-type greenhouse that are used year-round and have hot water and electric heating. Compared with earlier generation greenhouses, the 3rd generation greenhouses have better operational and environmental indicators due to the ability to control the microclimate, their effective space utilization, and their simplified installation process. In particular, these greenhouses have better illumination and increased ventilation capacity, stable thermal conditions of the soil and air, and the ability to accommodate vehicles and tillage machines. In these greenhouses, it is easy to mechanize or automate ventilation, sprinkling, and other procedures (Ryzhenko, 2007; Mamedov, 2015; Dorzhiev et al., 2018).

The fourth- and fifth-generation greenhouses are the most commonly used type in Russia nowadays. Modern 4th generation greenhouses are suited to high-tech production. Those produced by Venlo, for example, are tall, well-sealed, highly automated, and range in size from 1,000 to 10,000-30,000 m^2. Multi-span greenhouses are a combination of 2-3 or more double-sloped greenhouse modules adjacent to each other and joined along the longitudinal sides. The roof sides of adjacent modules are connected by gutters, which discharge water as well as functioning as load-bearing elements of the roof. All modules of multi-span greenhouses are interconnected and make up a structure with a glass roof, in which it is possible to move freely from one block to another. (Litvinov and Shatilov, 2015). The main advantages of multi-span greenhouses are the lower costs of construction per unit, and reduced heat consumption (lower heating costs). The disadvan-

Fig. 3 A fourth-generation greenhouse (multi-span greenhouse)

Fig. 4 A fifth-generation Ultra Clima greenhouse



tage of this type of greenhouse is that it is unable to sustain an optimum microclimate during the warm period of the year. Because there is no system to reduce the internal temperature, the risk of over-heating is high (**Fig. 3**)

The fifth-generation greenhouses are represented by innovative Dutch companies, and include the Ultra Clima type by the KUBO company; SuprimAir by CERTHOM, and ModualAIR by Vander Hoeven (**Fig. 4**). These greenhouses have several advantages: they can maintain an optimum level of CO_2 and an ideal microclimate any time of the year, and have low energy costs because of thermal energy re-use. In the Ultra Clima greenhouses, the rising warm air is directed by fans to plastic hoses located under each row of plants for another heating cycle. Whereas the heat from the lamps (approximately 90% of the lamp power) disappears in an ordinary greenhouse, the heat in an Ultra Clima greenhouse is almost fully re-used and there is very little heat loss. In addition, the positive pressure inside the greenhouse acts as a shield to prevent insects from entering (Sokolov, 2015; Gish and Karpenko, 2016).

In 2015, the first 32-ha fifth-generation greenhouse complex was built using KUBO technologies in Dankov city, Lipezk region. This project was achieved as a cooperation between the Russian manufacturer of automation systems for industrial greenhouses "NPF FITO" and the "Greenhouse technologies" company (Gish and Karpenko 2016; Sokolov, 2015). By November 2018, "NPF FITO" constructed almost 100 ha (six complexes in several regions of Russia) of 5th generation Ultra Clima greenhouses, representing one-third of the world's total of 300 ha (Semykin, 2018).

Contemporary greenhouse technologies are changing and developing every 2-4 years. At the same time, older greenhouses with obsolete technologies are still used in Russia. All greenhouse complexes should be staffed by highly qualified personnel who are able to adapt to technological changes easily, or even lead these transformations. Ideally, greenhouse managers should be able to quickly implement new technologies for modern high-tech production, analyze complex situations, and make responsible decisions.

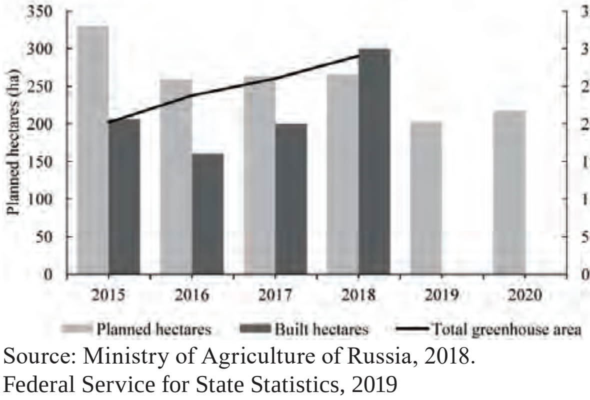
State Policies Supporting Greenhouse Industry

The further development of greenhouse production in Russia is impossible without government support. Although there are various state programs for agricultural support in Russia, the industry still needs a more profound approach to address its problems. For instance, while new greenhouse enterprises receive financial support from the Government, there are no state support programs for the repair and reconstruction of existing greenhouse complexes (Muravyev, 2011; Aleksashkina, 2016).

To encourage the construction of new greenhouse complexes with investor support, the Russian Government adopted the following resolution dated 24 July 2015: № 624 "On approval of rules for provision and distribution of subsidies from the federal budgets of the Russian Federation for reimbursement of the direct costs on creation and modernization of projects in of the Agro-industrial complex". In the period from 2015 to 2017, the Commission of the Ministry of Agriculture of Russia selected and approved 47 investment projects with a total investment of 892,577 USD. The projects received subsidies of 179,000 USD that covered part of the direct costs incurred in the construction and modernization of greenhouse complexes with a total area of 366.5 ha. An analysis of greenhouse construction and development from 2015 to 2018 and beyond is summarized in **Fig. 5**.

According to the Russian regional authorities responsible for Agro-industrial complex management, the state plan for the construction

Fig. 5 Greenhouse construction development supported by the state program



Source: Ministry of Agriculture of Russia, 2018. Federal Service for State Statistics, 2019

Fig. 6 Map of agricultural educational organizations

Note: Information is from www.agrovuz.ru.
Source: Agrovuz, 2019

and modernization of greenhouse complexes in 2015-2017 was not completed due to insufficient funding (**Fig. 5**). Thus, out of 329.4 ha planned greenhouses, only 206 ha of greenhouses were built. In 2016, the area of new greenhouses amounted to 160 ha out of the planned 259.8 ha. In 2017 about 200 ha of greenhouse construction was completed. In 2018, the industry finally built 300 ha of winter modern greenhouses, creating more than 6,000 new jobs. So far, the total greenhouse area in Russia is 2,900 ha (Ministry of Agriculture of Russia 2019; Greenhouses of Russia Association 2019).

Unfortunately, the statistical data on the area and volume of greenhouse production is unreliable because the industry is continually changing and evolving, and because there is no official information on the volume of vegetables produced annually in greenhouse complexes owned by private investors. Thus, a considerable amount of greenhouse production remains unaccounted for.

There are two state policies that provide the legal basis for agricultural education: The Workforce Training and Skills Development in the Russian Federation for the period up to 2020; and the Federal State Target Program of Education Development for 2016-2020 (approved by RF government on May 23, 2015, № 497). The development of a new strategy for agricultural education in the Russian Federation has been debated since 2014. These policies state that the roadmap for the development of educational strategies must be well planned and adequately prepared with cooperation among industries, educational and scientific institutions, and the government.

Agricultural Education System in Russia

Nearly half of the total workforce employed in agriculture in Russia has a basic and/or secondary level education (**Fig. 2**). Vocational schools and lyceums provide the basic level of vocational education and training for agricultural workers. The secondary level of vocational education is provided by vocational technical schools or colleges, and leads to a qualification as a specialist. Students can start vocational training after 9-11 years of general education. Those who start vocational training from year 9 also study general subjects, allowing them to take standardized state examinations and continue to university. Agricultural universities have established vocational educational institutions that provide methodological and research training to produce middle-ranking specialists. There are 253 of these vocational educational institutions located in 73 regions of Russia (Volkov et al., 2017).

The higher agricultural education system subordinate to the Ministry of Agriculture of Russia encompasses 55 educational institutions located in 58 regions of Russia (**Fig. 6**). They include one agricultural institute, 17 agricultural academies, and 37 agricultural universities, 22 of which have 43 branch campuses (Agrovuz, 2019).

Across Russia, 29 universities have faculties of agriculture that provide educational training in several agricultural majors. The leading majors are Mechanization of Agriculture, Agronomy, and Food Processing Technology. Higher education in Russia consists of two main degrees: Bachelor's and Master's degrees. Bachelor's courses are 4 years long, and Master's courses are 2 years long. Many agricultural universities also offer Ph.D. courses (3-4 years).

The agricultural education system in Russia has implemented the principle of "lifelong education" through a network of continuing educational institutions. Advanced training and professional requalification of employees is provided by specialized educational establishments and qualification centers, while continuing education programs are provided by all higher educational institutions subordinate to the Ministry of Agriculture (Volkov et al., 2017).

We reviewed different curriculum of higher education programs in Russian agricultural educational organizations, focusing on educational programs for the greenhouse industry and relevant sector qualifications.

Results and Discussion

Higher Education for Greenhouse Industry

General Information

We reviewed and analyzed curriculums related to the greenhouse industry in the last 5 years, from 2014 to 2019. We selected this period because the international sanctions imposed on Russia in 2014 had a massive impact to increase domestic greenhouse production and increasing competitiveness in the world market. The embargo on the import of vegetables forced the Russian government to include greenhouse production in the state program to support agriculture (Mamedov, 2014). Thus, the Russian Ministry of Agriculture has developed a plan for the construction (modernization) of greenhouses for 2015-2020.

Analyses of the curriculums focused on qualifications for greenhouse production showed that, before 2015, there were no specific study programs to prepare qualified personnel for the industry. However, two main agricultural majors were directly connected to the greenhouse industry (**Fig. 7**).

Figure 7 shows two agricultural majors, known as "specializations" in Russia. These two majors produce specialist agricultural engineers and agronomists.

An agricultural engineer is a specialist who can mechanize, electrify, and automate production processes; ensure the efficient use of agricultural machinery; calculate modes of operating agricultural machinery in accordance with specified conditions; and organize the storage, repair, and maintenance of agricultural equipment. An agronomist deals with soil management practices; improves agricultural production lines in terms of crop production, and develops operations that include farmers, gardeners, agricultural machine operators, and post-harvest processors.

Agricultural engineering and agronomy courses have two sub-majors (**Fig. 7**, third line) that are studied in detail. When we analyzed the curriculums of both specializations, we found that agricultural engineering and agronomy share many common subjects (e.g., agricultural engineers study the principles of crop growth, and agronomists learn the principles of agricultural machinery and mechanization). However, only the agronomy curriculums, mostly at the Master's level, have subjects related to greenhouse production.

Producers have reported that almost every educated person employed recently lacks the practical knowledge to work to the required standard immediately after taking a position (Semykin, 2018). As discussed above, the fourth- and fifth-generation greenhouses represented by foreign and domestic modern operating technologies require highly qualified personnel to manage sophisticated technological production lines. Thus, producers want well-qualified personnel with suitable job experience for particular positions. To overcome the disparity between the knowledge of new university graduates and that required for the actual job, producers provide new employees with substantial additional training or sometimes even full requalification (Gavrish and Korol, 2014).

According to the estimates of the director of the Scientific Research Institute of the Protected Ground Vegetable Growing, to maintain 2,130 ha of winter greenhouses in Russia in 2015, the industry needed 500-600 specialists (3-4 specialists per ha). Most of the agronomists with specializations in technology, agrochemistry, plant protection, and automation engineering are already working, so the majority of specialists in the industry need to undergo retraining. Several dozen new graduates each year should be educated according to updated educational standards. The creation of a national training center for industry specialists has been debated since 2013. While the question of the financial burden remains open, a smaller training center is already operating at the Belgorod greenhouse complex (Gavrish and Korol, 2014; Semykin, 2018).

New Educational Standards for Greenhouse Industry Specialists

Meanwhile, Ph.D. (35.06.01), Master's (35.04.05), and Bachelor's (35.03.05) educational programs with the specialization "Horticulture" were approved by orders №1017, №1049, and №1165 of the Ministry of Science and Higher Education of the Russian Federation on 18 August 2014, 23 September 2015, and 20 October 2015, respectively. Bachelor's degree programs were launched at 17 agricultural universities on Sept. 1st, 2016. **Table 1** summarizes data on agricultural universities with educational programs for the greenhouse industry.

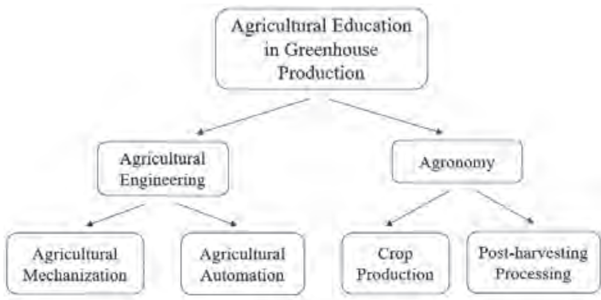
Since portions of the new curriculums directly relate to greenhouse production, Master's and Bachelor's students in horticulture programs will graduate as specialists for this industry. For instance, a major in the Bachelor of Horticulture (35.03.05) includes papers on fruit growing, viticulture and winemaking, vegetable growing, the production and processing of medicinal crops and essential oil raw materials, ornamental gardening and floristics, selection, genetics, and biotechnology of garden crops, and greenhouse gardening. The Master's program (35.04.05) includes courses on the development of production lines, and implementation of the cultivation of vegetables, fruits, medicinal crops, and grapes using modern, environmentally safe, intensive, resource-saving technologies that are adapted to certain technological and soil-climatic conditions. The Ph.D. programs will prepare scientists and experts with the highest level of knowledge in those areas. To ensure a certain number of future graduates, the Russian State Agrarian University-Moscow Timiryazev Agricultural Academy provides 20 state-funded places for greenhouse-related specializations annually (Agrovuz, 2019).

The first Bachelor of Horticulture students are expected to graduate in 2020. Some of those students will continue to the Master's program (2 more years). Thus, the lack of qualified personnel in the greenhouse industry is expected to ease only by 2020, and by 2022 the industry will have more highly educated specialists.

Concept to Solve Current Lack of Qualified Personnel

According to our collected data

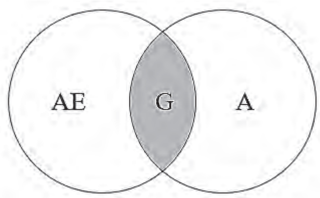
Fig. 7 Agricultural education chart for greenhouse production



Note: Agricultural majors providing specialist personnel for greenhouse production and observations, we have illustrated the concept to solve the current issue of a lack of qualified personnel in the greenhouse industry (**Fig. 8**).

As noted above, the first qualified personnel for the greenhouse industry will graduate by 2020-2022, and there are common subjects in the curriculums of agricultural engineers and agronomists who graduated before 2016. Only agronomy majors have studied subjects related to the greenhouse production industry. **Figure 8** illustrates that greenhouse specialists represent the crossover between agronomists and agricultural engineers. This figure highlights that all specialists with agricultural education and basic knowledge (e.g., agricultural engineers and agronomists) are able to requalify for greenhouse production in a short time. The G section represents specialists for the greenhouse industry. Producers should employ qualified personnel from those two main agricultural areas (AE and A) and supply further training to address current lack of qualified personnel.

Fig. 8 Concept to supply qualified personnel for the Russian greenhouse industry



Note: AE – Agricultural Engineer; G – Greenhouse specialist; A – Agronomist

Although higher educational institutions are expected to develop new educational programs and majors for the greenhouse industry, they should not act only as a provider of workers for the economy. Universities are expected to serve as innovation centers, ensuring interconnections among science, education, business, and the state, which is necessary for the development of the industry (Volkov et al., 2017).

Conclusion

Currently, the situation of the greenhouse production industry in Russia is complex and contradictory. On the one hand, substantial state support means that the greenhouse industry is a substantial contributor to the Russian economy that has reached a new stage of development. Modern greenhouse complexes are made up of innovative fourth- and fifth-generation greenhouses. On the other hand, several problems remain unresolved. Modern greenhouse technologies are changing and developing every 2-4 years, and the industry lacks highly qualified personnel. The issue of a shortage of qualified personnel is being addressed by employing the specialists from closely related spheres, such as agricultural engineering and agronomy, followed by further education and requalification. In accordance with the new state educational strategy and the demands of the greenhouse industry, an updated educational standard was developed in 2015, with relevant programs starting at universities in 2016. Therefore, new graduates that are qualified for the greenhouse industry will be available from 2020-

Table 1 List of universities with educational programs for the greenhouse industry

№	Name of University	Bachelor's course	Master's course	Ph.D. course	Location (City name)
1	Russian State Agrarian University - Moscow Timiryazev Agricultural Academy	35.03.05	35.04.05	35.06.01	Moscow
2	The Academy of Social Relations	35.03.05	-	35.06.01	Moscow
3	Saint-Petersburg State Agrarian University	35.03.05	35.04.05	35.06.01	Pushkin
4	Kazan State Agricultural University	35.03.05	35.04.09	35.06.01	Kazan
5	Ural State Forestry University	35.03.05	-	35.06.01	Yekaterinburg
6	Ural State Agrarian University	35.03.05	35.04.05	35.06.01	Yekaterinburg
7	South Ural State Agrarian University	35.03.05	35.04.05	35.06.01	Troitsk
8	Omsk State Agrarian University named after P.A. Stolypin	35.03.05	35.04.05	35.06.01	Omsk
9	Samara State Agricultural Academy	35.03.05	-	35.06.01	Ust-Kinelsky
10	Don State Agrarian University	35.03.05	35.04.05	35.06.01	Rostov
11	Kuban State Agrarian University	35.03.05	35.04.05	35.06.01	Krasnodar
12	Voronezh State Agrarian University named of Emperor Peter I	35.03.05	35.04.05	35.06.01	Voronezh
13	Volgograd State Agrarian University	35.03.05	35.04.05	-	Volgograd
14	State Agricultural University Northern Trans-Urals	35.03.05	35.04.05	35.06.01	Tyumen
15	Altai State Agricultural University	35.03.05	35.04.05	-	Barnaul
16	Dagestan State Agrarian University named after M.M. Dzhambulatova	35.03.05	35.04.05	35.06.01	Makhachkala
17	Smolensk State Agricultural Academy	35.03.05	35.04.05	35.06.01	Smolensk

Note: (-) no information was found; Ph.D. specializing in agriculture; Master's and Bachelor's degree courses with majors in horticulture;
Source: Agrovuz, 2019, from websites of each university.

2022 onwards.

The State Program for the Development of the Agro-Industrial Complex is projected to enable Russian greenhouse producers to fully satisfy the domestic demand for fresh vegetables by the end of 2020. This plan assumes that there will be further intensive development of the industry. To cope with the industry's needs and state strategies, all stakeholders in the industry, educational/scientific institutions, and the government should cooperate in the development of new educational programs and qualifications.

At present, there is a lack of statistical data and in-depth studies reflecting the actual situation with abandoned and newly constructed greenhouses, and there are rapidly evolving trends in education and retraining for the greenhouse industry. Given these uncertainties, it is important to conduct further research to fully understand the current state and the future directions of the greenhouse industry in Russia.

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Rice Husk Handling and Combustion in Rural Areas: Assessment of Household Proximity to Exposure Risk in Nigeria

by

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Abstract

Exposure to rice husk particles and its combustion emissions may pose health risk. This study evaluated the effect of households' distance to exposure risk in rural rice milling communities in Nigeria. The method involves administration of a questionnaire interview in collaboration with the local health department. Four rice mill clusters were selected; 240 selected respondents were living within 1 km of the rice mill clusters. The study hypothesis predicted an inversely proportional relationship between household distance and health symptoms. Household distance of the respondents to the rice mill clusters, had a significant effect on exposure risk. For Lafia rice mill cluster, strong negative correlation was found with symptoms such as eye irritation (-0.71), chest pain (-0.67), skin irritation (-0.67), itchy throat (-0.66), cough (-0.65), nausea (-0.60). For Otukpo rice mill cluster, the symptoms include chest pain (-0.76), eye irritation (-0.75), nausea (-0.74), headache (-0.72), shortness of breath (-0.71), itchy throat (-0.69). In Makurdi rice mill cluster, the symptoms include nausea (-0.92), itchy throat (-0.89), headache (-0.83), shortness of breath (-0.83), sneezing (-0.71) and skin irritation (-0.65). In Aliade rice mill cluster, the symptoms include dizziness (-0.84), chest pain (-0.79), nausea (-0.76), headache (-0.66), shortness of breath (-0.63) and eye irritation (-0.61). In conclusion, the current mills established in the locations poses significant health risk. Replacement of these technologies with modern integrated milling system is recommended. Filtration systems should be installed. Moving rice mill clusters further away from residential areas, especially when setting up new rice mill clusters. Frequent monitoring of PM and tougher sanctions for noncompliance with the air quality regulation is recommended.

Keywords: rice husk combustions, particulate matter (PM),

health symptoms, household distance, rice husk dust, exposure risk.

Introduction

To respond the increasing emissions of greenhouse gases and the rapid occurrence of climate change effects, the United Nations (UN) sustainable development goal no. 13 (SDG 13) was established. The need to lessen this effect is a vital point stressing the critical role of smart energy sources such as biomass, solar, wind, hydroelectric and geothermal energy. The utilization of biomass fuels for heating has been associated with air pollution and emission of toxic pollutants. Pollutants emitted during biomass combustion include carbon monoxide, nitric oxides, hydrocarbons and particulate matter (PM), which constitute air pollution (Juntarawijit et al., 2014).

Pollution, which is closely associated with climate change, is among the primary causes of disease and early death globally. Air pollution from household fuel poses the most critical global environmental health risk (WHO, 2014). It accounted for about 9 million deaths in 2015 (Landrigan et al., 2018). Human contact with biomass pollutants increases the possibility of pneumonia and other lung illness and were among the causes of '800,000 deaths in children' below the age of 5 (June et al., 2011; Emmelin et al., 2007). A World Bank report in 2012, showed that outdoor air pollution in Africa accounted for 49,000 deaths yearly, and Sub-Saharan Africa with the most recorded deaths (Dieter, 2012). Nigeria is one of the countries that suffer such health exposures and symptoms due to outdoor airborne particulate matter (PM) from a biomass generating facility or the combustion of agricultural residues such as rice husk in open air.

There is a risk of human exposure to particulates and smoke due to biomass generation and combustion (Iwegbue et al., 2018; Chakraborty et al., 2017). The risk of exposure is severe in rural rice milling areas due to their over-reliance on old milling technologies and the uncontrolled burning of rice husk. Therefore, necessitating the need for continuous health impact assessment of clusters of rice mills in the rural areas. Paying attention to the minimization of airborne particulates and other toxic pollutants is a crucial step towards achieving a "biomass material recycling and clean society'' (Shinichi et al., 2017).

The use of rice husk in modern boilers with advanced particle removal systems (Jaehong et al., 2017), can generate enough heat energy needed for the parboiling and drying of paddy, thereby, reducing the overreliance on wood fuel. Previous studies have linked rice milling activities to occupational health issues (Juntarawijit et al., 2013; 2014). Especially manual handling of rice husk or separation of bran from broken (Farukh et al., 2005). However, a case study dedicated for Nigeria is required due to the geographical, cultural and technological differences.

Having site-specific knowledge of rice mill clusters and emission sources that pose health risk is needed for continuous assessment to improve the environmental conditions of rice mills and its operating conditions. One such way of getting reliable environmental data is through health impact assessment. It is an organized procedure for evaluating health effects of projects and policies in the non-health sector (Lock, 2000). This may include real-time measurement of PM and field observations. Also, health impact assessment takes qualitative data of public opinion into account for a wider and comprehensive view of impacts (Morgan, 2003; Wright et al., 2005).

The high level of open burning of rice husk in large heaps among some rural communities in Nigeria is of significant concern and is environmentally unsustainable. The noncompliance with environmental protection guidelines and

Fig. 1 Descriptive map of Nigeria, showing the target states (Nasarawa and Benue) and the four study locations

lack of tougher sanctions have led to an increased number of airborne particles. Which exceeds the world health organization (WHO) guidelines ($PM_{2.5}$: 25 μg/m^3 for 24-hour mean and PM10: 50 μg/m^3 for 24-hour mean). Thus, putting nearby residents at risk of exposure. Therefore, it is highly necessary to assess the severity and risk of exposures, physical symptoms and public opinions of people living close to these rice mill clusters.

This paper focuses on evaluating health risk from rice mill clusters, using residents' perception on health issues. The study evaluates the hypothesis that households' proximity to the rice mills have significant effects on exposure risk in the rural rice milling communities. It will affect the symptoms and will have an inversely proportional relationship with the symptoms. The study integrated real-time PM measurement techniques, field observation, and public opinion in collaboration with the local health department for evaluation.

Methods

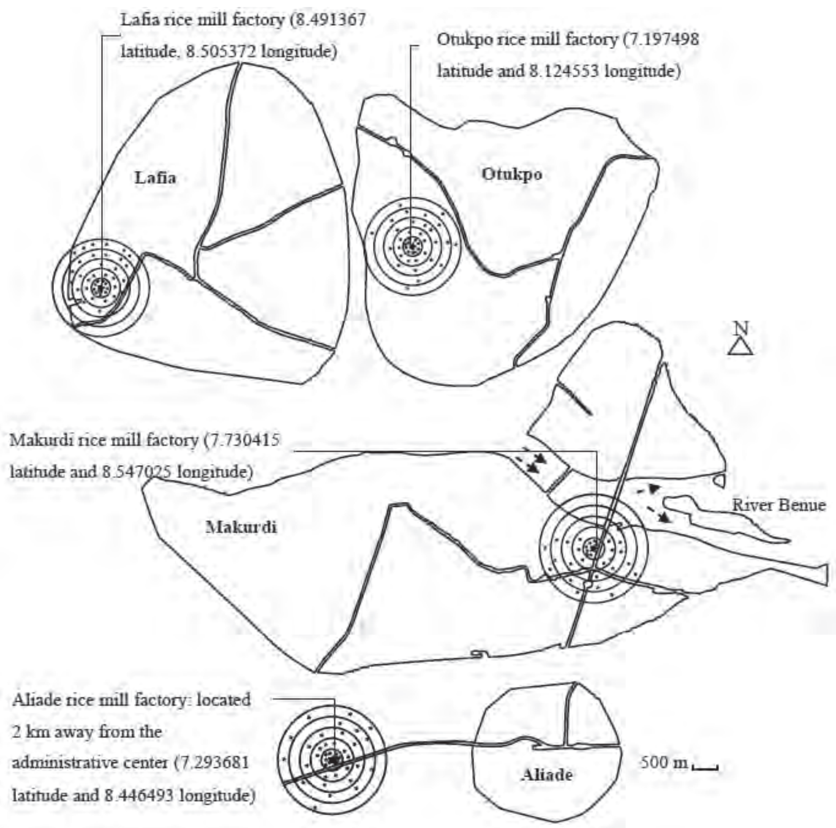
Study Design and Site Selection

Two states were purposively selected from the middle belt region of Nigeria namely; Nasarawa state and Benue state because rice cultivation and its milling are highly practiced in these states (**Figure 1**). Within the two states, four rice mill clusters were purposively selected as case studies based on the background of public complaints and the nearby residents required for the study. The selected rice mill clusters are Lafia, Otukpo, Makurdi and Aliade (**Figure 2**). A rice mill cluster is defined as an area mapped out for multipurpose activities such as rice milling, selling and distribution. A rice mill is a place for business interactions between farmers, millers, traders and consumers. The trading commodity is paddy rice or milled rice. Farmers and rice traders bring their paddy rice for milling. Nearby residents and people from other cities come to buy the milled rice in wholesale or retail. A rice mill cluster is a crucial rice distribution centre in the rice value chain of Nigeria.

Annual rice production in Nigeria increased from 5.5 million tonnes in 2015 to 5.8 million tons in 2017. With a consumption rate of 7.9 million tons, the production rate has increased to 5.8 tons per year (RIFAN, 2017). Therefore, the continuous expansion of rice mill clusters or the establishment of new rice mill clusters is expected to continue. In Nigeria, local milling involves the removal of the husk (de-husking), bran and some portion of the endosperm in one cycle of operation. Small-scale milling machines such as the Amuda and Engelberg steel hullers were used in all four locations. The rice husk is grinded in the process. Therefore, its combustion efficiency in fixed bed or bottom vent combustion system is poor due to the smaller rice husk particles. This affects the inter-particle space between the husk particles and leads to low air-fuel mixing. Thus, the husk is either used as farm manure or burnt openly.

Lafia rice mill cluster is in Lafia, a town in Nasarawa state. The population of Lafia was estimated at 330,712 inhabitants (Census, 2007). Otukpo rice mill cluster is in Otukpo, a town in Benue state. The town has a population of 261,666 people. Makurdi rice mill cluster is in Makurdi, a town in Benue state and has a population of 300,377 people. Aliade rice mill cluster is situated in Aliade, a town in Benue state. The town has a population of 163,647 people.

Fig. 2 Survey location map of the 4 rice mill clusters



Questionnaire Survey, Study Subjects and Data Collection

To test the acceptance or rejection of the study hypothesis, a survey was carried out to examine the level of open combustion of rice husk, and the type of milling systems used in these rice mill clusters. The survey was carried out in the year 2018. Collected data include household cooking, health symptoms, tobacco smoking, use of medication, rice consumption, age, education, occupation and sampling of $PM_{2.5}$. This survey was permitted by the Nigeria Ministry of Agriculture and Rural Development. Each of the locations are geographically and culturally different from each other.

In order to evaluate accurately, the impact of the rice mills activities on public health, each study area was limited to 1 km diameter for purposive sampling. The eligibility criteria for participation was that, participants must either be working in the rice mill clusters or are living within 1 km diameter of the rice mill clusters. Those working in the rice mills are grouped as rice mill workers. This was done to cut out unnecessary factors that may interfere with the study outcome. For the sampled residents for each of the four locations (Lafia, Otukpo, Makurdi and Aliade), at every 200 m, 8 respondents were randomly interviewed, one per household. The survey team consist of a local health worker, a staff of the ministry of agriculture and rural development (agricultural/environmental engineer) and a community volunteer. The respondents must be more than 15 years old. 40 residents and 20 rice mill workers were interviewed for each location, making a total of 240 participants.

Symptoms influence how participants assess their health condition. Deciding on a disease is a difficult task as it is not only subjected to physical factors but also mental factors (Juntarawijit et al., 2014). From a miller and farmer's perspective, symptoms and signs often indicate changes in their bodies and probably changes in their environment. To understand the likelihood of health risk from the rice mills activities, we asked about their encountered health symptoms. Also, whether these signs were confirmed by the local health department personnel in relation to their activities or work. The frequency of occurrence of the symptoms was divided into three categories name; level A (more than 12 days per month), level B (3-12 days per month), and level C (less than 3 days per month).

Annual Rice Husk Production and Material Flow

In order to calculate the annual rice husk production, annual paddy milling data was collected from the record files of each rice mill cluster. The rice husk was estimated as 20% of the paddy. Therefore, a husk to grain ratio of 0.2 was used in the calculation (Garba and Zangina, 2015). Annual rice husk production for each rice mill was calculated using the equation;

$$H_{pro} = PR_{pro} \times HGR \quad (1)$$

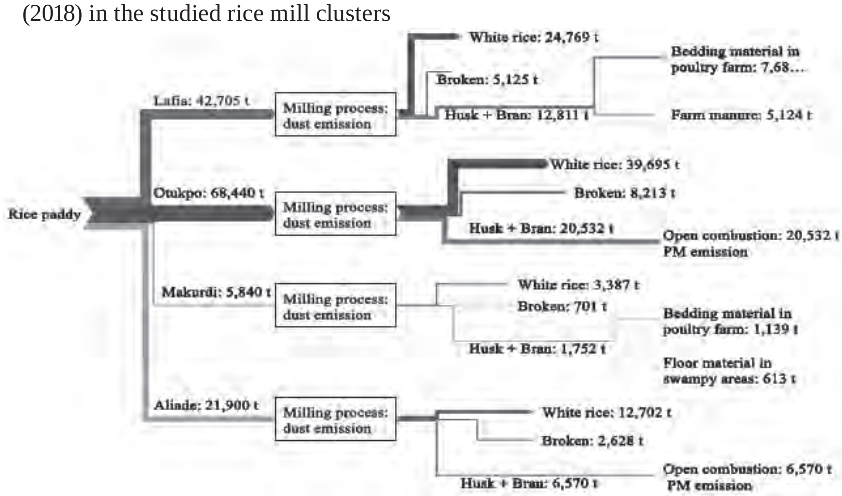
Where H_{pro} is the quantity of rice husk in ton per year (t/year), PR_{pro} is the paddy rice production in ton per year (t/year), HGR is the husk to grain ratio. Percentage of white rice, broken grain, bran was estimated based on data from the field survey and information from rice knowledge bank (IRRI, 2019) and the food and agriculture organization website (FAO, 2019). The material flow of rice milling, generated rice husk and its combustion/utilization was calculated (**Figure 3**). The rice milling process generates husk dust, while the combustion of rice husk leads to the emission of particulate matter and gaseous emissions.

Real-time Airborne Particulate Matter Sampling

On-site measurement of $PM_{2.5}$ was limited to two locations where rice husk disposal is open combustion. This measurement is essential in understanding the trend of $PM_{2.5}$ emission in the context of open combustion, in real-time. Furthermore, to know if the on-site values exceed the WHO limits, which is 25 μg/m^3 for 24-hour mean (WHO, 2019). The measurement is critical as it may affect the commonly encountered symptoms. A single channel aerosol counter (Dust Track II analyzer), was used to record levels of $PM_{2.5}$ in the atmosphere at the husk burning sites.

The dust track II analyzer is a real-time aerosol measuring instrument and uses impactors (size-selective inlet conditioners) to narrow down the particle size entering the instrument (Abah et al., 2018).

Fig. 3 The material flow of rice paddy milling and generated rice husk per year (2018) in the studied rice mill clusters



Note: In the studied rice mill factories, husk and bran were removed in one process. Thus, the husk is mixed with bran, hence the use of "Husk + Bran" to represent the waste

The instrument was program to the log mode for an aggregated one-hour sampling (12 tests with each test duration of 5 minutes). The experiments were conducted between 11:00-16:00 April 3rd and 4th, 2018. Prior to the sampling, multiple field visit of the sites was carried out to carefully observe the daily husk combustion volumes and to decide on the sampling day to ensure that the sampling is representative.

Results

Demographic Characteristics of the Respondents

Table 1 presents the participants information and the meteorological data of the four locations. The information includes age groups, education, occupation, smoking, and use of medication and meteorological data. The middle age group (31-45 yrs.) is the highest with 43.8%, followed by the old age group (>45 yrs.) 28.3%, and lastly by the young age group (15-30 yrs.) 27.9%. Respondents with no education is 26.3%, those with primary education is 33.3%, while 27.9% had secondary education. Also, 12.5% have tertiary education. Rice mill worker and farming constitute over half of the occupation of the respondents (33.3%, and 28.3%). Trading is 26.3%, and civil service as 12.1%. Rice was consumed as a staple food and 6.3% of the respondents were on medication, and 93.7% were not on medication. Also, 92.1% have no history of smoking. Therefore, the use of medication and smoking have no significant impact on the outcome of the study.

Significance of Household Distance to Health Symptoms

The combine number of respondents for the four study locations was 240 and referred to both rice mill workers (33.3%) and residents (66.7%) and satisfies the eligibility criteria of working or living within 1 km of the rice mill clusters. For each location, the respondents were asked about symptoms (such as eye irritation, chest pain, itchy throat, headache, skin irritation, shortness of breath, dizziness, nausea, sneezing, cough and catarrh) and by using the occurrence category explained in the questionnaire section.

Table 1 Participants' information and meteorological data for the study locations

Respondents particulars		Lafia	Otukpo	Makurdi	Aliade	Total (%)
Age (Years)	15-30	20	15	16	16	67 (27.9)
	31-45	27	22	32	24	105 (43.8)
	>45	13	23	12	20	68 (28.3)
Education	No education	19	15	10	19	63 (26.3)
	Primary	23	20	15	22	80 (33.3)
	Secondary	12	18	24	13	67 (27.9)
	Tertiary	6	7	11	6	30 (12.5)
Occupation	Farming	17	18	10	23	68 (28.3)
	Trading	15	17	18	13	63 (26.3)
	Rice mill worker	20	20	20	20	80 (33.3)
	Civil service	8	5	12	4	29 (12.1)
Smoking	Yes	6	4	5	4	19 (7.9)
	No	54	56	55	56	221 (92.1)
On medication	Yes	3	4	6	2	15 (6.3)
	No	57	56	54	58	225 (93.7)
Temperature °C		27.5	27.2	27.2	26.7	
Yearly rainfall (mm)		1,316	1,723	1,248	1,471	
Elevation(m)		176	170	83	168	
Wind speed (m/s)		2.5	2.4	3	3	
Mill capacity (ton/day)		72-162	125-250	20-May	40-80	

Encountered Symptoms by Rice Mill Workers

Table 2 presents the symptoms encountered by rice mill workers. Distance 0.0 km represents rice mill workers. Respondents highlighted the physical symptoms they encountered. Rice mill workers experienced multiple symptoms. For Lafia rice mill cluster, positive response was obtained on common symptoms such as eye irritation (85%), itchy throat (70%) and skin irritation (85%). For Otukpo, positive response for symptoms reported include eye irritation (90%), skin irritation (90%) and itchy throat (75%). For Makurdi, 80% and 65% positive response was recorded for headache and eye irritation respectively. For Aliade, eye irritation had 85%, 90% for chest pain and 70% for skin irritation.

Encountered Symptoms by Nearby Residents

The total number of nearby residents interviewed for each rice mill cluster was 40, about 8 persons for every 200 m from the rice mill cluster. Therefore, all participants were living within 1 km of the rice mill clusters. Also, their socio-economic activities were within the study locations. Distance 0.2-1.0 km in **Table 2**, represents the positive responses to symptoms reported by the nearby residents of the four locations. The number of those who experienced these symptoms varies from household to household and may be affected by the respondent's household distance to the rice mill clusters. Hence, necessitating Pearson's correlation analysis.

Correlation Between Household Distance of Respondents and Encountered Symptoms

To determine whether the participants living distance to the rice mill cluster had significant effect on each encountered symptom, and to accept or reject the study hypothesis, the Pearson's correlation analysis was employed. The study hypothesis predicted an inversely proportional relationship (negative correlation) between distance and health symptoms. **Figure 4** shows the effect of distance (independent variable) on symptoms (dependent variable). As predicted by the study hypothesis, households distance had a strong (negative) correlation with the symptoms.

In **Table 3** and for Lafia rice mill cluster, participants household distance had strong correlation with symptoms such as eye irritation (-0.71), chest pain (-0.67), skin irritation (-0.67), itchy throat (-0.66), cough (-0.65), nausea (-0.60). For Otukpo rice mill cluster, strong correlation was found with symptoms such as chest pain (-0.76), eye irritation (-0.75), nausea (-0.74), headache (-0.72), shortness of breath (-0.71), itchy throat (-0.69). In Makurdi rice mill cluster, strong correlation was found with nausea (-0.92), itchy throat (-0.89), headache (-0.83), shortness of breath (-0.83), sneezing (-0.71) and skin irritation (-0.65). In Aliade rice mill cluster, strong correlation was found with dizziness (-0.84), chest pain (-0.79), nausea (-0.76), headache (-0.66), shortness of breath (-0.63) and eye irritation (-0.61).

Figure 5 compares the percentage of positive response to symptoms from rice mill workers and residents of the rice mill clusters. Rice mill workers reported to have more health concerns compared to rice mill residents. This is because, the rice mill workers are at zero distance (R 0) to the rice mill clusters and their economic activities is within the rice mill clusters.

Real-time Airborne Particulate Matter Measurement

From the results of the $PM_{2.5}$ sampling at Otukpo and Aliade rice mills, Otukpo rice mill recorded higher $PM_{2.5}$ emission than Aliade. This is because of the higher quantity of rice husk generated and combusted. The maximum 1-hour mean $PM_{2.5}$ concentration was 93.2 mg/m^3 at Otukpo and 65.4 mg/m^3 at Aliade (**Figure 6**).

Discussion

Significance of Household Distance to Health Symptoms

The rice milling technology found in the locations generated smaller rice husk particles that was breathable. Thus, posing health risk. The poor handling of rice husk was confirmed by the encountered symptoms among rice mill workers and nearby residents. Participants whose activities were within the rice mill clusters (rice mill workers) experienced symptoms more frequently. Since they spent an average of 9 h at the rice mill clusters and are exposed to higher concentration of the pollutants. Eye/skin or throat irritation and respiratory problems was predominant among rice mill workers from all four locations. Besides their work schedule, another factor was the use of similar old and inef-

Table 2 Number of positive responses reported health symptoms from rice mill workers and residents and their corresponding household distances

Location	Distance (km)	Eye irritation	Chest pain	Itchy throat	Headache	Skin irritation	Shortness of breath	Dizziness	Nausea
Lafia	0.0 (workers)	17	14	14	11	17	9	5	9
	0.2	6	3	5	4	5	4	3	4
	0.4	5	5	3	4	2	5	5	5
	0.6	5	3	6	8	6	3	3	5
	0.8	8	4	4	0	4	6	4	0
	1.0	2	3	4	5	3	5	4	5
Otukpo	0.0 (workers)	18	17	15	11	18	15	11	13
	0.2	6	4	3	4	4	4	4	3
	0.4	8	4	6	4	3	2	2	2
	0.6	6	3	4	5	2	5	4	4
	0.8	5	2	5	5	5	3	4	3
	1.0	5	2	2	2	3	2	3	0
Makurdi	0.0 (workers)	13	9	10	16	13	7	8	7
	0.2	4	4	5	5	5	5	4	5
	0.4	3	5	5	6	5	5	5	5
	0.6	3	4	5	4	2	6	5	5
	0.8	6	5	3	2	4	4	3	2
	1.0	2	4	2	2	5	3	5	2
Aliade	0.0 (workers)	17	18	15	13	14	12	6	8
	0.2	6	5	2	4	5	5	4	3
	0.4	5	8	2	6	2	5	5	5
	0.6	6	6	5	6	6	3	3	5
	0.8	8	2	3	0	3	5	2	2
	1.0	5	3	3	5	5	5	3	2

Table 3 Comparative evaluation of Pearson's correlation analysis of the recorded symptoms vs household distances across the four study locations

Location	Eye irritation	Chest pain	Itchy throat	Headache	Skin irritation	Shortness of breath	Dizziness	Nausea	Sneezing	Cough	Catarrh
Lafia	-0.71	-0.67	-0.66	-0.54	-0.67	-0.41	-0.23	-0.60	-0.42	-0.65	-0.39
Otukpo	-0.75	-0.76	-0.69	-0.72	-0.65	-0.71	-0.63	-0.74	-0.59	-0.80	-0.52
Makurdi	-0.64	-0.63	-0.89	-0.83	-0.65	-0.83	-0.57	-0.92	-0.71	-0.55	-0.57
Aliade	-0.61	-0.79	-0.57	-0.66	-0.59	-0.63	-0.84	-0.76	-0.52	-0.49	-0.55

ficient milling technologies that was found in all the locations. Thus, exposing them to higher concentration of small rice husk particles generated during milling at concentrations, which exceeds the WHO limit of 25 $\mu g/m^3$ for $PM_{2.5}$.

Encountered symptoms level for nearby residents was less compared to those experienced by rice mill workers. As predicted by the study hypothesis, distance of residents' households to the rice mill clusters had significant impact on the reported symptoms. Distance was inversely proportional to symptoms (-ve correlation). A decrease in household distance causes an increase on the reported symptoms due to high exposure risk.

Lafia had the lowest (-ve) correlation between households' distance and symptoms, with an average value of -0.54. This is because of the cultural and geographical characteristics of the location and the inhabitants. A cultural food made from rice (tuwo chinkafa) is highly consumed. The food is made by manually beaten paddy to remove the husk. This further exposed individuals to breathable rice husk particles. The vegetation type is the guinea savannah, influenced by the north-east trade wind. Ugwanyi et al. (2016) reported high levels of PM10 in Lafia rice mill, which exceeds set standard of the national air quality guidelines.

Otukpo had the second highest (-ve) correlation between households' distance and symptoms, with an average value of -0.68. This is partly because of the vegetation and housing pattern, which makes it more difficult for particulate matter to be evenly dispersed over distances. In addition, uneven exposure levels of open combustion of rice husk was highly practiced.

Makurdi had the highest (-ve) correlation between household distance and symptoms, with an average value of -0.71. Makurdi rice mill cluster is located closer to the River Benue. The river acts as barriers to the transport and even distribution of air pollutants over long distances because some particles will acquire moisture and dissolved before reaching further distances. Therefore, causing significant uneven distribution and exposure levels.

Aliade had the third highest (-ve) correlation between households' distance and symptoms, with an average value of -0.64. Aliade vegetation is like that of Otukpo however, with a dispersed settlement pattern. Thus, favouring uneven exposure levels. Residents closer to the rice mill cluster encounter more symptoms.

Generally, and starting from the highest, symptoms that had the highest correlation with households' distances across the four locations are nausea (-0.76), chest pain (-0.71), itchy throat (-0.70), headache (-0.69), eye irritation (-0.68), shortness of breath (-0.65), skin irritation (-0.64) and cough (-0.62). The bottom three are dizziness (-0.56), sneezing (-0.56) and catarrh (-0.51).

Fig. 4 Household distance vs symptoms Pearson's correlation (r) analysis

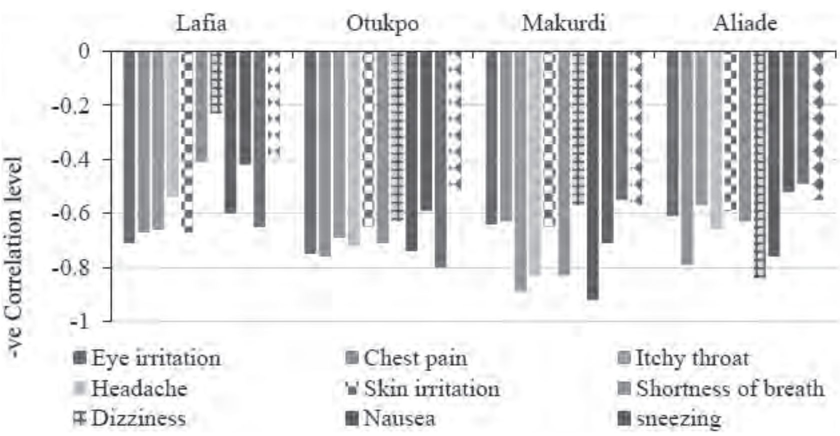
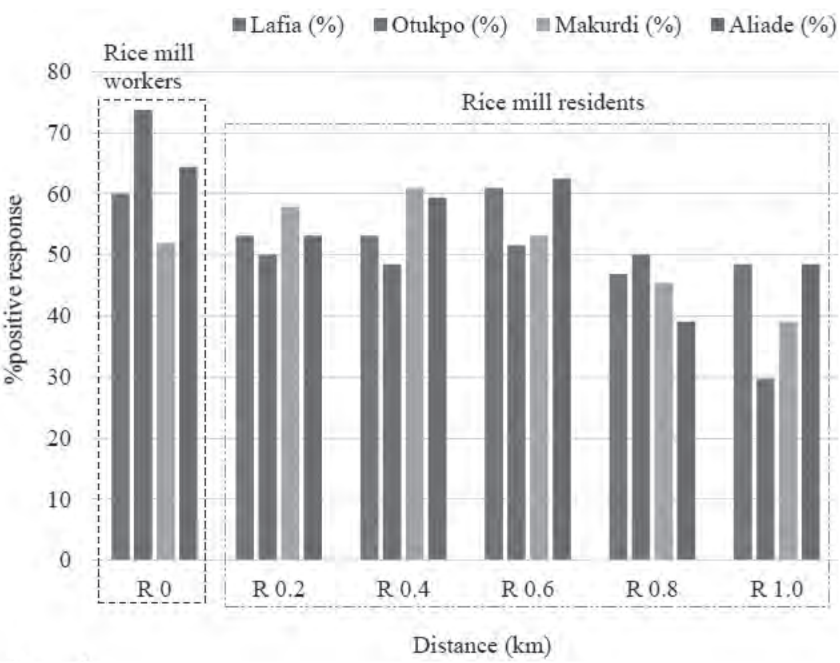


Fig. 5 Rice mill workers vs rice mill resident response analysis



Real-time Airborne Particulate Matter Measurement

$PM_{2.5}$ sampling was limited to Otukpo and Aliade rice mill clusters. This is because, open combustion of rice husk was highly practiced. $PM_{2.5}$ emission at Otukpo and Aliade exceeds the WHO limit of 25 μg/m^3. The high concentration can be attributed to the moisture content of the rice husk, quantity combusted, and meteorological conditions. The rice husk heaps burn for several days. Wind speed determines the transit period of emissions from a source location to the receptor, and the number of pollutants diluted in the windward direction (Hosler, 2005). Otukpo has an average wind speed of 2.40 m/s compared to Aliade which has an average wind speed of 3.02 m/s. This implies that emitted particles in Otukpo were poorly dispersed compared to Aliade. This could be partly responsible for the higher emissions and symptoms at Otukpo rice mill cluster. Zhang (Wang et al., 2014), reported high PM2.5 values in the winter season in China, and was attributed to unfavorable meteorological conditions rather than increase emission from the emission source. Owoade et al., 2012 and Kothai et al., 2008 reported that mass concentration of pollutants increased in the 'dry season' compared to the 'rainy season'.

Conclusions

This study evaluated the effect of households' distance to exposure risk in rural rice milling communities within 1 km of each rice mill cluster. Rice mill workers reported higher health impacts because of their longer work duration and their socio-economic activities was within the rice mill clusters. The study hypothesis predicted an inversely proportional relationship between household distance and health symptoms. Household distance of the respondents to the rice mill clusters, had a significant effect on exposure risk. Irritation sensation and respiratory symptoms were commonly felt. People living closer to the rice mill clusters were more prone to exposures. As a policy intervention, we recommend moving rice mill clusters further away from residential areas, especially when setting up new rice mill clusters. Also, frequent monitoring of PM is recommended. Tougher sanctions must be implemented for noncompliance of air quality regulations. The health symptoms data was limited to information the respondents in collaboration with the local health departments were willing to share. The $PM_{2.5}$ sampling was limited to one-hour sampling due to the power constraint of the studied locations. The sampling was limited to two locations where open combustion was prevalent.

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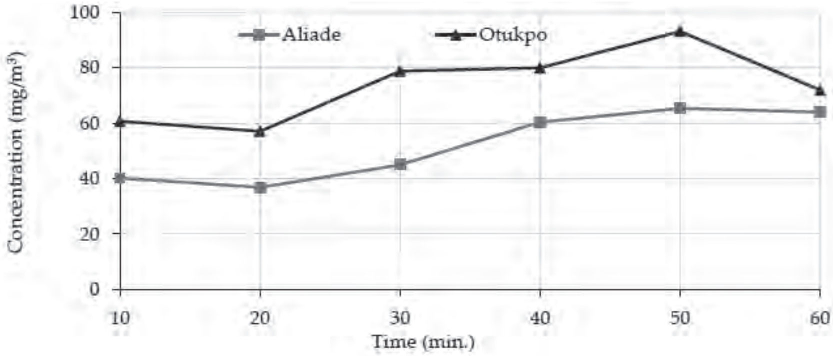
Disclosure Statement

The authors declare that they have no conflict of interest.

Fig. 6 1-hour mean of $PM_{2.5}$ mass concentration in the rice mill clusters sites of Otukpo and Aliade



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The Recent Developments in Sugarcane Mechanization in India

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Abstract

Sugarcane is an important agro-industrial crop of India, which plays a crucial role in social and economical upliftment of rural population of the country. It is the main source of sugar, jaggery, khandsari and ethanol production in the country. It is cultivated in about 5.04 million hectare area with an average productivity of 81.5 tonnes/ha. Uttar Pradesh state is the largest producer of sugarcane as it contributes 46.21% of the total area and 43.65% of the total production of sugarcane in the country. Besides other essential inputs like variety, fertilizer etc., farm power availability has also contributed notably in increasing area and productivity of sugarcane. Most of the sugarcane cultivation operations are being performed by the conventional tools and equipment. Lot of R&D efforts on sugarcane mechanization has been carried out at many institutes/organizations but ICAR-IISR, Lucknow has taken a lead in the country for development and commercialization of machines for mechanizing various operations of sugarcane cultivation. Many farmers are using these machines and benefitted through mechanization. This paper highlights the recent advancements/efforts done by the various institutes/organizations in sugarcane mechanization technologies in India.

Keywords: Mechanization, sugarcane, cultivation, India

Table 1 Area and production of sugarcane in India

Year	Area, million ha	Production, million tonnes	Yield, tonnes/ha
2010-11	4.88	342.38	70.1
2011-12	5.10	353.76	69.3
2012-13	5.27	354.4	67.1
2013-14	5.34	345.6	64.7
2014-15	5.30	366.8	69.1
2015-16	5.28	336.9	63.7
2016-17	4.94	303.6	61.3
2017-18	5.04	411.0	81.5

Source: Anon. (2019)

Table 2 Major Sugarcane producing states in India

Yield (tonnes/ha)	Area, million ha	% to All India	Production (million tonnes)	% to All India	Yield (tonnes/ha)
Uttar Pradesh	2.33	46.21	179.40	43.65	77.0
Maharashtra	0.915	18.15	99.10	24.11	108.0
Karnataka	0.415	8.23	39.20	9.54	94.5
Bihar	0.300	5.95	18.50	4.50	62.0
Tamil Nadu	0.201	3.98	12.10	2.94	60.0
Gujarat	0.182	3.60	13.10	3.18	72.0
Andhra Pradesh & Telangana	0.177	3.51	11.50	2.80	65.0
Madhya Pradesh & Chhattisgarh	0.140	2.78	10.00	2.43	71.0
Haryana	0.122	2.41	10.10	2.45	83.0
Uttarakhand	0.120	2.38	7.80	1.90	65.0
Punjab	0.105	2.08	8.80	2.14	84.0
Odisha	0.035	0.69	1.40	0.34	40.0
All India	5.042	100.0	411.00	100.00	81.5

Source: Anon. (2019)

Introduction

Sugarcane plays an important role in social and economic upliftment of rural masses because it an important cash and industrial crop of India. It is the main source of sugar, jaggery, khandsari and ethanol production in the country (Murali and Hari 2011). It is grown in 5.04 million hectare area with production of 411 million tonnes of sugarcane and productivity of 81.5 tonnes/ha (**Table 1**). Uttar Pradesh state is the largest producer of sugarcane in the country as it contributes 46.21% of the total area and 43.65% of the total production in the country but have the average yield (77.0 tonnes/ha) slightly less than the national average (**Table 2**). The cultivation of sugarcane is very labour and energy intensive and about more than 375 man-days (**Table 3**) are required for performing all cultural operations of sugarcane per hectare (Singh et al., 2016). Harvesting, interculture and planting are the most labour intensive operations. Non-availability of manpower during peak crop season is becoming a major problem in mechanization of sugarcane. In sugarcane cultivation still some operations viz. furrow opening, sett cutting, fertilizer and insecticide application, weeding/ interculturing, harvesting, de-trashing, de-topping and ratoon initiation operations are being performed with conventional tools and implements that resulted in low output with high involvement of cost, labour and human drudgery. To mechanize these operations, lot of R&D work on sugarcane mechanization has been carried out in India by various organizations/ institutes. ICAR-Indian Institute of Sugarcane Research, Lucknow has taken a lead in development of sugarcane mechanization technologies in the country.

Small improved machinery is the need of hour that suits to local conditions as majority of the operational holdings (86%) falls under marginal and small category and scattered however big machines find scope on custom hiring basis (**Table 4**). The need of collaboration between research institutions and farm machinery manufacturers will definitely be beneficial for the promotion of appropriates machine at farmers' level. Machines for seed bed preparation to harvesting then ratoon management operations have been developed that have been the most labour, cost and energy saving as compared to the conventional practices followed by the growers. Thus, there is need of concentrated efforts to popularize these machines so that adoption among farmers could be increased. This paper highlights the latest R&D efforts done by the various Institutes/organizations for advancements of sugarcane mechanization in India.

Table 3 Average man power required per ha for sugarcane cultivation

Operation	Yield (tonnes/ha)
Seed bed preparation	30
Planting	35
Weeding and other inter-cultural operations	100
Irrigation	20
Fertilization	10
Harvesting including de-trashing	150
Transportation and loading	30

Table 4 Number and size of operational holding by size group

Category of holdings	No. of holdings ('000 no.)		Area ('000 ha)		Average size of holdings (ha)	
	2010-11	2015-16	2010-11	2015-16	2010-11	2015-16
Marginal (<1 ha)	92,826 (67.0)	100,251 (68.45)	35,908 (22.5)	37,923 (24.0)	0.39	0.38
MSmall (1.0-2.0 ha)	24,779 (17.9)	25,809 (17.6)	35,244 (22.08)	36,151 (22.9)	1.42	1.40
Semi-medium (2.0-4.0 ha)	13,896 (10.0)	13,993 (9.55)	37,705 (23.6)	37,619 (23.8)	2.71	2.69
Medium (4.0-10.0 ha)	5,875 (4.2)	5,561 (3.79)	33,828 (21.2)	31,810 (20.15)	5.76	5.72
Large (10.0 ha & above)	973 (0.7)	838 (0.57)	16,907 (10.6)	14,314 (9.06)	17.38	17.07
All Holdings	138,348 (100.0)	146,454 (100.0)	159,592 (100.0)	157,817 (100.0)	1.15	1.08

Source: Agriculture Census 2015-16 (Phase I), Agriculture census Division, Department of Agriculture, Co-operation & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Government of India, 2019.

Development in Sugarcane Mechanization Cultivation

Sugarcane cultivation requires various operations like seedbed preparation, planting, interculture, earthing up, plant protection, harvesting, transportation and ratoon management. Mechanized operations lead to reduction in time, cost, labour and drudgery as compared to conventional practices. Some operations of sugarcane cultivations viz. planting, interculturing earthing up and ratoon management operations are in semi mechanized stage.

Seedbed Preparation

Now days, due to non availability of draught animal power, the tractors are playing key role for farming operations not only in sugarcane but in other crops also. The most commonly equipment used by the farmers are disc plough, mould board plough, cultivator, duck foot cultivator, disc harrows, leveller, rotovator, ridger, bund and channel former etc.

Sugarcane is a vegetative propagated crop. The plants roots penetrates very deep in search of water and nutrients that may be over 6 m in sugarcane. The compacted soil can reduce crop yield by as much as 50% due to reduced aeration, limited root growth, poor water infiltration and water stagnation. The hard pan, if exist should be disrupted as soon as possible. The top 15-20 cm soil layer can be ploughed with normal soil cultivation operations using M.B. plough and disc plough but deeper pans must be broken with special type of equipment such as chiseler and sub-soiler. The seed bed preparation with culti-harrow developed by IISR, Lucknow have been found quiet effective as this implement can perform three operations viz. cultivating, harrowing and planking in a single pass thus thereby saves lots of time and fuel, minimize compaction as compared to conventional tillage (Singh et al., 2013). The use of commercially available reversible plough and power harrow is increasing in agriculture for seedbed preparation (**Fig. 1**).

Planting

Sugarcane planting involves seed setts cutting, furrow opening, placement of seed setts, fertilizer and chemicals and soil covering over setts which consumes about 35 man-days per hectare. Most of these operations are being done manually with conventional tools and equipment which are very time, labour consuming and involve lot of drudgery which ultimately increases the cost of operation and reduces the net profit to the growers (Singh et al., 2017). Different methods of sugarcane planting are being followed in India viz. flat planting, trench planting, deep furrow planting, ring pit planting, furrow irrigated raised bed (FIRB) planting, staggered row planting and spaced transplanting. Most of the area in Northern India is flat planted. In the areas where sugarcane lodging takes place, trench planting or deep furrow planting is followed. Different rows spacing are maintained at different places ranging from 60-70 to 90-150 cm. IISR, Lucknow has developed various models of sugarcane cutter planters viz. ridger type, trench planter, paired row planter, deep furrow planter etc. as per the agronomic practices followed time to time. Different variants are either tractor PTO or ground wheel driven. Sett cutting is continuous and uninterrupted in PTO driven planters but proper sett metering can't be achieved. This is because there is no fixed ratio of tractor rear wheel and PTO rpm. The ratio is different in various tractors and even differs in same tractor in different gears (Singh et al., 2012).

Sugarcane cutter planter completes all unit operations of sugarcane planting viz. opening of furrows, seed setts cutting, placement of setts in the furrows, application of fertilizer and insecticides, soil covering over setts and soil covering over setts in single pass of tractor. IISR deep furrow sugarcane cutter planter developed by Singh and Singh (2017) facilitate the planting of cane in deep furrows that is considered as one of the most efficient method of sugarcane planting (**Fig. 2**) This method offers several benefits such as avoids lodging of cane due to deep planting of cane in furrows, 10-15% saving in irrigation water as irrigation has to be carried out in furrows only and better germination of ratoon.

Study conducted by Singh et al., 2017 also found IISR deep furrow opener most efficient in terms of lowest specific draft, improved soil disturbance and enhancement in germination of sugarcane than IISR furrower and conventional ridger. Now a day's trench method of sugarcane planting is gaining popularity among farmers. Hence, IISR trench planter was developed for mechanizing trench planting of sugarcane (**Fig. 2**). It is used for planting of single pair of cane in 25-30 cm deep trench at 30 cm apart at the bottom in paired row geometry. Fertilizer, insecticide application and laying of sub-surface lateral for drip irrigation system are also carried out in a single pass. It can cover one hectare in 5-7 hours depending upon plot size. The cost of operation is one third of the conventional planting.

Ring pit method is another method of cane cultivation. Though, cane yield is very high in this method of cultivation but production cost is also very high mainly because of digging of pits and placement of

Fig. 1 Commercially available 3-bottom reversible M.B. plough and power harrow

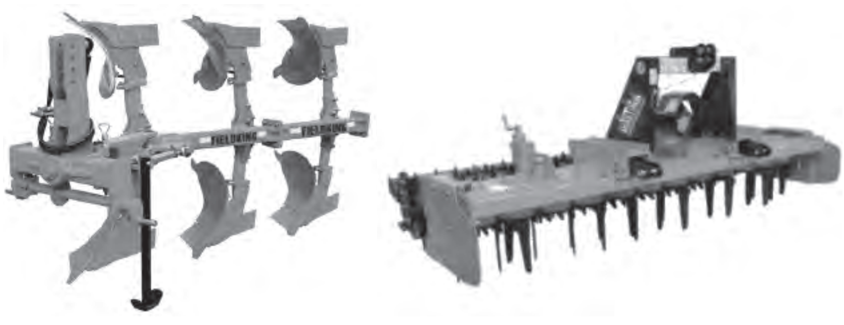

Fig. 2 IISR Deep Furrow Sugarcane Cutter Planter and Trench Planter in operation

setts etc. A tractor operated double bottom pit digger was developed at IISR, Lucknow for mechanizing ring pit planting of sugarcane (Singh et al., 2017). This machine can dig 150 pits in an hour and saves lots of labour and cost over conventional digging of pits.

For sugarcane production spaced transplanting technique is being followed in some parts of Maharashtra on large scale. Recently trend of single bud sugarcane transplanting for the production of cane requires attention for development of a sugarcane transplanter. A tractor-mounted two row mechanical planter was developed and commercialized for sugarcane seedlings raised from sugarcane bud chip and single-bud setts (Naik et al., 2013). The optimum speed of operation was standardized as 1.4 km/h by experimentation where the missing percentage was 2.33%. The field capacity of the equipment was 0.15 ha/h. There was saving of 40 and 85% in cost and labour, respectively with mechanical planter showed over manual bud chip settling planting (**Fig. 3**).

Fig. 3 Field operation of two row tractor drawn mechanical planter for sugarcane bud chip settlings raised in protray (Naik et al., 2013)

Machine for Companion Cropping with Sugarcane

In sub-tropical India, there are two seasons of cane planting, October-November (Autumn) and February-March (Spring). The autumn planted cane provides higher yield and sugar recovery as compared to spring planted. However, area coverage during autumn remained very less because cane growers like to take Rabi crop also. Sugarcane is widely spaced crop (75-90 cm in sub-tropical belt and upto 150 cm in tropical belt). Crop grows slow initially and is of long duration and one time income generating crop. All these factors make the crop highly suitable for intercropping. IISR Lucknow has developed many machines for sowing intercrops along with sugarcane (**Fig. 4**).

Furrow irrigated raised bed (FIRB) is improved and economical method of cultivation accepted by the farmers. In north-west India, mostly farmers grow cane after wheat. Thus, planting is delayed by 2-3 months and that results in decline of yield of cane by 35-50%. This system was employed for intercropping of wheat with sugarcane at IISR, Lucknow and a tractor operated raised bed seeder was developed to make three furrows and three raised beds (2 full beds + 2 half beds) and drill three rows of wheat & pulse seeds at each bed, at a spacing of 17 cm. A another machine known as IISR RBS (raised bed seeder) cane planter was developed to performs planting of

Fig. 4 Machine for sowing intercrop with sugarcane

IISR Raised bed seeder

IISR Raised bed seeder (RBS) cane planter

IISR Deep furrow sugarcane cutter planter cum multicrop raised bed seeder

IISR Sugarcane-cum-potato planter

IISR Sugarcane trench planter cum seeder

IISR Manual multicrop planter for sowing intercrop in sugarcane two rows of sugarcane in furrows and sowing of two rows of seeds of companion crop like wheat, pulses etc on the raised beds and fertilizer dispensing operations simultaneously in a single pass of the tractor (Singh, 2008).

A prototype of IISR tractor operated deep furrow sugarcane planter-cum-multicrop raised bed seeder was designed, developed and field tested. This machine performs planting of two rows of cane in deep furrow and sowing of two rows of companion crop on raised beds between two furrows, simultaneously in a single pass of machine (Annual Report, 2016-17). The intercrops like wheat, black gram, green gram, mustards etc. could be planted with this machine.

Intercropping of potato with sugarcane can be used as a means to increase land and water utilisation efficiency vis-à-vis income of the farmer. Farmers of some states like Uttar Pradesh and Bihar are using this combination but doing all operations manually resulting in lot of labour, cost and energy. In order to mechanise simultaneous planting of sugarcane and potato for intercropping, IISR, Lucknow developed sugarcane-cum-potato planter (Gupta et al., 2017). This machine planted two rows of sugarcane in furrows and two rows of potato on ridges simultaneously in single pass. Potato seed metering was automatic, whereas sugarcane seed stalk feeding for sett cutting was manual. As area under trench planting is increasing in many state like Uttar Pradesh, the inter crops along with sugarcane is the requirements for increasing the farmers' income. Therefore, a new prototype named trench planter-cum-seeder has been developed for planting of two rows of cane in a trench in paired row geometry and sowing of two rows of intercrops one each on left and right of the trench on the raised bed. A new prototype of manual multicrop planter was developed for sowing intercrop in sugarcane. The planter has PVC vertical rotor with grooves on periphery for seed metering.

Weeding and Interculture

Number of interculture operations is required in sugarcane crop to control weeds, moisture conservation, microbial action and creation of better environment for overall growth of the plant (Singh et al., 2016). Two models of IISR tractor operated sugarcane manager were developed for interculturing and fertilizer application in standing crop near root zone of sugarcane covering three rows of cane at a time.

IISR tractor operated multipurpose interculturing equipment (**Fig. 5**) was developed for inter row interculturing, intra-row herbicide spraying and fertilizer application attachment. This equipment has more than 80% weeding efficiency and field capacity of 0.54 ha/h at 2.8 km/h speed of operation. Recently tractor operated three row rotary weeder has been introduced to Indian market for wide spaced crops. The efficient and high capacity equipment like self propelled power weeders, power tillers, mini tractors of various makes and designs are available in the market for weeding and interculturing operation.

Harvesting and Detrashing

In India, generally green cane harvesting is practiced and mostly done manually using different types of knives/tools giving an average output of 0.8 to 1.0 quintal per man-days involving the highest labour requirements i.e. 150 man-days per ha. Sugarcane harvesting includes base cutting of cane stalks, detrashing, detopping, bundle making of 10-15 stalks, finally loading of clean cane to transport vehicles to the sugar mills. Under the present scenario due to non availability of labour, the harvesting gets delayed affecting the production of sugar. The mechanization efforts in the country have been basically limited to the development of whole stalk harvesters for the partial mechanization of harvesting of sugarcane. Efforts at IISR, Lucknow was done for development of whole cane harvester. A new prototype of tractor front mounted sugarcane harvester was developed for cutting and windrowing of two rows of cane such that windrowing of one row was in transverse direction while other row windrowed linearly to the direction of travel (Singh et al., 2012). This harvester resulted in clean cutting of cane without any splitting and rupture of stubbles at cutting blades speed of 450-500 rpm. Lodged and intermingled canopy cane creates problem during operation. Other limitations were of operation in one direction only and free space requirement on right hand side; so equipment was not commercialized.

The developed harvesters provided partial solution of sugarcane harvesting and rest of the operations such as detrashing, detopping etc. could be performed manually. That's again a drudgery and time consuming operation. A new prototype of power operated sugarcane detrasher was developed at IISR, Lucknow for removal of green top as well as dry trash from the harvested sugarcane stalks (Singh and Solomon 2015). The trash removal efficiency was 77.5 to 94.5% depending upon the variety and output was 2-4 t/h.

Initially, combine chopper harvesters have been imported at few places in Tamil Nadu and Maharashtra. These harvesters found ac-

Fig. 5 IISR Multipurpose interculturing equipment

ceptability at some places in India especially in Southern part of the country due to wider row spacing of sugarcane cultivation. At least 4 feet rows spacing is required to operate these harvesters. Few firms are now manufacturing combine chopper harvester in India and about 700 harvesters are being used for this operation (**Fig. 6**). The small size of field, cane purchase system, initial cost, field losses etc. are some other factors limiting the introduction of big sugarcane harvesters especially in northern India.

Ratoon Management

Shaving cane stubbles is one of the pre-requisite of sugarcane ratoon crop. Doing this work manually is highly uneconomical and exhaustive. Efforts at IISR, Lucknow were made to mechanize this operation. A ratoon management device (RMD) was designed and developed for stubble shaving, off-barring and deep tilling; placement of manure and bio-fertilizer, application of chemical, vegetative extracts etc. liquid form; interculturing and ridge making (Srivastava, 2010).

For performing ratoon initiation operations like stubble shaving, off-barring and fertilizer application in ratoon field with trash, disc-type ratoon management device (Disc RMD) was designed and developed at IISR Lucknow (Singh et al., 2017). It was equipped with stubble shaving serrated blades mounted on a disc, two tillage discs for off barring (pruning of old roots) on either side of the stubbles and device for application of fertiliser at root zone (**Fig. 7**). The machine was evaluated extensively in ratoon field and recommended for commercial use. The effective field capacity of the equipment was 0.28 ha/h at forward speed of 2.4 km/h.

Promotion of Sugarcane Mechanization

Centre and State Government has taken some steps to promote mechanization in sugarcane cultivation in the country. Subsidy on purchase of sugarcane machinery viz. mould board plough, sub-soiler, sugarcane cutter planter, ratoon management machines have been provided to the farmers. Some state government like Uttar Pradesh has announced the creation of custom hiring service centres in sugarcane growing districts of the state for availability of sugarcane machinery to the farmers.

IISR Lucknow has signed memorandum of agreement (MoA) with few farm machinery manufacturers for multiplication of IISR designed sugarcane machines so that the farmers can get the latest machines from theses manufacturers on subsidy through the respective state government.

Some important aspects to formulate appropriate policy for successful sugarcane mechanization and promotion of sugarcane machinery are discussed below:

- Financial assistance to cane growers should be given through Government and Sugar Industries for purchase of sugarcane machinery. Banks may liberalize their credit policy for farm mechanization in sugarcane for farmers/rural youths.
- There should be frequent training/short term courses on operation, utilization, repair & maintenance of sugarcane machineries for the farmers/cane growers.
- Entrepreneurship development programmes (self help groups) for manufacturing, repair & maintenance, marketing and custom hiring of the machinery should be started in sugarcane growing belts in rural areas.
- There should be a strong network of extension agencies for dissemination of improved sugarcane mechanization technology among the farmers through Front Line Demonstrations, Trainings, Kisan Melas/Divas, TV/Radio talk etc.
- There must be collaborations between R&D institutions, manufactures, extension agencies and stake holders for better implementation of mechanization strategy.
- More support shall be required from the government for coordination between development and implementation of agriculture machinery and technology in future.
- Custom hiring of sugarcane equipment is already in vogue in many parts of the country. Large machines/costly equipment should be promoted through custom hiring service centers.

Conclusion

The newly developed sugarcane machine not only reduces the cost of operation, labour requirement but also help in improving the quality of work by reducing human drudgery to a great extent. The timely completion of the various operations with the help of mechanization technologies definitely improves the yield of the crop and ultimately increases the net profit to the growers.

Fig. 6 Commercially available sugarcane harvester

Fig. 7 IISR disc type ratoon management device (RMD)

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ABSTRACTS

The ABSTRACTS pages is to introduce the abstracts of the article which cannot be published in whole contents owing to the limited publication space and so many contributions to AMA. The readers who wish to know the contents of the article more in detail are kindly requested to contact the authors.

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Optimization on Kinematic Characteristics and Lightweight of a Camellia Fruit Picking Machine Based on the Kriging Surrogate Model: Di Kang, Zejun Chen, Youhua Fan, Cheng Li, Chengji Mi* (michengji1986@hotmail.com), Yinghong Tang

In order to achieve fully automated picking of camellia fruit and overcome the technical difficulties of current picking machinery such as inefficient service and manual auxiliary picking, a novel multi-links-based picking machine was proposed in this paper. The working principle and process of this device was analyzed. The mechanism kinematics equation was given, and the velocity executive body was obtained, as well as the acceleration. The acceleration at pivotal positions was tested in the camellia fruit forest, and the simulated results agreed well with the experimental ones. Then, the maximum acceleration of executive body and weight was considered as the optimization objective, and the rotating speed of crank, the radius and thickness of crank and the length and radius of link rod were regarded as the design variable. Based on the Kriging surrogate model, the relationship between variables and optimization objectives was built, and their interrelations were analyzed. Finally, the optimal solution was acquired by the non-dominated sorting genetic algorithm II, which resulted in the reduction of the maximum acceleration of executive body by 31.30%, as well as decrease of weight by 27.51%.

Design and Development of Tractor Operated Carrot Harvester

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Abstract

A prototype of tractor-drawn carrot harvester was developed to harvest carrot crop grown on raised beds. The carrot harvester performs operations namely, digging, pulling, conveying, foliage removal and collection of carrot. These operations were performed using a foliage guiding unit, puller mechanism, and collection unit (hopper). All these units were mounted on the mainframe. Digging unit loosens the raised bed at depth below carrot roots. Puller mechanism holds carrot form loosen raised bed by its foliage and conveys it to a hopper. The conveying inclination was kept adjustable from 40-50° from the line of motion. The developed prototype of carrot harvester was tested for its field performance with three carrot varities. Harvesting was done at three forward speeds (2, 3, and 4 km h^{-1}) and three moisture levels on dry basis (10 ±1 %, 12 ±1 %, and 15 ±1 %). Maximum lifting efficiency was observed (96.90%) at 2 km h^{-1} forward speed and 40° puller inclination. Minimum carrot damage (1.96%) was found at a forward speed of 2 km h^{-1}. The average draft requirement was 1,070 kg. Optimum forward speed and moisture content for the carrot harvesting was found to be 2 km/h and 12 ±1%, respectively. The average field capacity (ha/h) and field efficiency were 0.30 ha/h and 77.42%, respectively. Cost of operating carrot harvester with the tractor as a prime mover was INR 800. The Break-even point of the carrot harvester was 370 hours $year^{-1}$, and the payback period for the developed prototype was 5.20 years.

Introduction

Carrot (*Daucuscarota* L.) is one of the important vegetables. Carrot is the second most popular root vegetable, after potato in the world. India is one of the largest producers of carrots in the world, with an annual production of 20 Mt from mere 1.14 Mha land. The area and production of carrot is increasing since

2010-11 to 2018-19 (Anonymous, 2018). Carrot cultivation operations, namely planting, intercultural operation, harvesting, post-harvest operations, are very labor-intensive. Farmers rely on traditional tools and methods for carrot production, harvesting, handling/storage, transport, and post-harvest process, result in low yields, higher losses (30-40%), and high cost of cultivation. The mechanization is one of the significant constraints in expending the area under vegetable cultivation, especially in carrot.

Carrot harvesting is usually done manually with a low outcome of 700 kg/man-day. On an average, about 350-450 man-hours are needed for digging and pulling out carrots in one hectare (Shirwal and Mani, 2015; Naresh et al., 2018). Manual harvesting is not only energy-intensive work but also very time-consuming. The increased cost of labour and scarcity has made the manual harvesting uneconomical. Mechanization help to solve the labour shortage (Satish and Umesh, 2018). Mechanization in the harvesting of carrot (vegetable) crops in India is less than one percent (FICCI, 2015-16). India has made leap head progress in mechanizing cereal production; however, mechanization in the vegetable crops, especially carrot, remains un-attempted. Mechanization levels for harvesting and threshing in rice, wheat, maize, sorghum, pulses, oilseeds, cotton, and sugarcane crops were 60, 70, 30, 10, 25, 25, 0 and 10%, respectively (Mehta et al., 2019).

The mechanized process of carrot harvesting involves digging of carrots by digger at appropriate soil moisture content, picking of dugout carrots with green foliage, separating the green foliage, cleaning, and bagging them for transportation/storage/marketing. Mechanical harvesting of carrots in India is mainly accomplished by the digger or digger cum windrower. However, this also requires a large number of manual labor for collection and foliage removal.

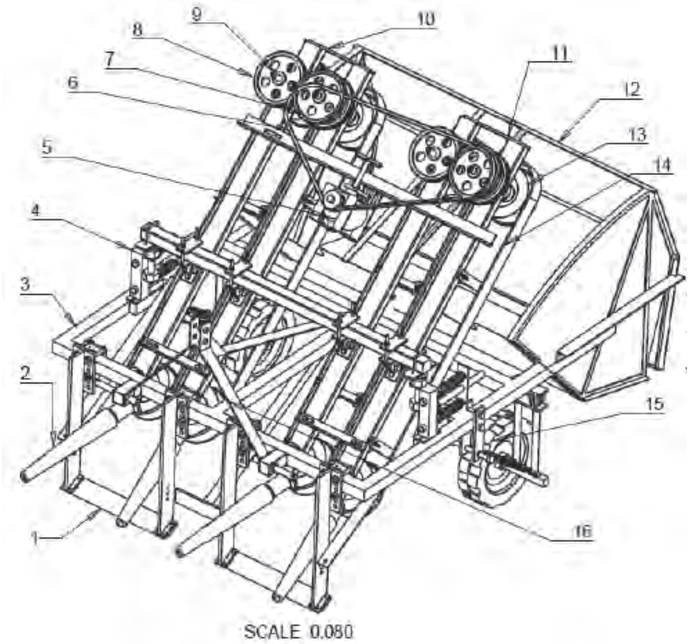
Worldwide available carrot harvester is of large capacity and difficult to operate on fragmented Indian farms. A commercially available model "Devulf," a leading carrot harvester manufacturer, make harvester of 18 m length and 8 m width operated by 90 kW tractor, which are not suitable for small landholdings. In India, very few attempts were made to develop carrot harvester. It was reported that a tractor-mounted digging and elevating machine for carrot crop had a field capacity of 0.28 ha/h at a forward speed of 2.78 km h^{-1}. The damage was less than 1.0%. Saving in labour for harvesting carrot was 59%, compared to manual harvesting (Anonymous, 2015). Naresh et al. (2018) developed a carrot digger comprised of digging unit, conveying unit, detopping unit, and collecting unit for a single row with effective field capacity of 0.11 ha/h and 61.7% field efficiency. In another study, Shirwal et al. (2015) developed a carrot digger with 0.21 ha h^{-1} field capacity. The performance parameters, carrot harvesting, and damage percentage observed were 97.8 and 4.6, respectively. The cost of carrot harvesting was 49% lesser than the traditional method. The breakeven point for the single unit carrot harvester was 148 h/year, which was 52% of annual utility and with a payback period of three years.

Harvesting of carrot mechanically ensures timeliness, labor-saving, and cost minimization during harvesting. The losses in carrot harvesting can be further reduced by integrating digging, conveying, and collection with foliage removal in a single operation. In the present paper, an effort has been made to develop a carrot harvester to improve the harvesting operation.

Material and Methods

The prototype of carrot harvester consists of two sets of digging units, puller mechanisms, and one unit

Fig. 1 Isometric view of carrot harvester



1. Digger blade, 2. Passive guider, 3. Main frame, 4. Foliage Height adjustment unit, 5. Hydraulic motor, 6. 'A' type belt, 7. 'V' pulley, 8. Spur gear, 9. Shaft, 10. Puller mechanism - I, 11. Puller mechanism - II, 12. Hopper, 13. Conveyor pulley, 14. Rough top conveyor belt, 15. Support wheel, 16. 3 point linkage

hydraulic power pack along with accessories and a hopper. The main functions of carrot harvester were digging, pulling, conveying, and collecting the carrots in the hopper. The digging unit and puller mechanism were the main component of carrot harvester to uproot the carrot from the soil bed and convey it to the hopper at the rear end for collection (**Fig. 1**). The puller mechanism of carrot harvester performs the following two functions: (a) pulling the carrots by holding the foliage and (b) conveying it at an inclination. The carrot harvester was designed such that it could perform efficiently in terms of carrot harvesting percentage and collection of carrots with minimum damage. Design values for components are given in **Table 1**.

Development of the Carrot Harvester

The design and development of carrot harvester were based on the physical and engineering properties of the carrot and its foliage (Nath et al., 2019). Physical properties of carrot were effective foliage length, combined foliage diameter, carrot length and its diameter. The engineering properties were pulling force and foliage tensile strength. The effective foliage length was observed in the range of 16 to 35 cm, with good agronomical practices (Horia et al., 2008). The foliage length facilitated the holding from 10-15 cm from the carrot crown. Digger was operated at a depth of 25 cm for loosening soil. However, raised bed height was 20 cm, so the depth of the digger below the raised bed was kept at 5 cm. It was observed that, in the loosened soil, resistance to lifting carrot was 5 to 6 times lesser than undisturbed (unloosen) raised bed. Foliage detachment force was ten times higher compared to the required pulling force in loose raised bed. It ensured that the chances of breaking the foliage from the carrot crown were meager while pulling the carrot from the loose bed. The designed machine is shown in **Fig. 1**. The design of components of the harvester is explained below.

Mainframe

The mainframe with overall dimensions of 1604 × 1604 × 1045 mm was made with a mild steel square pipe of 50 × 50 mm with a 2 mm thickness. The entire functional units of carrot harvester were mounted on the mainframe (**Fig. 1**).

Digging Unit

Digging unit, dig the carrots on a raised bed with digger blades. Separate digger blades were used for each of the raised beds. The length of the digger was selected based on the bottom width (700 mm) of the trapezoidal cross-section of the raised bed. Carrots were only needed to be disturbed at the maturity stage. Therefore, flat type digger blade was designed for digging. High carbon steel (EN 8) rectangular digger blade of 500 × 80 × 10 mm was used. Blade was tapered at its face and fixed at a rake angle of 25 degrees.

Foliage Guiding Unit

Foliage guiding unit passively gathers the carrot foliage towards the front end of the puller mechanism (**Fig. 1**). The passive guiding unit was made of two conical nylon rods. The front end of the rod was 40 mm in diameter, and the rear end of the rod was 80 mm diameter. The rear end of each of the rod was fixed to the puller mechanism through 78 mm MS bush.

Puller Mechanism

The puller mechanism comprised of two units of identical components of ‘A’type pulley (01), spur gear (02), conveyor pulley (04), idler pulley (04) and rough top conveyor belt (02). These components were fixed on shafts. The puller mechanism can be adjusted on the mainframe to adjust the height of foliage catch and conveying inclination. A hydraulic motor powered by a hydraulic pump driven by tractor PTO was used to power the puller mechanism.

‘A’ type pulleys were used for transmitting mechanical power from the hydraulic motor to the puller mechanism. The driver pulley was on the hydraulic motor, and an ‘A’ type belt was used for power transmission. The diameter of the driven pulley was 200 mm, and the diameter of the driver pulley was 120 mm. Two spur gears (100 teeth) were used to give opposite direction rotation to the pulley for rotation of conveyor belts.

Conveyor pulleys were made of aluminum for assisting rough top conveyor belt. ‘L’ groove was provided at the lower face of conveyor pulley to guide rough top conveyor belt from slipping. Idler pulley was used for providing tension to a rough top conveyor belt while conveying the uprooted carrot to the rear end. The diameter of the idler pulley was 58 mm with 70 mm length.

A rough top flat conveyor belt was selected for pulling the carrots from the loosen bed. The belt was joined at the ends to make it endless. It also acted as a power transmission component from the rear end to the front end of the puller mechanism with the help of aluminum pulleys. Theoretical length of belt was determined as (Khurmi and Gupta, 2005):

$$L = 2C + 1.57\,(D_1 + D_2) + (D_1 - D_2)^2 / 4C$$

$$L = 2 \times 130 + 1.57\,(21 + 21) = 325 \text{ cm} \quad (1)$$

Where L = length of the belt with a rough top surface

D_1 = Diameter of the driver pulley

D_2 = Diameter of the driven pulley

C = Central distance between two pulleys

Therefore the length of conveyor belts was 325 cm. The width and thickness of the belt were 65 mm and 10 mm, respectively.

Foliage cutting discs were fixed at the lower side of conveyor pulley in such a way that both overlap each other while rotating. During trans-

Table 1 Design values and cost of components of carrot harvester

Components	Dimension	Unit Cost (INR)	Units	Total Cost
Complete Carrot Harvester				
Length × Width × Height, mm	2,260 × 1,512 × 1,520			
Mainframe		**10,000**	**1**	**10,000**
Length × Width × Height, mm	1,604 × 1,604 × 1,045			
Material	MS			
Digging Unit		**5,000**	**2**	**10,000**
Digging Blade				
Length × Width × Thickness, mm	500 × 80 × 12			
Distance below from mainframe, mm	600			
Rake angle, degree	25			
Pulling Unit		**12,500**	**2**	**25,000**
Foliage Guiding Unit				
Type	Passive			
Shape	Conical			
Length, mm	415			
Front end diameter, mm	40			
Rear-end diameter, mm	80			
Material	Nylon			
Puller Mechanism				
Length, mm	1,500			
Width, mm	450			
Height, mm	300			
'A' type pulley, number	01			
Spur gear (100 teeth), number	02			
Conveyor pulley (Aluminium)	04			
Diameter of conveyor pulley, mm	210			
Rough top Conveyor belt, Length × Width × Thickness, mm	3,250 × 65 × 10			
Number of idler pulleys	04			
Diameter of idler pulley, mm	60			
Foliage catch adjuster	Adjustable			
Inclination of Conveyor	Adjustable from 40 to 50 °			
Power Transmission System		**45,000**	**1**	**45,000**
Hydraulic motor (OMP 50)				
Maximum torque, Nm	52			
Maximum output, kW	7.0			
Max pressure drop, bar	140			
Maximum oil flow, lpm	60			
Maximum starting pressure with unloaded shaft, bar	10			
Minimum starting torque, Nm	80			
Hydraulic Pump (3044)				
Nominal displacement, cc/rev	13.33			
Nominal Delivery @ 1500 rpm & Pressure, lpm	20			
Max pressure drop, bar	207			
Maximum Speed at maximum continuous Pressure, lpm	3,500			
Minimum Speed at maximum continuous Pressure, lpm	50			
Hydraulic tank capacity, lit.	40			
Hopper		**5,000**	**1**	**5,000**
Shape	Trapezoidal			
Length × Top width, Bottom width × Height, mm	1,400 × 800, 350 × 700			
Support Wheels		**2,500**	**2**	**5,000**
Diameter, mm	500			
Number of Lugs	14			

Total cost: Component cost + manufacturing cost (INR 100,000 + 100,000 = 200,000) portation of carrots from the front to the rear end, these round cutting disc cut the foliage and allow them to fall in the hopper. The diameter of the cutting disc was 230 mm. The cutting disks kept overlapping with each other to ensure foliage cutting.

Pulling of Carrot

Carrot foliage directed toward the front end of the puller mechanism by the passive guide and forward motion of carrot harvester. Foliage coming towards the puller mechanism was held by opposite rotating rough top conveyor belts. The average effective foliage stem (bunch) diameter was considered as 'd' (**Fig. 2**), which was entering into the puller mechanism of the carrot harvester inclined at an angle of *δ* in the direction of motion (Klenin et al., 1985). The foliage stalks were subjected to a normal force N_f and a friction force F_f. The dual belts of the puller mechanism would hold the carrot foliage when

$$2\,F_f \sin \omega t \geq 2\,N_f \cos \omega t \qquad (2)$$

Since,

$$F_{fmax} = \mu N_f$$

$$\mu \sin \omega t \geq N_f \cos \omega t$$

From the triangle SOT, the following relation was derived

$$\sin \omega t = OS/r, \text{ and } OS = r + (g/2) - (1/2)\,Q'S' \qquad (3)$$

From the (**Fig. 2**) we have

$$Q'S' = (d/\sin \delta) + (b/\tan \delta) \qquad (4)$$

Substituting the above in the expression for sin ωt we have

$$\sin\omega t = 1 + [g - (d/\sin \delta) - (b/\tan \delta)] / 2r \qquad (5)$$

Replacing sin ωt and cos ωt in equation (2) by the above expression resulted in

$$[2r + g - (d/\sin \delta - b/\tan \delta)] / \sqrt{(4r^2 - [2r + g - (d/\sin \delta) - (b/\tan \delta)^2]} \geq 1/\mu \qquad (6)$$

Where,

r = radius of the pulleys carrying the belts,

g = gap between the belts at the entry,

d = foliage diameter (combined)

b = width of the belt

δ = carrot harvester inclination angle in the direction of motion

N_f = normal force on foliage stalks

μ = Coefficient of static friction, and

F_f = Friction force

For the developed carrot harvester the parameters inequality (5) were, r = 10.5 cm, b = 6.5 cm and g = 1.0 cm. Here, μ was assumed as 0.5, then above inequality was satisfied for the carrot foliage of diameter d not exceeding 0.8 cm at (δ = 70°)

From the above equations, it can be observed that when the diameter (d) increases, the gap between rough top conveyor belt decreases, and with a decrease of the angle of inclination δ, the ability to hold the foliage decreases.

Fig. 2 Puller mechanism of carrot harvester

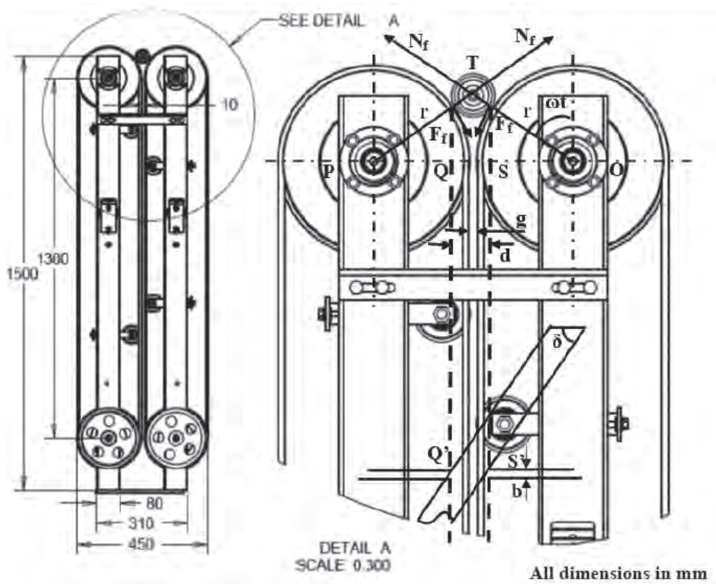
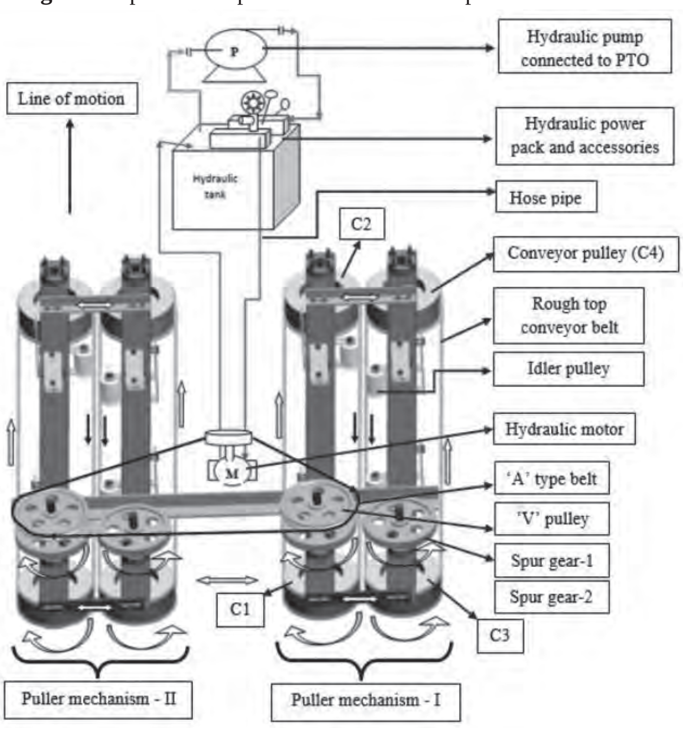


Fig. 3 Components of puller mechanism and power transmission



Power Transmission of Puller Mechanism

The power transmission comprised of a hydraulic power pack, hydraulic pump, and motor for operating the puller mechanism of carrot harvester by providing rotational power to the pulleys at the rear end of both puller mechanisms simultaneously (**Fig. 3**). The tank capacity was 40 litters. Hydraulic pump was driven by the PTO of the tractor, the hydraulic motor was driven by a hydraulic pump. The pump inlet pipe (1.5″ diameter) was connected to the hydraulic tank. The output of the hydraulic pump was connected to the inlet (0.75″ diameter) of hydraulic motor causing rotation of motor shaft and driving pulley. The driving pulley transmits power to the puller mechanism. The power train of the carrot harvester was shown in **Table 2**.

Collection Unit

Hopper was used as a collection unit of carrot harvester. The hopper was a combination of two sections of the trapezoidal and triangle shape. It was made of 18 gauge commonly available GI sheet with a suitable angle to collect carrot after foliage cutting. The design was done as per the maximum coefficient of friction, $\mu = 0.5$.

The carrots were discharged freely, using the relationship between the angle of inclination θ and the coefficient of friction as: $\tan \theta \geq \mu$. It was considered that $\theta \geq \tan^{-1}\mu$ (0.5) or 27°. The discharge angle was chosen as 35°, about 20% above the calculated value. The hopper facilitated the loading of carrots and outlet for unloading using gravity flow. Hopper volume was determined as follows:

Trapezoidal volume = ½(base width + top width) × height × length
= 0.05 (0.65 + 0.85) × 0.8 × 1.45
= 0.87 m^{-3}

Triangular volume = ½(base width × height) × length
= 0.5 (0.65 × 0.3) × 1.45
= 0.14

Volume of hopper = 0.87 + 0.14 = 1.01 m^{-3}

Assuming the bulk density of whole carrot as 640 $kg.m^{-3}$, the hopper had capacity to handle weight of 650 kg in the particular swath of bed.

Support Wheels

The support wheels helped to maintain the inclination of the puller mechanism. It was mounted at the rear end of the mainframe to support the carrot harvester. Two commercially available support wheels of diameter 500 mm were used with fourteen numbers of lugs. Two springs were used to maintain the inclination as per the change in the digging depth.

Evaluation of the Developed Harvester

Experimental Procedure

The experiments were conducted in the experimental farm of the Division of Agricultural Engineering, ICAR-IARI, New Delhi. Three varieties of carrot, namely PusaKeshar, PusaRudhira, and Nantes, were grown each in an area of 40 × 6 m^2 for each variety. For each test, the developed carrot harvester (**Fig. 4**) was operated at three forward speed (2, 3, and 4 km/h), and three moisture contents (10 ±1%, 12 ±1%, and 15 ±1%)

Fig. 4 Carrot harvester

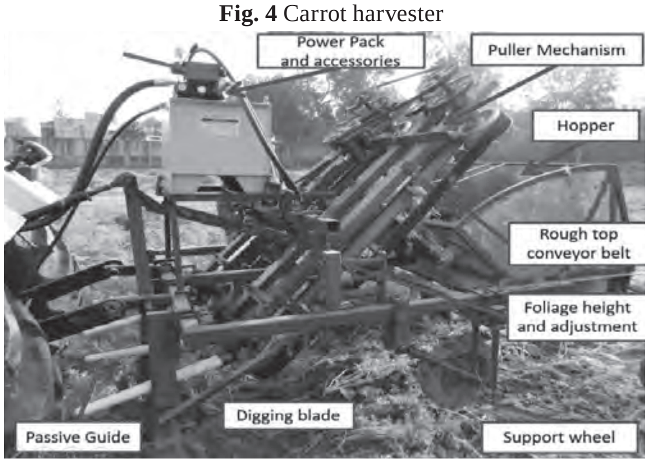


Table 2 Power train of the carrot harvester

From	Through	To
Tractor PTO	'V' pulley and belt	Hydraulic pump
Hydraulic pump	Hydraulic power pack	Hydraulic motor
Hydraulic motor	'A' type belt	'V' pulley of 1st Puller mechanism
'V' pulley of 1st Puller mechanism	'A' type belt	'V' pulley of 2nd Puller mechanism
Power transmission in Puller mechanism (Fig. 3)		
Hydraulic motor	'A' type belt	'V' pulley
'V' pulley	Shaft	Spur gear
Spur gear	Shaft	Conveyor pulley (C1)
Conveyor pulley (C1)	Rough top Conveyor belt	Conveyor pulley (C2)
Spur gear	Shaft	Conveyor pulley (C3)
Conveyor pulley (C3)	Rough top Conveyor belt	Conveyor pulley (C4)

on dry basis (db) in the field. Three replications were taken for each combination of variables. The following field performance parameters were determined for the evaluation of the prototype carrot harvester.

Percentage of Carrot Lifted

It was determined by calculating the ratio of the number of carrot picked up successfully to the total number of carrot on beds and multiplying it by 100.

Lifting percentage, % = (Number of carrot picked-up) / (Total number of carrots on beds) × 100 (7)

Percentage of Carrot Damaged

It was found by calculating the ratio of the number of carrot damaged while uprooting to the total number of carrot on beds and multiplying it by 100.

Damage percentage, % = (Number of damaged carrots) / (Total number of carrots on beds) × 100 (8)

Power Requirement

The power required to pull the carrot harvester was determined at the respective speed of operation by using the following formula:

P (kW) = draft (kN) × Speed (m/s) (9)

The puller mechanism was optimized to determine the optimum puller inclination and puller speed along with forward speed and soil moisture for efficient performance in the field. A factorial randomized complete block design of experiments was used for evaluation with the levels of variables.

Results

A prototype of the machine was fabricated (**Fig. 4**) as per the design values (**Table 1**) of different components using standard machine design procedures, as elaborated earlier. The carrot harvester can perform digging, pulling, conveying, and collection in a single operation. The two sets of puller mechanisms in the carrot harvester perform three functions; pulling the carrots by holding the foliage, conveying it at an inclination, separating foliage from carrot with the help of rotating disc blade and collecting the carrot in an attached hopper.

Developed prototype of carrot harvester was tested for its performance evaluation in the Division of Agricultural Engineering. Lifting efficiency (%), carrot damage (%) and draft (kg) at three forward speed (2, 3 and 4 km/h), and three moisture level (10 ±1%, 12 ±1%, and 15 ±1% db) and had been recorded at harvesting stage of carrot. It was found that at 12 ±1% moisture content, the performance of carrot harvester was the best. Analysis of variance of the effect of variety on lifting efficiency, damage percentage, and the draft of carrot harvester showed that it did not have a significant effect. So, developed carrot harvester could work efficiently for all three varieties (**Tables 3-5**).

Maximum lifting efficiency was observed (96.90%) at 2 km h^{-1} forward speed, whereas minimum lifting efficiency (76.50%) was observed at 50° puller inclination and 4 km h^{-1} forward speed. Minimum carrot damage (1.96%) was found at a forward speed of 2 km h^{-1}, whereas the maximum (8.24%) was at a forward speed of 4 km/h. The average draft requirement was of 1,070

Table 3 Varietal effect of different parameters on lifting efficiency (ANOVA)

Source	DF	Type I SS	Mean Square	F Value	Pr > F
R	2	11.85	5.92	0.23	0.79
MC	2	195.14	97.57	3.88	0.0266
FS	2	1,437.78	718.89	28.60	<.0001
MC*FS	4	176.40	44.10	1.75	0.1515
VR	2	38.84	19.42	0.77	0.4668
MC*VR	4	165.46	41.36	1.65	0.1762
FS*VR	4	127.08	31.77	1.26	0.2954
MC*FS*VR	8	107.28	13.41	0.53	0.8260

Where, R = Replication, MC = Moisture content, FS = Forward Speed, VR = Variety

Table 4 Varietal effect of different parameters on damage percentage (ANOVA)

Source	DF	Type I SS	Mean Square	F Value	Pr > F
R	2	0.15	0.07	0.08	0.92
MC	2	12.83	6.41	7.43	0.0014
FS	2	209.33	104.66	121.31	<.0001
MC*FS	4	2.33	0.58	0.68	0.6118
VR	2	0.95	0.47	0.55	0.5799
MC*VR	4	2.34	0.59	0.68	0.6096
FS*VR	4	5.06	1.26	1.47	0.2254
MC*FS*VR	8	0.56	0.07	0.08	0.9996

Where, R = Replication, MC = Moisture content, FS = Forward Speed, VR = Variety

Table 5 Varietal effect of different parameters on draft (ANOVA)

Source	DF	Type I SS	Mean Square	F Value	Pr > F
R	2	803.43	401.72	3.35	0.043
MC	2	311,833.28	155,916.64	1,196.29	<.0001
FS	2	3,024,160.46	1,512,080.23	1,1601.6	<.0001
MC*FS	2	399.43	199.71	1.53	0.2253
VR	4	107,252.42	26,813.10	205.73	<.0001
MC*VR	4	477.67	119.42	0.92	0.4612
FS*VR	4	912.71	228.17	1.75	0.1524
MC*FS*VR	8	1,364.84	170.60	1.31	0.2589

Where, R = Replication, MC = Moisture content, FS = Forward Speed, VR = Variety kg. Optimum forward speed of the carrot harvester was found to be 2 2 km h^{-1}. Average field capacity (ha h^{-1}), and Average field efficiency (%) were 0.30 ha h^{-1}, and 77.42% respectively. The power requirement (kW) of the machine with the tractor was 5.89 kW. The ratio of forward speed and puller belt speed was close to unity in the case of forward speed 2 km h^{-1} and puller belt speed 0.5 m s^{-1}. Whereas in other combinations of forward speed and puller belt speed, it deviated from unity. In the developed prototype, manual detoping was not needed as the foliage was an essential part (used for pulling) for the working of carrot harvester and subsequently removed by rotating discs.

Cost Economics

The cost of the developed machine is INR 200,000 (**Table 1**). Cost of operating carrot harvester with a tractor as a prime mover was 800 Rs h^{-1}. The Break-even point of the carrot harvester was 370 h $year^{-1}$, and the payback period for the developed prototype was 5.20 years.

Conclusions

The designed carrot harvester performed digging, pulling, conveying, foliage removal and collection of carrot in one go. Maximum lifting efficiency was 96.90%, and minimum carrot damage of 1.96% was observed at 2 km h^{-1} forward speed. The average field capacity and field efficiency were 0.30 ha h^{-1} and 77.42%, respectively. The cost of operating carrot harvester with the tractor was INR 800. The Break-even point of the carrot harvester was 370 hours/year, and the payback period for the developed prototype was 5.20 years.

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Optimization of Pre-heated Brewer Spent Grain-saw Dust Blend for Biogas Production

by

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Abstract

The effect of preheating brewer spent grain-sawdust blend before digestion on biogas yield was empirically evaluated using proximate, Fourier transform infra red, x-ray flourescence and desirability function analyses. Results revealed that preheating of this blend reduces its pH, K, Mg, S, Cl, Ca, Cr, Mn, Fe, Ti and Zn, and increases its ash, crude fat, crude fibre and protein contents as desired for effective biogas yield from any feedstock. This study also established 6.8, 17 days and 5.22 kg m^{-3} for pH, retention time and organic loading rate, respectively, as the optimal settings for efficient biogas production from this blend. This optimal process yielded 0.0068 m^3 of biogas from the preheated blend against 0.0048 m^3 from non-preheated sample. Comparative analysis showed that process parameters of the biogas from the preheated feedstock conformed to set specifications for liquified natural gas and its production amounts to 33.9% cost savings. Hence, preheating of brewer spent grain-sawdust blend before digestion is essential for biogas production.

Keywords: Biogas, brewer spent grain, optimal process, preheating, sawdust

Introduction

Biogas is a gaseous mixture of methane, carbon dioxide, hydrogen sulphide and several other gases, produced by anaerobic fermentation of organic materials such as plants, animals and human wastes, under specified conditions. It is very important because of the presence of methane which gives it the property of combustion and makes it suitable for cooking, lighting and powering prime movers. Biogas technology energy is one of the steps in this direction (Okogbue and Ojo, 2014). The interest in the production of biogas from industrial wastes and biomass has stimulated intensive studies of the methane fermentation process (Ezeonu et al., 2013).

The brewing industry generates relatively large amounts of by-products and wastes, such as brewer spent grain (BSG), spent hops and yeast. Utilization of these by-products in a form of animal fodder or compost is well known. However with increasing energy costs, the brewing industry strives to convert most of its wastes to alternative energy sources (Clare and Frank, 2017). In such perspective, anaerobic digestion has become an alternative to produce renewable energy through biogas from these waste substrates.

Anaerobic digestion/treatment have been relatively promising solution for decreasing the amount of solid wastes by providing treatment of a wide spectrum of wastes streams and at the same time producing renewable energy in the form of biogas (Pierre et al., 2008). The first step of this process is hydrolysis and consists of the breakdown of cellulose, hemicellulose and lignin into monomers by the enzymatic action of hydrolytic fermentative bacteria (Lehtomaki et al., 2009). The resulting products are then converted during the acido-genesis process by acidogenic bacteria to acetic acid in the absence of oxygen. The final phase involves the action of methanogen on the acetic acid to produce biogas having a methane content of 40-60% by volume (Taherzadeh and Karimi, 2008). One possible solution for yield increase that is yet to be explored is pre-treatment of the lignocellulose materials in order to make them more susceptible to biodegradation.

Pretreatment is needed because the sugars necessary for biochemical reactions are trapped inside the cross linking structure of the lignocelluloses, thus inhibiting the process and decreasing yield (Parveen et al., 2009). Pretreatment of substrate increases biogas production, volatile solids and solubilisation of substrates which make it more accessible to enzymes (Kucharska et al., 2018). The effective pretreatment have three qualities of increasing the porosity of the substrate which makes the carbohydrates more accessible to enzymes; preserving the different fractions without losing or degrading organic matters and limiting the formation of inhibitors.

Pretreatment methods include the physical pretreatment, which can be done through chipping, grinding, milling and irradiation (Deublein and Steinhauser, 2008). There are chemical and biological methods also. As stated earlier, pretreatment of biomass materials are of various methods and these means have been evaluated and tested. Evaluations of pretreatment methods focusing on lignocellulosic materials have been reviewed by researchers (Taherzadeh and Karimi, 2008; Hendriks and Zeeman, 2009; Monlau et al., 2012). Several pretreatment methods have been applied for sewage sludge (Carrère et al., 2010 and Carlsson et al., 2012). There are also research on treatment of household waste (Anna et al., 2014; Sylwia, 2019) and slaughterhouse waste (Cavalerio et al., 2013; Rodrìguez-Abalde et al., 2011).

In recent times sawdust (SD) which is considered an agricultural/industrial waste have shown to be of economic value from various research done so far (Otaraka and Ogedengbe, 2013; Akwaka et al, 2014). Ipeghan and Ogedengbe (2013) findings showed that varied amount of saw dust, co-digested with cow dung and water hyacinth produced biogas, which lies within the recommended percentage range for optimum biogas production. Also Manyuchi et al. (2015); Musaida et al. (2016) studied on biogas produced from sawdust using actienzyme as digestion catalyst, established that an upgraded biogas can be gotten from saw dust.

It is worthy of note that Nigeria as a country spends considerably on the processing of fossil fuel to produce cooking gas; yet a lot of brewer spent grain (BSG) and sawdust deposits abound in the country which can be harnessed to meet cooking gas needs.

Hence, this study aims at determining the quantity of biogas produced from brewer spent grain-sawdust blend, studyng the effect of thermal pretreatment on anaerobic digestion of the blend and determining the optimal settings for producing biogas from the brewer spent grain-sawdust blend using the response surface methodology to encourage local production of cooking gas from this alternative source. The outcome of this study will thereby contribute in diversifying into the use of cooking gas production and other cooking fuels.

Material and Methods

This study involves the empirical evaluation of brewers spent grain-sawdust blend for biogas production and the effect of preheating the blend before digestion process on its biogas yielding rate. The brewers spent grain and sawdust used in this study were both obtained from Ama Brewery and Industrial timber market, Enugu State. The unwanted non bio-waste and coarse grains (> 70 mm) content of the substrates were removed through sorting/sieving before blending the spent grain and sawdust into a ratio of 5:2 and heating the mixture using ratio 1:1 of the blend specimen and water with microwave power of 300 W for 450 s without stirring. Thereafter proximate and chemical analysis were applied as preliminary viability assessment of both preheated and control samples of this blend before its desirability function optimization. Proximate analysis of moisture, ash, phosphorus, carbon, crude fat and crude fibre contents and pH/conductivity of the test samples were based on AOAC procedures, while Kjeldhal method was applied to determine their nitrogen and protein contents. The chemical compositions of the blends' minerals and their surface chemistry were analyzed with X-ray fluorescence

Table 1 Proximate analysis of brewer spent grains-sawdust blend

Properties	Control	Preheated
Ash content (%)	1.74	3.40
Crude fat (%)	0.50	0.70
Moisture content (%)	83.56	68.42
Crude fibre (%)	6.9	8.0
Carbon content (%)	6.5	7.0
Protein content (%)	3.25	5.68
Nitrogen (%)	0.012	0.014
Phosphorus (%)	0.66	0.72
pH	7.8	6.9
Energy value (kJ/kg)	13,559.89	14,734.50

and Fourier-transform infrared spectrometery (FTIR), respectively.

The percentage moisture contents (M) of the test samples were determined using Equation (1) by heating five grams of each sample placed in tarred aluminum dishes with hot air at 105 ±2 °C for one hour before cooling to room temperature in a desiccator containing fused calcium chloride till constant weight was obtained.

$$M = 100[(W_2 - W_1) / (W_2 - W)] \quad (1)$$

Where, W constitutes the weight of empty aluminum dish while W_1 and W_2 are for the dishes with specimen before and after heating respectively. The blends' percentage ash content (A) were determined from equation (2) by heating 5 g of each sample placed in a tarred crucible (W_4) to char with Bunsen burner before its incineration at 650 ±10 °C for 5 h in muffle furnace and cooling to constant weight (W_5) .

$$A = 100[(W_5 - W_3) / (W_4 - W_3)] \quad (2)$$

Where,

W_3 = weight of empty crucible (g).

W_4 = weight of sample placed in a tarred crucible (g)

W_5 = weight of sample after cooling (g)

The carbon concentration of the blend samples were determined using oxygen combustion gas chromatography with an elemental analyzer, while their crude fat and fibre contents were assessed with Solet and Fibra Plus instruments, respectively. Crude fat test involves placing 10 g of each specimen contained in a thimble with petroleum ether at 40-60 °C in Solet extractor for 16 h before evaporation of excess solvent in the flask with steam bath. Thereafter, the residual fat was dried in hot air at 80 °C for one hour and cooled in a desiccator. The percentage fat content of each blend sample (F_a) was determined as follows:

$$F_a = 100[(W_9 - W_7) / (W_8 - W_6)] \quad (3)$$

where,

W_6 = weight of empty thimble (g)

W_7 = weight of empty flask (g)

W_8 = weight of the thimble with test sample (g)

W_9 = weight of cooled fat and flask (g)

The percentage crude fibre content of the blends (f_i) was assessed using Equation (4) by heating 1 g of each sample contained in a glass crucible fixed in digestion tubes with 1.25% sulphuric acid (200 ml) at 400 °C for 30 mins before cooling of the crucible and filtration of the acid solution. The test was repeated with 200 ml of 1.25% sodium hydroxide before removal and drying of the crucible in oven at 100 °C for 1 h. Thereafter, the crucibles were cooled in a desiccator and weighed (W_{10}) before ashing in muffle furnace at 550 ±5 °C for 4 h, cooled in a desiccator and weighed again (W_{11}).

$$f_i = 100[(W_{10} - W_{11}) / W_3] \quad (4)$$

Where,

W_3 = weight of the crucible and 1 g of the test sample (g)

W_{10} = weight of crucible before ashing (g)

W_{11} = weight of crucible after ashing (g)

Nitrogen and protein contents of the samples were assessed using Gerhardt nitrogen digestion and distillation auto apparatus by weighing 0.5 g of each blend into Kjeldhal digestion tubes before adding concentrated sulphuric acid of 10 ml and digested mixture of 0.5 g to it. The tubes were kept in the digestion chamber for 3 h before distillation of the digested sample using a programmed distillation unit. The distilled samples were collected in a conical flask containing boric acid and mixed indicator and titrated against standard 0.1 N hydrochloric acid. The percentage Nitrogen (N) and protein (P_c) contents of the samples were estimated from the titre values as follows:

$$N = 14DTn / 1000DWV \quad (5)$$

$$P_c = 6.25N \quad (6)$$

Where,

D = dilution value

T = titre value

n = normality of HCl

W = weight of test sample (g)

Table 2 X-Ray Fluorescence (XRF) Analysis of brewer spent grains-sawdust blend

Elements	Concentration (wt %)	
	Control	Preheated
Na_2O	0.37	5.36
MgO	4.10	0.76
Al_2O_3	3.28	3.68
SiO_2	16.59	52.76
P_2O_5	12.38	14.52
SO_3	7.25	4.63
Cl	5.20	2.23
K_2O	14.94	4.06
CaO	25.57	9.82
TiO_2	0.39	0.34
Cr_2O_3	0.01	0.01
Mn_2O_3	1.11	0.22
Fe_2O_3	5.93	3.65
ZnO	0.66	0.06
SrO	0.01	0.03

Table 3 FTIR analysis of brewer spent grains-sawdust blend

Wave number (cm^{-1})	Blends Functional Groups		
	Description	Control	Preheated
3695-3620	Axial deformation in kaolinite	NIL	O-H
3500-3100	Stretching vibration link by hydrogen bond and N-H	O-H	O-H
2918-2500	Asymmetric axial deformation in methyl and methylene	NIL	C-H
1670-1620	Asymmetric axial deformation in anion carboxylate	COOH	COOH
1400-1500	Symmetric axial deformation in carboxylate anion	NIL	COOH
1080-1050	Axial deformation in polysachride	NIL	C-O
1030-1020	Axial deformation in kaolinite or O-H	Si-O	Si-O
900-690	Out plane folding in aromatics	NIL	C-H
540-500	Angular deformation kaolinite or gibbsite	Si-O	Si-O
470-400	Angular deformation in koalinite or gibbsite	Si-O	Si-O

V = volume of test sample (m^3)

The pH measurement was taken with a hydrogen electrode on a 1:1 (v/v: 10 cm^3 of sample in 10 cm^3 water) slurry of each blend sample to deionized water that has been allowed to stand for 60 minutes. Phosphorus content of this feedstock was determined by evaporation and charring of a mixture of each test sample (2 g) and 1 ml 95% ethanol saturated with magnesium nitrate before ashed for 16 h in a muffle furnace at 600 °C. Thereafter, hydrolysis/boiling of the magnesium pyrophosphate with 20 ml 5% sulfuric acid solution for 1 h, reduction of the phosphomolybdate with freshly prepared stannous chloride solution and phosphorus colour determination followed sequentially.

Fourier transformed infrared (FTIR) spectra of the feedstocks were analyzed by scaning the test samples using FTIR instrument (CARY 630) with wave number range of 1,000-3,500 cm^{-1} and Potassium bromate (KBr) as a background material. The molecules/chemical structures in each sample were identified from their unique spectral fingerprints displayed in the detector unit of this apparatus. An ARL 9400XP + Wavelength-dispersed XRF spectrometer with Rh source was used for the x-ray fluorescence analyses of the samples. The test samples were prepared as compressed powder pellets and excited with x-ray radiation from an x-ray tube operated at a potential of between 10 and 100 kV. Each element present in the substrates was identified from its unique energy lost in this fluorescence process as detected/categorized and registered by the detector of XRF instrument.

In addition, to these preliminary asssement, the limits at which system parameters (factors) influence the biogas yield (response) from the brewer spent grain-sawdust blend was also evaluated which was used to determine the optimal setting for gas production using desirability function analysis. The system's pH, retention time and organic loading rate constitute the factor investigated. A central composite experimental plan comprising 33 runs, two level factorial points (+1 and -1), center points (0) and augumented axial points (-α, α) of -1.633 and 1.633 was used to evaluate the concurrent impacts of main effects/interactions of these factors on the response. The data obtained were used to fit best quadratic functions relating the factors and the gas yield of both preheated and control blend. The adequacy of the developed functions were confirmed using analysis of variance and lack of fit tests before simulating them with Minitab response optimizer for optimal factor level prediction. Thereafter, the predicted optimal factor settings for biogas production from the brewer spent grain-sawdust blends were confirmed experimentally and compared with standard specification for liquified natural gas.

Results and Discussion

The proximate analysis conducted on the brewer spent grains-sawdust blend showed that preheating improved biogas yield (**Table 1**). This reduced the blend's pH from 7.8 to 6.9 thereby encourages the activities of hydrolytic and acidogenic bacteria. It also increased its ash, crude fat, crude fibre and protein

Table 4 Parametric evaluation of brewer spent grains-sawdust blend for biogas production

Run order	Factor Setting			Biogas Yield (m^3)	
	p	*l*(kg)	*t* (day)	Control	Preheated
1	6.8	3.0	12	4.2	4.21
2	6.8	3.0	12	3.39	3.38
3	7.2	3.0	12	4.22	4.02
4	7.2	3.0	12	4.0	3.99
5	6.8	7.0	12	3.22	3.02
6	6.8	7.0	12	3.34	3.32
7	7.2	7.0	12	5.2	5.08
8	7.2	7.0	12	4.54	4.51
9	6.8	3.0	19	4.6	4.59
10	6.8	3.0	19	4.6	4.56
11	7.2	3.0	19	3.56	3.53
12	7.2	3.0	19	4.43	4.41
13	6.8	7.0	20	5.3	5.06
14	6.8	7.0	20	5	4.98
15	7.2	7.0	20	5.6	5.06
16	7.2	7.0	20	3.24	3.23
17	6.8	5.0	17	6.44	6.10
18	7	5.0	17	4.3	4.04
19	6.6	5.0	15	2.45	2.43
20	7.4	5.0	15	3.4	3.42
21	7	1.0	15	6.7	5.73
22	7	9.0	15	3.23	3.30
23	7	5.0	6	5.66	5.34
24	7	5.0	30	5.10	5.44
25	7	5.0	15	4.4	4.20
26	7	5.0	15	5.4	5.30
27	7	5.0	15	5.4	5.35
28	7	5.0	15	5.4	5.37
29	7	5.0	15	4.4	4.34
30	7	5.0	15	5.34	5.4

contents due to cellulose content increment induced by disruption of the lignocelluloses structure of the feedstock by the thermal process. Results obtained from XRF analysis also showed that the preheated substarte is a better biogas application because it exhibits high P and low K, Mg, S, Cl, Ca, Cr, Mn, Fe, Ti and Zn contents (**Table 2**). The FTIR analysis showed O-H, N-H, C-H, COOH, C-O and Si-O as the major functional groups of this blend (**Table 3**). The presence of methyl and methylene functional groups in the spectra revealed its aptness for biogas production which is in line with Babakhouya et al. (2010).

The parametric analysis of the process variables that influence biogas yielding potentials of brewer spent grains-sawdust blend revealed the limits at which the substrate pH (*p*), retention time (*t*) and organic loading rate (*l*) affect the gas yield at 6.8-7.2, 12-18 days and 3-7 kg, respectively. The empirical functions (Equations 7 and 8) derived from assessing multifactor effects of these three process parameters (**Table 4**) revealed that their main and quadratic effects provides strong contribution to gas yield of both control (Y_C) and preheated (Y_p) feedstocks.

$$Y_C = -24.14 + 6.07p + 0.25t + 1.33l - 0.50p^2 - 0.02t^2 - 0.13l^2 \quad (7)$$

$$Y_p = -26.8 + 6.59p + 0.34t + 1.53l - 0.54p^2 - 0.02t^2 - 0.14l^2 \quad (8)$$

Further examination shown in **Tables 5** and **6** indicated that these functions did not violate constant variance assumption. Hence, their simulation with response optimizer which revealed pH of 6.83, retention time of 16.91 days and organic loading rate of 5.07 kg m^{-3} as the optimal settings for efficient biogas production from brewer spent grains-sawdust blend (**Fig. 1**). The optimal setting yields 0.0068 m^3 of biogas from the preheated blend against 0.0048 m^3 from non-preheated sample. Experimental evaluation of the simulation result shown in **Table 7** revealed prediction error of 0.11 to 0.65% and also the respective measured pH of 6.8, retention time of 17 days and organic loading rate of 5.22 kg m^{-3} conformed to set specifications for liquified natural gas.

Cost analysis of biogas production obtained from preheated brewer spent grain-saw dust blend shown in **Table 8** indicated a sum of Naira ₦1,100 as cost of producing 5.2 kg of biogas from the developed optimal preheated formulation. This amount to two hundred and eleven

Table 5 Analysis of biogas yielding function for control blend of brewer spent grains-sawdust

Source	DF	SS	F	P	SD	M	CV	Press	R^2	Adj. R^2	Pred. R^2	Adeq. Precision
Model	9	25.87	7.25	0.002	0.34	4.85	8.50	7.50	0.87	0.75	0.71	25.78
x_1	1	0.01	0.04	0.005								
x_2	1	5.64	14.23	0.004								
x_3	1	3.70	9.35	0.001								
x_1^2	1	6.31	15.29	0.000								
x_2^2	1	9.46	23.88	0.000								
x_3^2	1	6.63	16.73	0.002								
x_1x_2	1	0.55	1.39	0.629								
x_1x_3	1	0.06	0.15	0.266								
x_2x_3	1	0.10	0.26	0.624								
Residual		3.96										

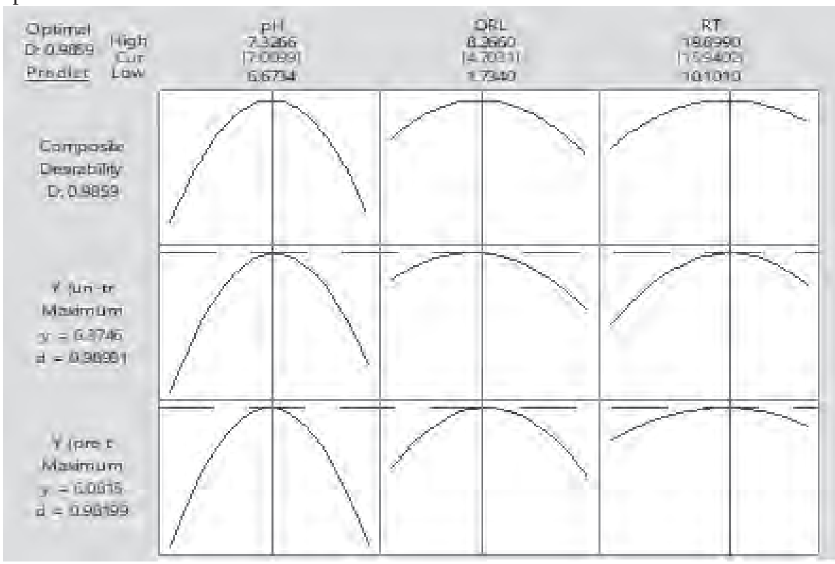
Lack of fit Test: No evidence of lack of fit (P > 0.1)

Table 6 Analysis of biogas yielding function for preheated blend of brewer spent grains-sawdust

Source	DF	SS	F	P	SD	M	CV	Press	R^2	Adj. R^2	Pred. R^2	Adeq. Precision
Model	9	29.33	9.88	0.000	0.44	5.85	6.50	9.50	0.90	0.81	0.75	25.77
x_1	1	0.06	0.19	0.002								
x_2	1	6.71	20.34	0.000								
x_3	1	4.00	12.13	0.002								
x_1^2	1	7.25	21.97	0.042								
x_2^2	1	10.12	30.68	0.032								
x_3^2	1	8.29	25.15	0.002								
x_1x_2	1	0.41	1.23	0.290								
x_1x_3	1	0.08	0.24	0.630								
x_2x_3	1	0.05	0.14	0.720								
Residual		3.30										

Lack of fit Test: No evidence of lack of fit (P > 0.1) naira, fifty-four kobo (₦211:54k) per unit mass of the gas aginst the prevailing market price of three hundred and twenty naira (₦320) for liquified natural gas thereby saving 33.9% cost for the owner. Therefore, preheating of brewer spent grain-sawdust blend before digestion is essential for biogas production.

Fig. 1 Desirability function analysis of brewer spent grains-sawdust blend for biogas production



Conclusions

This study revealed that preheating of brewer spent grain-sawdust blend before digestion is essential for biogas production because it reduces the blend's pH, K, Mg, S, Cl, Ca, Cr, Mn, Fe, Ti and Zn and increases its ash, crude fat, crude fibre and protein contents as desired for effective biogas yield from any feedstock. In addition, production of biogas from optimal formulation of preheated brewer spent grain-sawdust blend amounts to 33.9% cost savings when compared with prevailing market price of fossil gas in Nigeria.

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Table 7 Comparative analysis biogas from preheated brewer spent grain-saw dust blend

Parameters	Factor Levels Prediction			ASTM Specification
	Actual	Predicted	Error	
pH	6.80	6.83	±0.11	5.6-7.0
Retention Time (days)	17.00	16.91	±0.65	17-19
Organic Loading rate (kg)	5.22	5.07	±0.29	4.9-6.2

Table 8 Cost analysis of biogas from preheated brewer spent grain-saw dust blend

S/N	Description	Quantity (kg)	Unit Price ₦ K	Amount ₦ K
1	Brewer Spent Grain	50	5.00	250.00
2	Saw dust	20	5.00	100.00
3	Preheating/adiabetic digestion	-	LS	350.00
4	Labor Cost	-	LS	400.00
	Total			1,100.00

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ABSTRACTS

The ABSTRACTS pages is to introduce the abstracts of the article which cannot be published in whole contents owing to the limited publication space and so many contributions to AMA. The readers who wish to know the contents of the article more in detail are kindly requested to contact the authors.

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Software to Determine Parameters of Screw-Type Paddle Mixers for Animal Feed: Pedro A. Valdés-Hernández (pvaldes@unah.edu.cu), Pedro Paneque-Rondón, Lilian de la Caridad Cordero-Hernández, Alexander Laffita-Leyva, Héctor R. de las Cuevas-Milán, Carmen M. Chuairey-Medina, Yanoy Morejón-Mesa

The design of the technologies for mixing products, in particular, and for agricultural machines, in general, requires the calculation of several parameters that becomes very awkward manually and sometimes it is difficult to interpret the different variables to be evaluated. The objective of this work was to develop software for the determination of the design parameters of an endless type paddle mixer, in a professional Mathcad 2000 environment, for the production of animal feed, thus the user manual “PARMEZ.1” is presented. The program developed allows the theoretical calculation and graphical evaluation of the helicoid pitch; the productivity of the mixer, the helicoid diameter; maximum permissible value of revolutions of the mixer helicoid; power required by the mixer and the moment necessary to overcome the resistance (Mo), during the thrust of the material to be mixed, depending on the X coefficient.

Development of a Motorized Paddy Thresher for Hilly Areas

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Abstract

A motorized paddy thresher was developed for hilly areas. The prototype consisted of threshing unit, power transmission unit, canopy, sliding chute, main frame and a prime mover (1.5 kW electric motor). The thresher was evaluated on various machine parameters. The recommended combination of the independent variables, which resulted in grain damage of less than 1%, germination count of more than 80% and highest threshing efficiency of 98.65%, was achieved at a treatment combination of threshing cylinder diameter 400 mm, cylinder speed 500 rpm and input feed of 1 kg for Basmati-370 paddy variety.

Keywords: Paddy, Motorized thresher, Wire loop, Sliding chute, Hilly area

Introduction

Paddy is cultivated in almost all the states of India, but most of its cultivation is concentrated in the river valleys, deltas of rivers and coastal plains. The major paddy producing states in India are West Bengal, Uttar Pradesh, Arunachal Pradesh, Punjab and Odisha with a production of 14.71, 12.22, 11.57, 11.11, 8.29 million tonnes respectively. In the state of Jammu and Kashmir (J&K), the total rice yield in 2014-15 was 1,710 kg ha^{-1} and the total area under high yielding varieties of paddy in J&K was 65 thousand hectare. (DES, 2015). Jammu and Kashmir, being a hilly state in India, is blessed with naturally occurring micro agro-climatic regions suitable for cultivation of a wide range of agri-horticultural crops with a great potential for development. But the level of farm mechanization in the state is very poor with respect to mechanical power, efficient implements, water management, land reclamation, renewable energy and postharvest technology sectors. The traditional threshing of paddy which is practiced in hilly areas is generally done by hand: bunches of panicles are beaten against a hard element (e.g. a wooden bar log, bamboo table, or stone). This method often results in some losses due to the grain being broken or buried in the earth (FAO, 1995). The output is 10 to 30 kg of grain per man-hour according to the variety of paddy and the method applied. The grain losses amount to 1-2%, or up to 4% when threshing is performed excessively late (FAO, 1994).

Material and Methods

The methodology and procedure adopted for the development of different components of motorized paddy thresher are presented in this section.

Design Analysis

The design analysis was carried out in order to calculate the necessary design parameters such as strength and size of material to be used for the fabrication of various machine parts in order to avoid failure by excessive yielding and fatigue during the required working life of the machine (Gbabo et al., 2013). The designing of the following machine parts was carried out as:

Determination of Shaft Dimensions

The steel material (St. 42) of σ_{ut} = 410 N/mm^2 and σ_{yt} = 250 N/mm^2 was used to fabricate the threshing drum shaft (Ahorbo, 2016). A.S.M.E. code (American Society of Mechanical Engineers) for shafts was used to design the shaft of the thresher drum.

$$\tau_d = \frac{16}{\pi d^3}[(k_b M_b)^2 + (k_t M_t)^2]^{1/2}$$

Where, k_b and k_t = combined shock and fatigue factor applied to bending moment and torsional moment respectively

τ_d = permissible torque, N/mm^2

M_b and M_t = maximum value of bending moment, N.mm and torque produced by prime mover, N.mm respectively

d = diameter of the shaft, mm

For minor shocks k_b and k_t are 2.0 and 1.5 respectively, and

$$M_t = \frac{60 \times 10^3 \times \text{(power in hp)}}{2\pi \times \text{(speed in rpm)}}$$

(Ahorbo, 2016)

Upon using the value of τ_d for the shaft with pulley keyed,

$$\tau_d = 0.75 \times (0.18\ \sigma_{ut})$$

(Ahorbo, 2016)

Design of Bearing

The bearing was designed for a life span of 5 years of 10 hours daily operations as suggested by Ahorbo, 2016. The following formula was used:

$$P = XF_r + YF_a$$ (Bhandari, 2001)

Where, P = equivalent dynamic load, N; F_r = radial load, N; F_a = axial load, N; X = radial factor and Y= thrust factor

Also,

$$L = (60nL_h) / 10^6$$

Where, L_h = bearing life, hours; n = speed of rotation, rpm, and

$$C = PL^{1/\rho}$$

Where, C = dynamic load capacity; ρ = 3 (for ball bearing); L = bearing life (in million revolutions)

Diameter of Pulley

The selection of the diameter of pulley was based on the following formula:

$$N_1 \times D_1 = N_2 \times D_2$$

Where, N_1 and N_2 = number of revolution of motor and drum respectively, rpm; D_1 and D_2 = diameter of motor and pulley respectively, mm

Length of open Belt

A V-belt was placed at the top of both small and large pulley. The belt helps in the transfer of motion from driving pulley to driven pulley and therefore helps with the movement of the pulleys. The length of open belt was calculated using the formula given below:

$$L = \frac{\pi}{2} \times (D_1 + D_2) + (D_1 - D_2)^2 \frac{1}{4C} + 2C$$

(Singh et al., 2014)

Where, D_1 and D_2 = diameter of the driving and driven pulley respectively

C = distance between the centres of two pulley

Results and Discussions

Size of the Shaft

The size of the shaft was selected on the basis of the total force (weight) acting on the shaft and bending moment on the shaft as a result of the total weight on the shaft. The total weight and bending moment on the shaft were calculated as:

Total weight acting on the shaft = W × g

Where, W = weight of the threshing drum, kg; g = acceleration due to gravity, 10 ms^{-2}

Total weight on the shaft = 25 kgf × 10 ms^{-2}

Where, 25 kgf is the maximum estimated weight of threshing drum of maximum diameter selected in the study i.e. 400 mm (**Fig. 1**)

Total weight on the shaft = 250 N

Now, the bending moment (M_b) = WL/4

Where, W = weight on the beam, kg; L = cylinder length, mm

$$M_b = \frac{250\text{N} \times 500\text{ mm}}{4}$$

or, M_b = 31,250 N.mm

The torque required for turning the threshing drum was 90,240 N.mm for the shaft rotating at high speed of 500 rpm and 134336 N.mm for the low speed of 300 rpm. The permissible torque is 56 N/mm^2 (Ahorbo, 2016) and the shaft diameter calculated for 500 rpm and 300 rpm speeds were 28 mm and 29 mm. Hence the selected shaft size was 30 mm.

Cylinder Shaft Bearing

The calculated dynamic load for speeds 500 and 300 rpm were 24,020 and 46,009 N respectively. Hence the design being for 5 years life span of 10 hours daily operation at low speed of 300 and high speed of 500 rpm threshing was an SKF self-bearing of number 1400.

Power Transmission

A two horse power single phase AC motor having 1,440 rpm was used to drive cylinder beater using V-belts and pulleys. The high horsepower motor was used for the prototype considering the factor of safety for the safe working of machine.

Diameter of pulley

Using the formula stated above, the diameter of the pulleys for speed 300, 400 and 500 rpm were selected as 381, 279 and 229 mm respectively.

Length of the Belt

Length of the open belt was selected based on the formula stated in Design analysis:

$$L = \frac{\pi}{2} \times (D_1 + D_2) + (D_1 - D_2)^2 \frac{1}{4C} + 2C$$

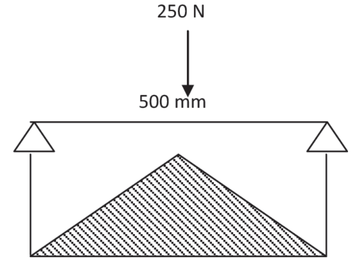
(Where, C = 48 cm)

The length of the open belt selected for the pulley of maximum diameter of 15 cm was 125 cm. A suitable system for the adjustment of belt was provided.

Fabrication

Keeping in view the design speci-

Fig. 1 Forces acting on the shaft



fications, a prototype of motorized paddy thresher was fabricated. The paddy thresher consisted of a threshing unit, power transmission system, a main frame and wheels for transportation. The threshing cylinders were made by MS flat 3 × 2.8 mm twirled in three rings; these rings were joined by another 12 MS flat of the same dimension equidistant from each other (Singh et al., 2003). The wire loops made of MS steel of 3 mm diameter and the height of the wire loop was 40 mm (Singh et al., 2003) were welded in a staggered manner on MS flats with a spacing of 40 mm (Singh et al., 2003). The threshing drum was mounted on a shaft of 30 mm diameter rotated with the help of belt and pulley attached to a 2 hp single phase electric motor. The overall length, width and height of the paddy thresher were 640, 730 and 1000 mm respectively excluding the height of wheels (140 mm) provided at the bottom of four corners for transportation of the thresher.

Functioning of the Thresher

The paddy thresher was operated with a 2 hp single phase electric motor. The power to the thresher was given by a belt drive by providing a pulley on the cylinder shaft connected to the shaft of the motor. Once the machine was running, paddy bundles were fed to the thresher. As the panicles of paddy come in contact with the wire loop, an impact force is acted upon the panicles due to the rotating motion of the threshing cylinder resulting in the detachment of paddy grains from the plant. The threshed paddy grains are thrown away from the thresher by the force and air stream created by the motion of threshing cylinder. The thresher was operated on three cylinder speeds of 300, 400 and 500 rpm on threshing cylinders of three different diameter viz., 300, 350 and 400 mm. The input was fed at three levels viz., 1, 1.5 and 2 kg. The optimum and recommended treatment combinations of cylinder speed, threshing cylinder diameter and input feed were 500 rpm, 400 mm and 2 kg respectively. The threshing efficiency of 98.65%, grain damage of 0.74% and output capacity of 69.79 kg/h was achieved at the recommended treatment combination for the threshing of Basmati-370 paddy variety by the developed thresher.

Conclusions

On the basis of field trials following conclusions are drawn:

i. A motorized wire loop paddy thresher was successfully designed and developed.
ii. The threshing efficiency of 98.65%, grain damage of 0.74 % and output capacity of 69.79 kghr-1 was achieved at the recommended treatment combination of cylinder speed (500 rpm), threshing cylinder diameter (400 mm) and input feed (1 kg) for the designed and developed paddy thresher.
iii. The germination count for all the treatment combinations under the study was well above the recommended certified standards of 80 % germination count for paddy seeds.

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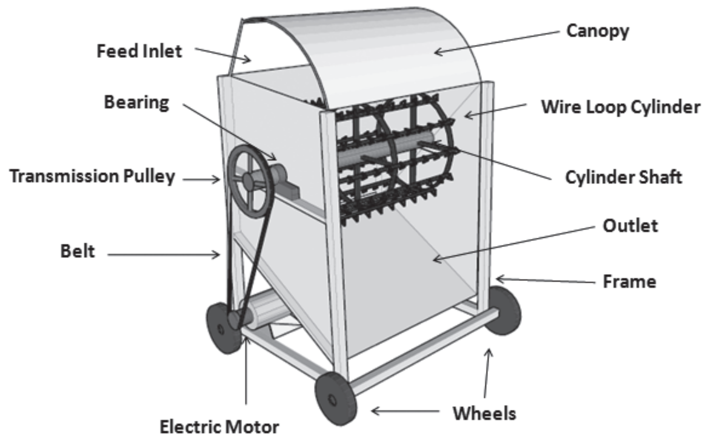
Fig. 2 Labelled isometric view of developed paddy thresher



Development and Evaluation of a Tractor-Operated Seeder for Mat Type Paddy Nursery under Controlled Field Conditions

by

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Abstract

A tractor-operated seeder for mat type paddy nursery was developed and evaluated in the laboratory/controlled field conditions on loam soil. The machine lays a polythene sheet and prepares one-meter wide soil bed on it with simultaneous uniform seed placement. In this study, the effect of independent parameters i.e., three levels of sieve oscillation (238, 318 and 398 spm), two levels of sieve opening size (25 × 20 and 50 × 25 mm) and two levels of depth of soil cut (40 and 80 mm) was observed on the selected dependent parameters. These independent parameters significantly affected ($p < 0.05$) the dependent parameters namely uniformity of seed spread, soil mat thickness and pulverization index whereas the effect on seed damage and plastic sheet damage was non-significant. The higher overall seed spread uniformity and overall soil mat thickness uniformity at the middle bite of transplanter cut for 950 mm bed width was 91.00% and 92.93% respectively at operational parameter combination of sieve oscillations 398 spm, sieve opening size of 25 × 20 mm and depth of soil cut of 80 mm. The pulverization index was 2.01 mm whereas seed damage and plastic sheet damage were negligible.

Introduction

Paddy is India's preeminent crop grown on more than 44.50 million-hectare area with the production of 172.58 million tonnes. The country has shifted remarkably from food deficit to a second major paddy producer in the world accounting for 22.07% of global paddy production (Anon., 2021). In Punjab state of India, paddy production was 19.13 million tonnes from an area of 3.10 million ha for the year 2018-19, which was 11.00% and 7.01%

of India's total production and the area under paddy crop, respectively (Anon., 2022). Presently, transplanting of paddy is mainly dependent on the labour migrated from other states of India. Manual transplanting of paddy is higher labour-intensive operation involving various actions i.e. nursery raising, seedlings uprooting, transporting and transplanting the seedlings in the field require about 250-320 man-h/ha (Jain and Philip, 2003). Due to the labour scarcity, now the farmers incline to mechanical transplanting of the paddy. Mechanical transplanting is found to be an efficient substitute for traditional transplanting while reducing human drudgery, getting uniform and desired plant population that is impossible with manual transplanting by hired labour. In general, mechanical transplanting saves about 78-88% labour as compared to conventional manual transplanting (Manes et al., 2013). Efficient paddy transplanters are available in the market which can transplant the seedlings in a line by allowing better intercultural operations after transplanting. At present, about 760 mechanical paddy transplanters are with farmers as well as cooperative societies provided by the State Government of Punjab on subsidy (Modi et al., 2022). Mechanical paddy transplanters require mat type nursery having uniform mat thickness and uniform seedling growth. At present, mat type nursery is grown manually in open field either on the polythene sheet or either in trays. Manual method for raising mat type nursery labour intensive and require skill as it requires several operations namely laying of polythene sheet, placing of frames on the polythene sheet, putting the soil in the frames, levelling of soil, putting the seed on the soil, then covering of seed with thin layer of soil, sprinkling of water for setting and then uplifting the frame for further sowing. In case of tray, instead of polythene sheet and frames, the trays are directly placed in line in the field and same process is repeated. Sometimes sieving of soil is also required to remove clods and previous crop residues. In North-West India, paddy transplanting window has only 20 days to raising the nursery and transplanting it in the field. Higher labour requirement throughout the peak periods badly affects the timeliness of operation, thus reducing the grain yield (Mahajan et al., 2009). The mechanization level is low in sowing or transplanting (20%) as compared to all other farm operations in paddy cultivation (Mehta et al., 2019). To uplift the mechanization, mechanical paddy transplanting should be boosted by developing a mechanized method of sowing mat type nursery in field itself (Modi et al., 2020). In order to solve this problem a lot of effort has been made at various places but could not achieve success as desired (Mahal et al., 2018). In view of the above, an innovative tractor-operated seeder for mat type paddy nursery was conceptualized and designed to assist the development of its critical components (Modi, 2020; Modi et al., 2022). The main objective of the study was to develop and evaluate a tractor-operated seeder for mat type paddy nursery under controlled field conditions.

Material and Methods

The machine cuts and convey the soil from both sides, sieves the soil, presses the soil before laying the polythene sheet, lays polythene sheet, puts the soil of uniform thickness on polythene sheet to make a mat and then puts the seed uniformly on the soil mat. The machine consisted of two cutting units on both sides with 1.2 m spacing, conveyor system for soil, sieving system, soil and seed metering system, press-

Table 1 Specifications of the developed tractor-operated seeder for mat type paddy nursery

Description of component/ particular	Specifications
Type of machine	Trailed type
Source of power, hp	Tractor PTO, 35
Soil cutting unit	
Type of cutting blade, radius, mm	Parabolic, 270
Number of soil cutting/scrapping units	2
Width of cut, mm	240
Soil conveyor unit	
Type of conveyor	Flat belt with cleats (angle iron)
Thickness of the belt, mm	6
Angle of inclination from ground, degree	40
Diameter and pitch of soil conveyor auger, mm	150, 150
Type of sieve unit (depends upon soil tilth)	
Rectangular opening sieve size, mm	25 × 20
Oval opening sieve size, mm	50 × 25
Soil metering unit	
Type	Fluted roller
Length and diameter of roller, mm	1000, 180
Flutes, number	13
Seed metering mechanism	
Type	Fluted roller
Length and diameter of roller, mm	1000, 40
Flutes, number	14
Length and diameter of soil pressing roller, mm	1000, 220
Length and diameter of polythene wrapping roller, mm	1040, 50
No. of soil conveying feeder	2
Overall machine dimensions (L × B × H), mm	3330 × 1675 × 1135

Table 2 Details and levels of independent parameters

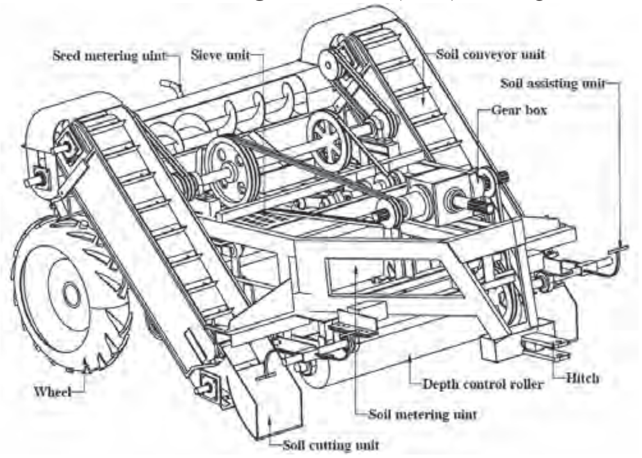
Parameter	Levels	Details	Remark
Sieve oscillation, O (strokes/min or spm)	3	O1 (238), O2 (318) and O3 (398)	Based on filling trays in the laboratory
Sieve opening size, S (mm)	2	S1 (25 × 20) and S2 (50 × 25)	Based on clod size of different soil types
Depth of soil cut, D (mm)	2	D1 (40) and D2 (80)	Based on the amount of soil required for bed

ing roller and a roller for wrapping polythene sheet. There is a provision for adjustment for depth of soil cut, tightening of soil conveyor belt and seed rate. The machine was developed based on the design calculations for major units such as soil cutting, conveying, soil and seed metering unit. The specifications of the developed machine are shown in **Table 1**. Structure drawings of the developed tractor-operated seeder for mat type paddy nursery and its seed and soil metering units are shown in **Fig. 1** and **Fig. 2**, respectively. Stationary views of the developed machine are shown in **Fig. 3**.

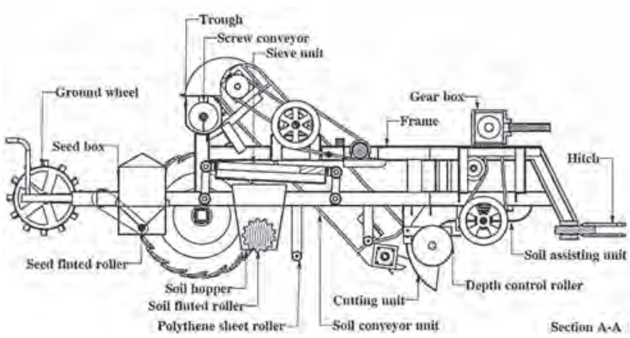
The preliminary evaluation of the developed prototype of a nursery seeder was carried out in laboratory/controlled field conditions in a well ploughed pulverized field (**Fig. 4**). The performance of nursery sowing seeder depends upon the depth of soil cut for providing sufficient soil to conveyor and effecting pulverization, sieve opening size to restrict soil clods, sieve oscillation for proper spread and sieving of soil to make uniform soil mat thickness was taken as independent parameters (**Table 2**). The effect of these parameters was studied on uniformity of seed spread, uniformity of soil mat thickness, pulverization index, seed damage and polythene sheet damage. Soil type was loam and moisture content varied from 10.0 to 14.0% (d.b.). Details and levels of independent parameters are given in **Table 2**.

The uniformity of seed spread was taken at various lengths of bite of cut of transplanter finger i.e. at minimum (8.22 mm), maximum (20.00 mm) and average (14.11 mm) and its width of cut (11.70 mm). Three frames of inner size 300 × 300 mm

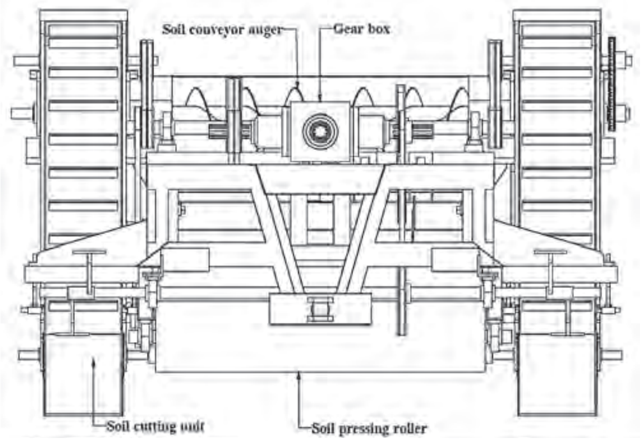
Fig. 1 Structure (CAD) drawings of the tractor operated seeder for mat type nursery



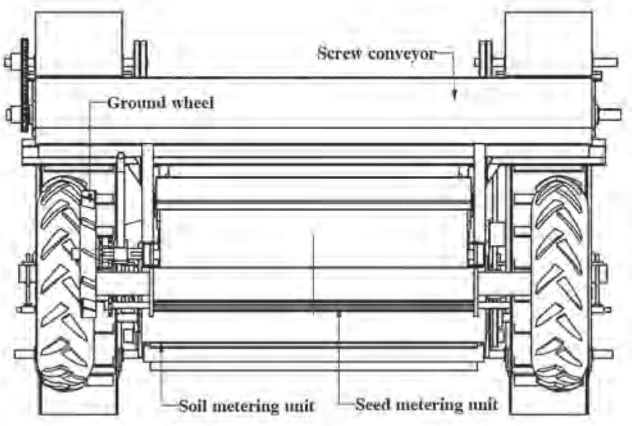
(a) Isometric view



(b) Sectional side view



(c) Front view



(d) Rear view

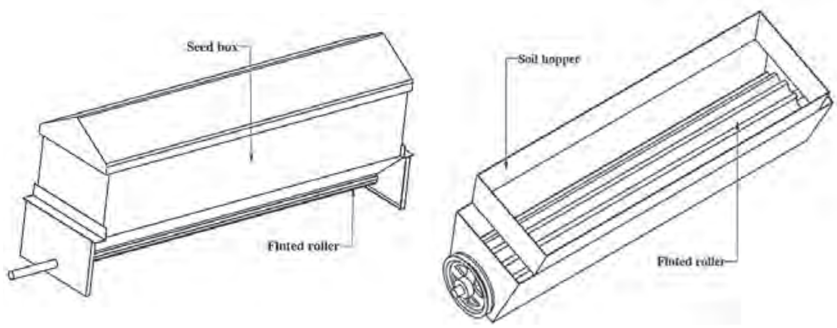
were made with required number of holes (11.70 × 8.22 mm, 20.00 × 11.70 mm and 14.11 × 11.70 mm) with the help of black colour strings. After the operation of seeder, the frame was placed randomly over the seeded bed (middle and sides) and number of seeds was counted in each rectangle. The soil mat thickness was assessed by scraping the soil on the polythene sheet lateral to direction of travel with the help of blade. The bed thickness varied at the outermost sides thus the last segment of 100 mm on both sides was divided into 4 sub-segments of 25 mm each, to work out width of uniform seedbed width. The seed spread (in terms of uniformity) and soil spread (in terms of soil mat thickness) were expressed in four different categories as shown in **Table 3**. A view of measurement of seed spread and soil spread in field is shown in **Fig. 5**.

Pulverization index of soil was taken as the mean mass diameter (MMD) of the soil aggregates and computed through sieve analysis method using standard procedure. Seed damage was determined by taking the sample of a known quantity of seed after passing through the seed metering device and separating the damaged seeds manually from the sample on weight basis. Damage to the polythene sheet was observed by removing the soil/ seed from the polythene sheet gently by hand and recorded along the 10 m length of polythene sheet. The effect of depth of soil cut, sieve opening size and sieve oscillation were analyzed using factorial experiment in completely randomized design at 5% level of significance. The pooled data of these parameters were analyzed using the Chi-square test and difference within the pairs of bite of transplanter cut using Z test. The analysis was done using statistical software "SAS 9.3" for Analysis of variance and post

Table 3 Details of different classes for seed spread and soil mat thickness

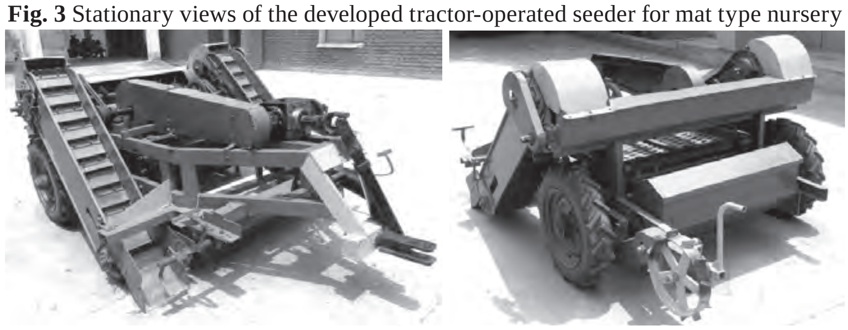
Seed spread (SP)		Soil mat thickness (M)		Remark
Class nomenclature	Seeds, number	Class nomenclature	Thickness, mm	
SP1	0-1	M1	< 20	Inadequate
SP2	2-4	M2	20-30	Proper
SP3	> 4	M3	> 30	Over
SP4	≥ 2	M4	≥ 20	Overall

Fig. 2 Structure (CAD) drawings of seed and soil metering unit



(a) Seed metering unit (b) Soil metering unit

Fig. 3 Stationary views of the developed tractor-operated seeder for mat type nursery



(a) Front (b) Rear

Fig. 4 A view of tractor-operated seeder for mat type paddy nursery operational under controlled field conditions

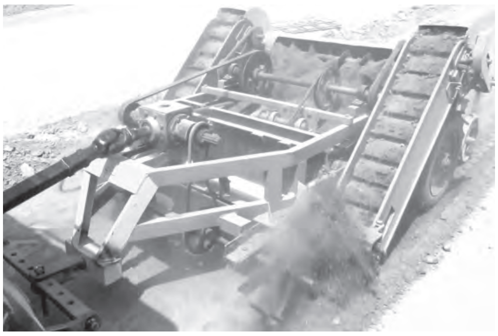
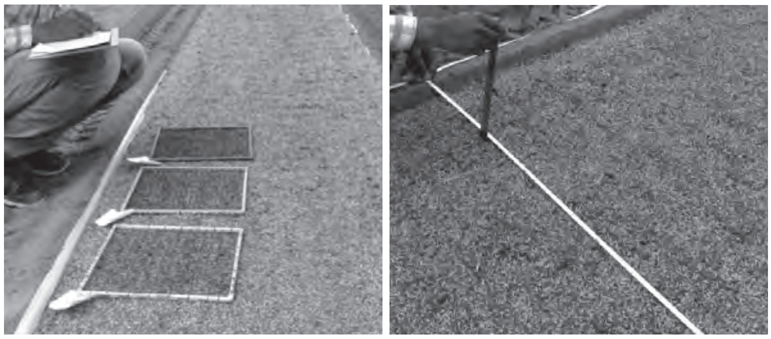


Fig. 5 Measurement of seed and soil spread



(a) Seed spread (b) Soil spread

hoc test for comparisons of different treatment combinations.

Results and Discussion

Seed Spread (SP)

The effect of three different sieve oscillations using two sieve opening sizes and two depths of soil cut on quality of seed spread corresponding to different bites of transplanter cut has been given in **Table 4**. It is clear from the table that the proper seed spread (SP2) at a particular bite of transplanter cut increased with increase in the level of sieve oscillation, sieve opening size and depth of soil cut. This might be due to formation of proper mat with higher quantity of soil as facilitated by higher depth of cut and continuous flow of soil through sieving system with higher oscillations. Inadequate seed spread (SP1) decreased and over seed spread increased (SP3) increased with increase in bite of transplanter due to increase in area. Proper seed spread (SP2) was also found on middle bite of transplanter cut whereas overall seed spread at maximum bite transplanter cut. At middle bite of transplanter cut, proper seed spread was observed more than 72% at operational combinations of O1S1D2, O2S1D2, O3S1D2, O2S2D2 and O3S2D2 and overall seed spread at these combinations was more than 95% at maximum bite of transplanter cut. A high value of over seed spread is not desirable as it affects the grot hog nursey, leads to wastage of seed.

Table 4 Effect of sieve oscillation, sieve opening size and depth of soil cut on quality of seed spread at different bites of transplanter cut

Sieve oscillations (O)	Sieve opening size (S)	Depth of soil cut (D)	Quality of seed spread (SP), %			
			Inadequate (SP1)	Proper (SP2)	Over (SP3)	Overall (SP4)
(a) Minimum bite of transplanter cut (BT1)						
O1	S1	D1	54.00	44.70	1.30	46.00
		D2	49.00	51.00	0.00	51.00
	S2	D1	56.00	43.00	1.00	44.00
		D2	48.00	52.00	0.00	52.00
O2	S1	D1	52.70	46.30	1.00	47.30
		D2	46.70	53.30	0.00	53.30
	S2	D1	54.00	45.00	1.00	46.00
		D2	43.00	57.00	0.00	57.00
O3	S1	D1	49.00	50.00	1.00	51.00
		D2	40.30	59.70	0.00	59.70
	S2	D1	52.30	46.70	1.00	47.70
		D2	42.70	57.30	0.00	57.30
(b) Middle bite of transplanter cut (BT2)						
O1	S1	D1	21.70	66.00	12.30	78.30
		D2	12.30	72.00	15.70	87.70
	S2	D1	23.70	60.00	16.30	76.30
		D2	15.30	68.70	16.00	84.70
O2	S1	D1	19.30	69.00	11.70	80.70
		D2	12.00	73.00	15.00	88.00
	S2	D1	16.00	67.70	16.30	84.00
		D2	13.00	72.00	15.00	87.00
O3	S1	D1	18.00	71.00	11.00	82.00
		D2	9.00	77.00	14.00	91.00
	S2	D1	14.70	69.30	16.00	85.30
		D2	12.30	73.70	14.00	87.70
(c) Maximum bite of transplanter cut (BT3)						
O1	S1	D1	10.00	50.00	40.00	90.00
		D2	5.00	56.00	39.00	95.00
	S2	D1	8.00	49.00	43.00	92.00
		D2	6.00	51.00	43.00	94.00
O2	S1	D1	7.00	55.00	38.00	93.00
		D2	5.00	56.00	39.00	95.00
	S2	D1	7.00	50.00	43.00	93.00
		D2	5.00	52.00	43.00	95.00
O3	S1	D1	6.30	55.70	38.00	93.70
		D2	3.00	59.00	38.00	97.00
	S2	D1	6.00	51.00	43.00	94.00
		D2	4.70	54.00	41.30	95.30

O1: 238 spm, O2: 318 spm and O3: 398 spm; S1: 25 × 20 mm (rectangular) and S2: 50 × 25 mm (Oval); D1: 40 mm and D2: 80 mm

Hence, in order to find the best bite of transplanter cut out of three, the data corresponding to each treatment (12 treatments) and all three bites of transplanter cut was pooled in different categories of quality of seed spread (according to **Table 3**). Pooled data also indicated that inadequate seed spread decreased and over seed spread increased significantly ($p < 0.05$) with the increase in bite of transplanter cut (**Fig. 6**). Proper seed spread was significantly found higher at middle bite of transplanter cut whereas it was non-significant for minimum and maximum bite of transplanter cut. Hence middle bite of transplanter cut was selected for further analysis. The overall seed spread (SP4) is the sum of SP2 and SP3. Hence proper seed spread and overall seed spread were taken for analysis.

Mean of seed spread at BT2 corresponding to three different sieve oscillations using two sieve opening sizes and two depths of soil cut for SP2 and SP4 have been given in **Table 5**. The effect of sieve oscillation, sieve opening size and depth of soil cut on proper seed spread was significant ($p < 0.05$). The sieve oscillation O3 offered better proper seed uniformity as compared to sieve O2 and O1 due to better sieving of the soil with maximum fragmentation facilitating minimum mass diameter of the soil on the bed gives higher proper seed SP2 placement (**Table 5a)**. The sieve opening size S1 offered better proper seed uniformity as compared to sieve S2 due to smaller sieve opening, retaining of soil clods gives higher proper seed placement (SP2) over the soil bed. Similarly, depth of soil cut D2 delivers more soil on the bed with uniform level facilitates higher seed uniformity or proper seed SP2 placement. Besides, the first order interactions, viz. sieve oscillation and sieve opening size and sieve oscillation and depth of soil cut were significant ($p < 0.05$) and whereas interaction of sieve opening size and depth of soil cut was non-significant. Mean value of SP2 was not significantly different for combinations O1D2 and O3D1 (**Table 5a**). It means that same condition of the soil bed might be achieved at sieve oscillations O1 at depth of soil cut D2 and sieve oscillations O3 at depth of cut D1. Mean value of SP2 was not significantly different between the combination O3S2 and O2S1; and combination O2S1 and O2S2; and combination O2S2 and O1S1. This indicates that the same value of SP2 can be achieved at sieve oscillations O2 as compared to O3 due to sieve opening size S1 reduces soil clods passing on soil bed as it was achieved at oscillations O3 with sieve opening size S2. A similar reason was for the non-significance in combination O2S2 and O1S1. Combinations O3S1D2, O3S2D2 and O2S1D2 give higher quality of seed spread 77.00, 73.67 and 73.00%, respectively.

The effect of sieve oscillation and depth of soil cut on overall seed spread (SP4) was significant ($p < 0.05$) whereas effect of sieve opening size was non-significant. The trend for the combinations of sieve oscillation as well as depth of soil cut was same as observed in SP2 (**Table 5b**) supported by same reasons. Mean value of SP4 for various combinations of interaction between sieve opening size and depth of soil cut in descending order were: S1D2, S2D2, S2D1 and S1D1 (Table 5b). Mean value of SP4 for various combinations of interaction between sieve oscillation and depth of soil cut in descending order followed exactly similar trend as observed in SP2. Moreover, mean SP4 was not significantly different between the combination O2D1 and O3D1; and combination O1D2 and O2D2 (**Table 5b**). The non-significance between the combination O2D1 and O3D1 was due to depth of soil

Fig. 6 Pooled percent frequency of quality of seed spread at different bites of transplanter cut (percent frequencies for the particular quality of seed spread with same letter are not significantly different, $p > 0.05$)

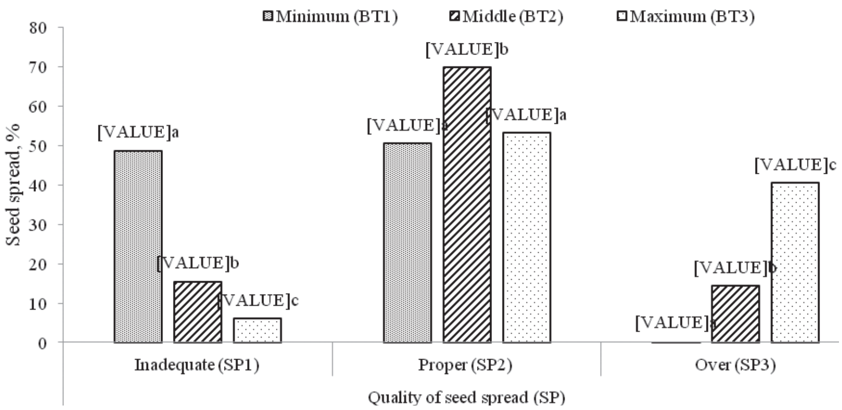


Table 5 Effect of sieve oscillation, sieve opening size and depth of soil cut on quality of seed placement for BT2

Sieve oscillation (O)	Mean (O×S×D)				Mean (O×D)		Mean (O×S)		Mean (O)
	D1		D2						
	S1	S2	S1	S2	D1	D2	S1	S2	
(a) Proper seed spread (SP2)									
O1	66.00f	60.00g	72.00bc	68.67e	63.00e	70.33c	69.00d	64.33e	66.67c
O2	69.00ed	67.67ef	73.00bc	72.00bc	68.33d	72.50b	71.00bc	69.83cd	70.42b
O3	71.00cd	69.33ed	77.00a	73.67b	70.17c	75.33a	74.00a	71.50b	72.75a
Mean (S×D)	68.67c	65.67d	74.00a	71.44b	Mean depth of soil cut (D)		Mean sieve opening size (S)		
					67.17b	72.72a	71.33a	68.56b	
(b) Overall seed spread (SP4)									
O1	78.33g	76.33g	87.67b	84.67d	77.33d	86.17b	83.00b	80.50c	81.75a
O2	80.67f	84.00ed	88.00b	87.00bc	82.33c	87.50b	84.33bc	85.50ab	84.92b
O3	82.00ef	85.33cd	91.00a	87.67b	83.67c	89.33a	86.50a	86.50a	86.50c
Mean (S×D)	80.33d	81.89c	88.89a	86.44b	Mean depth of soil cut (D)		Mean sieve opening size (S)		
					81.11b	87.67a	84.61a	84.16a	

Note: Means with same letter are not significantly different ($p > 0.05$)

Table 6 Effect of sieve oscillation, sieve opening size and depth of soil cut on quality of soil mat thickness at different width of soil bed

Sieve oscillations (O)	Sieve opening size (S)	Depth of soil cut (D)	Soil mat thickness (M), % Inadequate (M1)	Proper (M2)	Over (M3)	Overall (M4)
(a) Width of soil bed 1000 mm (W1)						
O1	S1	D1	57.58	42.42	0.00	42.42
		D2	28.28	69.70	2.02	71.72
	S2	D1	58.59	41.41	0.00	41.41
		D2	41.41	58.59	0.00	58.59
O2	S1	D1	35.35	64.65	0.00	64.65
		D2	16.16	81.82	2.02	83.84
	S2	D1	42.42	57.58	0.00	57.58
		D2	19.19	70.71	10.10	80.81
O3	S1	D1	25.25	74.75	0.00	74.75
		D2	12.12	82.83	5.05	87.88
	S2	D1	25.25	73.74	1.01	74.75
		D2	12.12	77.78	10.10	87.88
(b) Width of soil bed 950 mm (W2)						
O1	S1	D1	56.57	43.43	0.00	43.43
		D2	26.26	72.73	1.01	73.74
	S2	D1	58.59	41.41	0.00	41.41
		D2	41.41	58.59	0.00	58.59
O2	S1	D1	35.35	64.65	0.00	64.65
		D2	8.08	90.91	1.01	91.92
	S2	D1	42.42	57.58	0.00	57.58
		D2	10.10	76.77	13.13	89.90
O3	S1	D1	18.18	81.82	0.00	81.82
		D2	7.07	92.93	0.00	92.93
	S2	D1	20.20	78.79	1.01	79.80
		D2	0.00	88.89	11.11	100.00
(c) Width of soil bed 900 mm (W3)						
O1	S1	D1	55.56	44.44	0.00	44.44
		D2	20.20	78.79	1.01	79.80
	S2	D1	58.59	41.41	0.00	41.41
		D2	36.36	63.64	0.00	63.64
O2	S1	D1	32.32	67.68	0.00	67.68
		D2	4.04	94.95	1.01	95.96
	S2	D1	42.42	57.58	0.00	57.58
		D2	4.04	81.82	14.14	95.96
O3	S1	D1	13.13	86.87	0.00	86.87
		D2	3.03	96.97	0.00	96.97
	S2	D1	14.14	84.85	1.01	85.86
		D2	0.00	90.91	9.09	100.00
(d) Width of soil bed 850 mm (W4)						
O1	S1	D1	54.55	45.45	0.00	45.45
		D2	21.21	77.78	1.01	78.79
	S2	D1	58.59	41.41	0.00	41.41
		D2	33.33	66.67	0.00	66.67
O2	S1	D1	25.25	74.75	0.00	74.75
		D2	0.00	98.99	1.01	100.00
	S2	D1	42.42	57.58	0.00	57.58
		D2	2.02	84.85	13.13	97.98
O3	S1	D1	8.08	91.92	0.00	91.92
		D2	0.00	100.00	0.00	100.00
	S2	D1	8.08	90.91	1.01	91.92
		D2	0.00	87.88	12.12	100.00

O1: 238 spm, O2: 318 spm and O3: 398 spm; S1: 25 × 20 mm (rectangular) and S2: 50 × 25 mm (Oval); D1: 40 mm and D2: 80 mm

cut D1 (40 mm) delivered lesser soil allowed same amount of soil on the soil bed at both the oscillations O2 and O3. Mean SP4 was not significantly different between the combination O3S1, O3S2 and O2S2 due to sieve oscillations O3 had higher sieve oscillations (398 spm) irrespective of sieve opening size and sieve oscillation O2 had lesser oscillations but higher sieve opening size. The operational parameter combination O3S1D2 give significantly higher SP2 (77.00%) whereas combination O3S1D2 give higher SP4 (91.00%).

Soil Mat Thickness (M)

The effect of three different sieve oscillations using two sieve opening sizes and two depths of soil cut on quality of soil mat thickness corresponding to different width of soil bed has been given in **Table 6**. The value of inadequate mat thickness (M1) was higher for depth of cut D1 as compared to soil due to lesser quantity of soil. The value of proper mat thickness varied from 41.41 to 100.00% and overall mat thickness from 87.88 to 100%. The over mat thickness was up to 14.14% for depth of cut D2, sieve opening size S2 and sieve oscillation O2 and O3. At 950 mm width of soil bed (W2), proper soil mat thickness was observed more than 72.00 % at operational combinations of O1S1D2, O2S1D2, O3S1D2, O2S2D2 and O3S2D2 and overall soil mat thickness at these combinations was more than 78.00% at 850 mm width of soil bed (W2). High value of overall soil mat thickness is desirable but reducing width of bed is not desirable due to wastage of sown seed and polythene sheet.

Hence, in order to find the bed width out of four which have uniform soil mat thickness, the data of all bed widths were pooled (**Fig. 7**) for different categories of quality of soil mat thickness. The mean value of proper soil mat thickness increased when border area on both sides was not taken into account increased. It might be due border area effect due to non-overlapping of soil to outer area. Similarly, reverse trend was obvious for inadequate mat thickness. The over mat thickness was found non-significant because the mean value of overall mat thickness varied from 2.19 to 2.53%. Soil bed width W1W2, W1W3, W1W4 and W2W4 were significantly different for proper soil mat thickness (M2). The pair W2W3 and W3W4 were non-significant for M2. Based on these findings and keeping more soil mat width, soil mat width of 950 mm was taken for further analysis of proper soil mat thickness (M2) and overall mat thickness (M4).

Means of soil mat thickness at width of bed 950 mm (W2) corresponding to three different sieve oscillations using two sieve opening sizes and two depths of soil cut has been given in **Table 7**. Percent M2 and M4 increased with increase in levels of all combinations of sieve oscillation and depth of soil cut and decreased with increase in sieve opening size. The mat thickness M2 and M4 increased with increase in higher sieve oscillations (O3) as compared to the lower sieve oscillations (O1) due to the more rate of soil sieving, dropping of sufficient amount of soil on the bed through soil metering unit due to higher depth of soil cut (D2). The mat thickness M2 and M4 varied from 41.41 to 92.93% and 41.41 to 100.00%, respectively among all the treatments corresponding to W2. The maximum mean M4 was observed for sieve opening size S2 (100.00%) as compared sieve opening size S1 (92.93%) at depth of soil cut D2 and sieve oscillation O3. This might be attributed same reasoning given above. The effect of sieve oscillation, sieve opening size and depth of soil cut on proper soil mat thickness (M2) were significant ($p < 0.05$) for soil mat thickness. Besides, the first order interactions, viz. sieve oscillation and sieve opening size, sieve oscillation and depth of soil cut and sieve opening size and depth of cut were non-significant. Mean value of M2 was not significantly different between the combination O3S1, O3S2 and O2S1; and combination O2S2, O1S1 and O1S2. This indicates that the same value of M2 can be achieved with sieve S1 due to more number of openings which facilitates better soil sieving as compared to the sieve S2. Also, it can be achieved at oscillations O2 with sieve opening size S2 due to larger sieve opening

Fig. 7 Pooled percent frequency of quality of soil mat thickness at different width of soil bed (percent frequencies for particular quality of soil mat thickness with same letter are not significantly different p > 0.05)

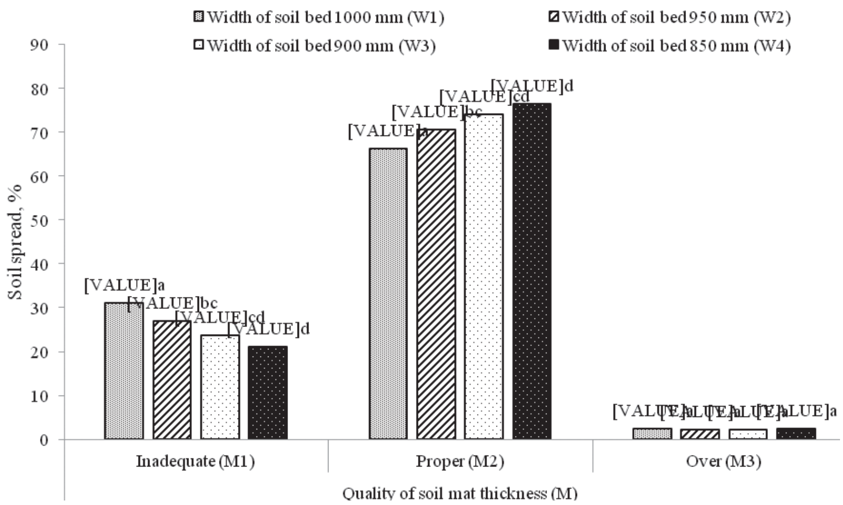


Table 7 Effect of sieve oscillation, sieve opening size and depth of soil cut on soil mat thickness at 950 mm bed width (W2)

Sieve oscillation (O)	Mean (O×S×D) D1 S1	D1 S2	D2 S1	D2 S2	Mean (O×D) D1	D2	Mean (O×S) S1	S2	Mean (O)
(a) Proper soil mat thickness (M2)									
O1	43.43d	41.41d	72.73abcd	58.59bcde	42.42d	65.66bc	58.08c	50.00c	54.04c
O2	64.65abcde	57.58cde	90.91a	76.77abc	61.11dc	83.84ab	77.78ab	67.18bc	72.48b
O3	81.82abc	78.79abc	92.93a	88.89ab	80.31ab	90.91a	87.38a	83.84ab	85.61a
Mean (S×D)	63.30bc	59.26c	85.52a	74.75ab	Mean depth of soil cut (D)		Mean sieve opening size (S)		
					61.28a	80.14b	74.41a	67.01b	
(b) Overall soil mat thickness (M4)									
O1	43.43de	41.41e	73.74abcd	58.59cde	42.42d	66.16bc	58.59bc	50.00c	54.29c
O2	64.65bcde	57.58cde	91.92ab	89.90ab	61.11c	90.91a	78.28a	73.74ab	76.01b
O3	81.82abc	79.80abc	92.93ab	100.00a	80.81ab	96.47a	87.38a	89.90a	88.64a
Mean (S×D)	63.30b	59.60b	86.20a	82.83a	Mean depth of soil cut (D)		Mean sieve opening size (S)		
					61.45b	84.51a	74.75a	71.21a	

Note: Means with same letter are not significantly different (p > 0.05) size. A similar reason was for the non-significance in combination O2S2, O1S1 and O1S2. Mean value of M2 was not significantly different for combinations O3D1, O3D2 and O2D2 (Table 7a). It means that same condition of the soil mat thickness might be achieved at sieve oscillations O3 and depth of cut D1 and D2 due to better soil sieving. Also, sieve oscillations O2 give same value of M2 at depth of cut D2. The operational combination O3S1D2 was better to give proper soil mat thickness M2 (92.93%) and combination O2S1D2 (90.91%). Both of these combinations were found to be not significantly different thus O3S1D2 was selected as an operational parameter.

The first order interactions, viz. sieve oscillation and sieve opening size, sieve oscillation and depth of soil cut and sieve opening size and depth of cut were non-significant for overall mat thickness M4. Mean value of M4 was not significantly different between the combination O3S1, O3S2, O2S1 and O2S2; and combination O2S2 and O1S1. This indicates that the same value of M4 can be achieved at sieve oscillations O2 as compared to O3 due to compensating effect of sieve opening size S1 and S2. A similar reason was for the non-significance in combination O2S2 and O1S1. Mean value of M4 was not significantly different for combinations O3D1, O3D2 and O2D2 (Table 7b). It means that same condition of the soil bed might be achieved at sieve oscillations O3 at depth of cut D2 and sieve oscillations O3 at depth of cut D1. The operational combination O3S2D2 was better to give overall soil mat thickness (M4) uniformly (100.00%) and combination O3S1D2 (92.93%). Both of these combinations were found to be non-significantly different. Thus O3S1D2 was selected as an operational parameter.

Pulverization Index

The mean pulverization index decreased with increase in levels of all combinations of sieve oscillation whereas it increased with increased in levels of depth of soil cut and sieve opening size (**Table 8**). Mean pulverization index was reduced in later stages due to the better soil sieving at higher sieve oscillation O3. Pulverization index varied from 1.60 to 3.34 mm among all the treatments.

The effect of sieve oscillation, sieve opening size and depth of soil cut was significant ($p < 0.05$). Besides, the first order interactions, viz. sieve oscillation and sieve opening size, sieve oscillation and depth of soil cut and sieve opening size and depth of soil cut are non-significant. Mean value of PI was not significantly different between the combination O3S1, O3S2 and O2S1; and combination O2S2 and O1S1. This indicates that the same value of PI can be achieved at sieve oscillations O2 as compared to O3 due to sieve opening size S1 reduces soil clods passing on soil bed as it was achieved at oscillations O3 with sieve opening size S2 due to collision of soil clods at higher oscillations. Similarly, compensating effect was the reason for the non-significance in combination and O2S2 as compared to O1S1. Mean value of PI was not significantly different for combinations O3D2, O2D1 and O2D2; and combination O1D1 and O1D2 (Table 8). The operational combination O3S1D1 (1.60 mm), O3S2D1 (1.93 mm) and O3S1D2 (2.01 mm) were better to give minimum pulverization index. All these combinations were found to be not significantly different, thus O3S1D2 was selected as an operational parameter.

Seed Damage

Mean seed damage varied from 0.096 to 0.233% among all the treatments. The effect of sieve oscillation, sieve opening size and depth of soil cut are non-significant. This was due to seed placement unit working independently and there was no direct effect of sieve oscillation or sieve opening size corresponding to seed damage.

Plastic Sheet Damage

It has been observed from **Table 9** that the mean plastic sheet damage incidents varied from 0.00 to 1.00 for 10 m among all the treatments. The effect of sieve oscillations, sieve opening size and depth of soil cut was non-significant. The soil clods were not bigger in size and sharp which might have not damaged the plastic sheet.

The results obtained from laboratory/controlled field evaluation indicate that the effect of sieve oscillation, sieve opening size and depth of soil cut significantly affect the uniformity of seed spread, soil

Table 8 Effect of sieve oscillation, sieve opening size and depth of soil cut on PI

Sieve oscillation (O)	Mean (O×S×D)				Mean (O×D)		Mean (O×S)		Mean (O)
	D1		D2						
	S1	S2	S1	S2	D1	D2	S1	S2	
O1	2.56d	3.23ab	2.72bc	3.34a	2.90a	3.03a	2.64b	3.29a	2.96a
O2	2.20cdef	2.40cde	2.21cdef	2.79abc	2.30b	2.50b	2.21c	2.59b	2.40b
O3	1.60f	1.93ef	2.01def	2.49cde	1.77c	2.25b	1.81d	2.21c	2.01c
Mean (S×D)	2.12c	2.52b	2.31bc	2.87a	Mean depth of soil cut (D)		Mean sieve opening size (S)		
					2.32a	2.59b	2.22a	2.70b	

Note: Means with same letter are not significantly different ($p > 0.05$)

mat thickness and pulverization index whereas non-significant on both seed and plastic sheet damage. The operational parameter for better performance of machine for middle bite of transplanter cut was obtained for the operational combination of O3S1D2.

Conclusions

The results obtained from laboratory/controlled field evaluation in loamy soil indicated that the effect of sieve oscillation, sieve opening size and depth of soil cut significantly affect the uniformity of seed spread, soil mat thickness and pulverization index whereas non-significant on both seed and plastic sheet damage. The operational parameter for better performance of machine for middle obtained bite of transplanter cut was obtained for the operational combination of O3S1D2 i.e. sieve oscillations 398 spm, sieve opening size of 25 × 20 mm and depth of soil cut of 80 mm. At this setting, the higher overall seed spread at the middle bite of transplanter cut was 91.00% and overall soil mat thickness at 950 mm bed width was 92.93%. The pulverization index was 2.01 mm whereas seed damage and plastic sheet damage were observed negligible (<0.19% and 0.67 incidents per 10 m length of bed).

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Table 9 Effect of sieve oscillations, sieve opening size and depth of soil cut on plastic sheet damage

Sieve oscillation (O)	Mean (O×S×D)				Mean (O×D)		Mean (O×S)		Mean (O)
	D1		D2						
	S1	S2	S1	S2	D1	D2	S1	S2	
O1	0.00a	0.67a	0.33a	0.67a	0.33a	0.50a	0.16a	0.66a	0.42a
O2	0.33a	0.67a	0.67a	0.67a	0.50a	0.67a	0.50a	0.66a	0.58a
O3	0.33a	0.67a	0.67a	1.00a	0.50a	0.83a	0.50a	0.83a	0.67a
Mean (S×D)	0.22a	0.67a	0.56a	0.78a	Mean depth of soil cut (D)		Mean sieve opening size (S)		
					0.44a	0.67a	0.39a	0.72a	

Note: Means with same letter are not significantly different (p > 0.05)

Performance Evaluation of a Pneumatic Planter for Sorghum

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Abstract

Effective and efficient use of pneumatic planter leads to increase in the uniformity of seed distribution, consequently improving the crop yield. A field experiment was carried out at Massad area, Gezira State, Sudan. The objective was to evaluate the performance of pneumatic planter under different operating conditions. The experiment was factorial laid out in strip-plot arranged in a randomized complete block design with three replications. The treatments consisted of two operating pressures (-72 mbar and -54 mbar) as main-plots, and two forward speeds 7.5 km/h and 11 km/h as sub-plots. Pneumatic planter performance parameters namely miss index, multiple index, quality of feed index and number of seeds per meter length were calculated. The effective field capacity and field efficiency were also determined. The results showed that the 11 km/h speed significantly increased the effective field capacity to 1.28 ha/h as compared to 0.85 ha/h that at 7.5 km/h speed. However, there was no significant difference in effective field capacity between the two pressures. Furthermore, the effect of two forward speeds and two operating pressures in the field efficiency was not significant. Effects of the two forward speeds and the two operating pressures on miss index, multiple index, quality of seed index and number of seed per meter were not significant. It is concluded that the pneumatic planter for sorghum planting could be successfully used at wide ranges of forward speed and operating pressure.

Keywords: Pneumatic planter; effective field capacity; seed spacing; miss index

Introduction

In precision planting the seeds are planted in rows with uniform spacing within rows. Among different sowing techniques, precision sowing is the preferred method since it provides more uniform seed spacing than other methods. There are two common types of row-crop planters: mechanical planters and pneumatic planters. In pneumatic planters, the air system (pressure or vacuum) is used to meter seeds. Pneumatic planters consist of the seed (metering) plate with metering openings on a predetermined radius.

It is necessary for seeds to be placed at equal intervals within rows. In manual seeding with conventional practice, the higher and non-uniform plant population adversely affect grain yield of different crops (Singh et al., 2007). There are many planters having different seed metering mechanisms, the application of single seed metered plate mechanisms (horizontal, vertical and inclined plate) has increased rapidly due to better seeding performance than that of other mechanical rotors. The proper design of a seed metering mechanism is essential for satisfactory performance of any seed planter. To achieve accurate seed spacing, different parameters that affect the placement need to be optimized for specific size of seed such as the shape of the seed hole on the disc for singulation, the speed of the disc and the vacuum pressure (Singh et al., 2005).

The most important component of a pneumatic planter is the vacuum seed metering system. Because, it must control the seeding rate and meter the seeds to attain the optimum yield when planting most kinds of crops (Murray et al., 2006). Karayel and Ozmerzi (2001) concluded that variability in seed spacing with a precision vacuum seeder increased with increasing forward speed.

Accurate placement of single seed in soil ensures saving in costly seeds, reduces the problem of thinning and crop yield also is higher as each plant gets the desired quantity of sunlight, water and nutrients (CIAE/FIM, 2004). The accuracy depends upon many factors such as operational parameters and field conditions. The parameters for the evaluation of performance of the planter include spacing between seeds or plants (Hollewell, 1992), percent multiples and misses (Singh et al., 2005; Singh et al., 2007; Sun et al., 2012; Yasir et al., 2012) and precision in spacing (Hofman, 1988; Jasa and Dickey, 1982). Kumar et al (2015) conducted a performance evaluation of a tractor mounted planter for sorghum in dry land in both laboratory and actual field condition. They found that average value of plant to plant spacing, miss index and multiple index, actual field capacity and field efficiency were 101 mm, 2.07%, 3.8%, 0.77 ha/h and 79.7%, respectively. In Sudan the adoption of modern agriculture in which maximum efficiency must be combined with minimum cost is highly needed. Effective and efficient use of pneumatic planter leads to increase the uniformity of seed distribution, as a result, improving the crop yield. Therefore, the objective of this study was to evaluate the performance of pneumatic planter under different operating field conditions.

Material and Methods

The experiment was conducted during 2017/2018 at Massad Training Center, Gezira State, at latitude 14′ 24″ N, longitude 33′ 30″ E. The soil of the experimental site is clay soil. The average soil moisture content was 4%.

The experimental design was factorial laid out in strip-plot arranged in a randomized complete block design with three replications. The treatments consisted of two operating pressures (-72 mbar and -54 mbar) as the main-plots, and two forward speeds 7.5 km/h and 11 km/h as the sub-plots. An experimental block of 20 m long and 5 m wide was used for each treatment.

A new Holland TT80 (80 hp) tractor was used in the experiment. The Agromaster pneumatic planter with the followings specifications which are given in (**Table 1**) was used for planting sorghum (Tabat cultivar) with uniform size and shape. **Figs. 1** and **2** show an operational view and construction drawing of the planter.

Table 1 Specifications of the pneumatic planter

Number of rows	4
Row spacing (cm)	80
Type of blower	Aspirator
Seed metering	Pneumatic disc suction principle
Number of holes on disc	36
Seed hole diameter (mm)	2
Working width (cm)	240

The pneumatic planter calibrated and tested at the laboratory to set the seeds spacing. The spacing of seeds which used was 9.7 cm. Then the field evaluation was carried out to study the below-mentioned performance parameters.

Speed of operation: The forward speed of tractor (km/h) was calculated by the following equation

$$S = (D_T / t) \times 3.6 \quad (1)$$

Where,

S = speed (km/h).

D_T = travelled distance (m).

t = time (sec).

Theoretical field capacity (ha/h) was calculated using the following equation ASABE (2006).

$$TFC = (W \times S) / C \quad (2)$$

Where,

TFC = Theoretical field capacity, (ha/h).

S = Speed, (km/h).

W = Width of implement, (m).

C = Constant, (10).

Effective field capacity (ha/h) was calculated using the following equation ASABE (2006).

$$EFC = Ac / Tt \quad (3)$$

Where,

EFC = Effective field capacity, (ha/h).

Ac = Actual area covered, (ha).

Tt = Time taken (h).

Field efficiency is defined as the ratio of effective field capacity to theoretical field capacity (Kepner et al., 1982):

$$FE = EFC / TFC \quad (4)$$

Where,

FE = field efficiency, %.

EFC = effective field capacity, ha/h.

TFC = theoretical field capacity, ha/h.

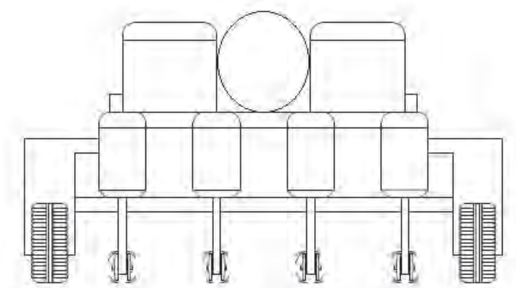
As stated by (Singh et al., 2005), the performance parameters for the pneumatic planter are as follows

Miss index

Indicated missed seed locations

Fig. 1 Operational view of the planter

Fig. 2 Construction drawing of the planter



or skips. The missing percentage is represented by an index called the Miss Index (MI) which is the percentage of spacing greater than 1.5 times the set spacing (X).

$M = n_1 / N$ (5)

Where,

n_1 = number of spacing > 1.5 X

N = total number of spacing measured.

Multiple index

The multiple, more than one seed, percentage is represented by an index called Multiple Index (DI) which is the percentage of spacing that are less than or equal to half of the set spacing (X).

$DI = n_2 / N$ (6)

Where,

n_2 = number of spacing < 0.5 X.

Quality of feed index

The quality of feed index is an alternate way to present the performance as a result of combined effect of misses and multiples. The quality of feed index (A) is the percentage of spacing that are more than half but not more than 1.5 times of the set spacing.

Quality of feed index = 100 − (Miss Index + Multiple Index) (7)

Number of seeds per meter length

The number of seeds per meter length was calculated from randomly selected sequence of seeds distributed on the rows.

The data were analyzed using Statistix 8 software program for analysis of variance and means separation.

Results and Discussion

Performance Variable

i. Effective Field Capacity

As shown in **Table 2**, the 11 km/h forward speed significantly increased ($P \leq 0.05$) the effective field capacity as compared to the 7.5 km/h forward speed, whereas the first speed scored the highest value of effective field capacity of 1.28 ha/h, while the latter speed recorded the minimum value of 0.85 ha/h. It was noted that the effective field capacity showed an increase when the forward speed increased, and this could be attributed to the positive relationship between them. However, the statistical analysis revealed no significant difference ($P > 0.05$) in effective field capacity between the two pressures. The highest value of effective field capacity obtained at the operating pressure (-72 mbar) is 1.08 ha/h, while the minimum value of effective field capacity obtained at the operating pressure (-54 mbar) is 1.04 ha/h. The results agree with those of Al ani (2012) who found that the effective field capacity was significantly affected only by the forward speed rather than operating pressure. The result of analysis also showed the interaction between two forward speeds and two operating pressures on the effective field capacity didn't give any significant difference.

ii. Field Efficiency

Table 2 shows the effect of two forward speeds and two operating pressures on the field efficiency was not significant ($P > 0.05$). Whereas, the second speed scored the highest field efficiency of 72.3 % as compared to the first speed of 70.3%. The field efficiency showed slight increase with the increase in speed due to the direct relation between the effective field capacity and field efficiency. Regarding the operating pressure, the highest value of field efficiency of 71.5% was obtained at the first operating pressure, while the lower value recorded at the second operating pressure was 70.5%. The interaction between two forward speeds and two operating pressures in the field efficiency didn't give any significant difference.

Table 2 Effect of forward speed and operating pressure on the effective field capacity and field efficiency

Treatment	Effective field capacity (ha/h)	Field efficiency (%)
First speed (7.5 km/h)	0.85	70.3
Second speed (11 km/h)	1.28	72.3
$LSD_{0.05}$	0.35	NS
First pressure (-54 mbar)	1.04	71.5
Second pressure (-72 mbar)	1.08	70.5
$LSD_{0.05}$	NS	NS

NS = Not significant

Performance Parameters of the Pneumatic Planter

i. Uniformity of Seed Spacing (Miss Index, Multiple Index and Quality of Feed Index)

The effect of the two forward speeds and two operating pressures on the miss index is shown in **Table 3**. The results of analysis showed that the effect of two forward speeds and two operating pressures in the miss index was not significant ($P > 0.05$). The highest value of miss index 0.73% and 0.68% obtained at both second forward speed and first negative pressure, respectively.

The same trend was observed in the multiple index. The effect of two forward speeds and two operating pressures didn't give a significant difference (**Table 3**). The highest value of multiple indexes 0.74% and 0.68% were obtained at the first speed and second negative pressure, respectively.

For the quality of feed index also the results of analysis revealed that the influence of the two forward speeds and two operating pressures was not significant (**Table 3**). The highest value 98.68% and 98.69% obtained at both first forward speed and second negative operating pressure, respectively.

It is to be noted that the multiple index and quality of feed index tended to be increased and the miss index decreased with an increase in negative pressure, while, the multiple index and quality of feed index were decreased and the miss index increased with the increase in forward speed. Similar findings were observed by (Yasir et al., 2012 and Singh et al., 2005). Moreover, as stated by (Kachman and Smith, 1995) smaller values of miss index indicate better performance than larger values and larger values of quality of feed index indicate better planter performance than smaller values.

ii. Number of Seeds Per Meter Length

Table 3 shows that the effect of forward speed in number of seeds per meter was not significant. The higher amount of seeds 10.8 was obtained at the first speed.

Table 3 also shows the effect of operating pressure in number of seeds per meter was not significant. The second pressure scored the higher number of seeds per meter is 10.45. This latter result agreed with that of Al ani (2012).

Conclusions

From the present study it can be concluded that the 11 km/h speed significantly increased the effective field capacity as compared to the 7.5 km/h speed, while the change in pressure didn't give a significant difference. However, both change in speed and pressure didn't give a significant difference in field efficiency. With regard to the uniformity of seed spacing (miss index, multiple index and quality of feed index) and number of seed per meter the influence of both two speeds and two pressures wasn't significant. Therefore, the selection of the optimum speed and pressure for the pneumatic planter should be based upon the field operating conditions as well as other factors that are related to the tractor and implement.

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Table 3 Effect of forward speed and operating pressure on the miss index, multiple index, quality of feed index and number of seed per meter

Treatments	Miss index	Multiple index	Quality of feed index	Seed number
7.5 km/h	0.58	0.74	98.68	10.80
11 km/h	0.73	0.60	98.67	9.90
$LSD_{0.05}$	NS	NS	NS	NS
-54 mbar	0.68	0.65	98.67	10.00
-72 mbar	0.63	0.68	98.69	10.49
$LSD_{0.05}$	NS	NS	NS	NS

NS = Not significant

Performance and Techno-economic Viability of Water Cooled Thermoelectric Refrigeration System for Storage-cum-Transportation of Fruits and Vegetables

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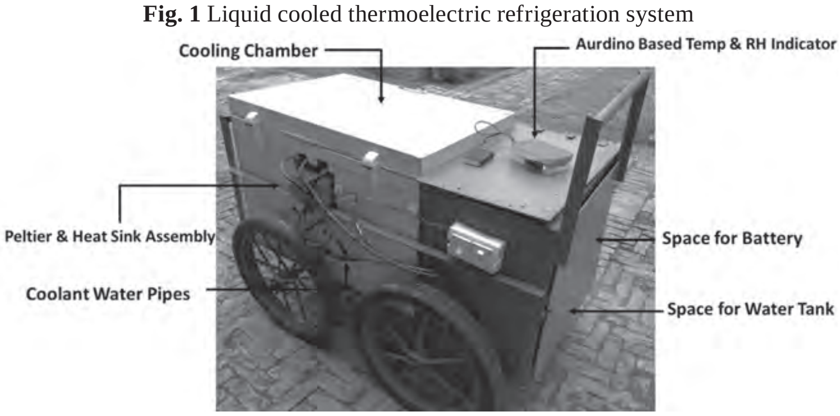
Abstract

A prototype mobile thermoelectric refrigeration system of capacity 100 liter (40 kg per batch) was designed and developed for maintaining 15 ±2°C temperature and 80 ±5% relative humidity. The developed system composed of four thermoelectric modules, liquid cooled evaporator, axial fan, diaphragm water pump, fogger and water tank and was operated by 12 V DC power source consuming 4.5 kWh energy per day. The techno-economic feasibility was evaluated in terms of fixed cost, operating cost, annual profit and payback period for storage and transportation of summer fruits and vegetables. The estimated cost of system was Rs 33,427. The economic feasibility indicator represented impressive return for entrepreneurs in terms of coefficient of performance (COP) 0.85, annual profit (Rs. 32,881), payback period (85 days) and cost: benefit ratio (1.11). The developed system is having higher COP i.e. 0.85 in comparison to existing lab scale (capacity ~ 5 liter) witnessing COP of 0.1.

Keywords: Thermoelectric refrigeration, Coefficient of Performance, Annual profit, Cost: Benefit ratio

Fig. 1 Liquid cooled thermoelectric refrigeration system



Introduction

Refrigerated storage condition is the basic requirement of fruits and vegetables during transportation that minimizes the detrimental changes such as growth of microorganisms, ripening, browning reaction, pigment degradation and moisture loss in crop (James and James, 2014). Refrigeration slows down the multiplication of microorganism as well as reduces the production of enzyme that provokes food rottenness and facilitates efficient cold chain management prolonging shelf life of freshly harvested commodities (Enescu et al., 2017). In this way, cold preservation is vital for maintaining quality during transportation and marketing of perishable fruits and vegetables.

Therefore, an eco-friendly refrigeration technology was required for cold chain management of perishable agricultural produce to minimum detrimental effect on environment ecosystem (Babar and Ali, 2019; Wiriyasart et al., 2019; Sarkar et al., 2015). In this context, a liquid cooled mobile thermoelectric refrigeration system was designed and developed for storage of fruits and vegetables during marketing (Chavan, 2020) as shown in **Fig 1**.

The thermoelectric refrigeration system is an eco-friendly technology and maintains the freshness and quality of perishable agricultural produce such as bitter gourd, okra, mango, papaya etc. The mobile thermoelectric refrigeration system increases the shelf life of the perishable agricultural produce. This study was focused on details of components and equipment incurred in development of thermoelectric refrigerator, cost economics and techno-economic feasibility of developed thermoelectric refrigerator.

Table 1 Specifications of components used in developed thermoelectric refrigeration system

Sr. No	Particular	Specification
1	Overall dimension of LCTR	145 × 650 × 120 cm
2	Material of cooling chamber	Polyurethane
3	Dimension of cooling chamber	45 × 50 × 50 cm
4	Cold chamber capacity	112 litre
5	Peltier module	TEC 12706A; (12 V DC, 6 A)
6	Number of Peltier modules	4
7	Number of water cooled heat sink	4
8	Number of air cooled heat sink	3
9	Number of axial fan	1 (12 V DC)
10	Number of water pump	2 (12V DC), 4.0 LPM
11	Number of fogger	1
12	Electric battery	1 (160 Ah)
13	Water tank capacity (l)	15
14	Cooling capacity	Temp 15-17°C / RH 80-90%

Material and Methods

2.1 Experimental Setup of Thermoelectric Refrigerator

A schematic diagram of mobile thermoelectric refrigeration system as shown in **Fig 2**. **Table 1** summarizes specifications of various components and accessories used in development of the liquid cooled thermoelectric refrigeration system. For easy transportation, storage and handling of fruits and vegetables, a horizontal refrigerator of 100 litre volumetric capacity with opening at the top was fabricated using polyurethane panel. The assembly of cooling appliances i.e. peltier modules, air and water cooled heat sink, cooling fan were fitted on the back side of the cooling chamber. The electric appliances were wired in parallel to electric battery (160 Ah). A diaphragm pump powered by battery was used to circulate water through liquid cooled evaporators attached on hot side of peltier modules. Two separate compartments were designed, one for storage of battery and another for storage of water tank to circulate water through evaporators. The design of thermoelectric refrigeration system is given in Chavan et al. (2021). The whole assembly was fitted on push type four wheeled mobile cart.

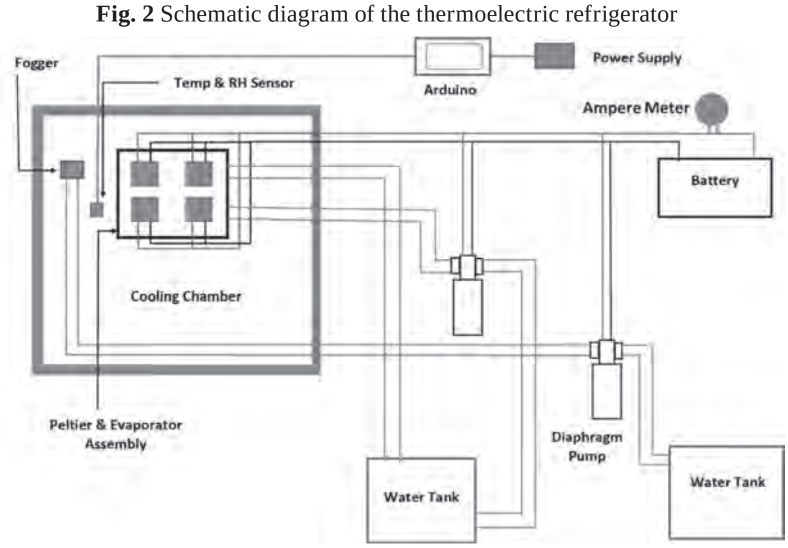
2.2 Evaluation of Techno-economic Feasibility of Thermoelectric Refrigeration System

The technoeconomic feasibility of mobile thermoelectric refrigeration system was determined to assess commercial adoptibility of the system for cold storage of fruits and vegetables during short term transportation. It was measured in terms of coefficient of performance (COP), fixed cost of system i.e. manufacturing cost, variable cost i.e. operating cost, annual profit generated by using this sytem and payback period.

2.2.1 Determination of Coefficient of Performance (COP)

The coefficient of performance is

Fig. 2 Schematic diagram of the thermoelectric refrigerator



the ratio between the refrigeration load and electrical power consumption. COP of the system was calculated using Eq. (1) (Gökçek and Şahin, 2017).

$$COP = Q_{cooling} / W \quad (1)$$

Where,

$Q_{cooling}$ = Refrigeration load due to cooling (Watt)

W = Electric power consumption (Watt)

2.2.2 Determination of Fixed Cost of System

Fixed cost of the thermoeletric refrigeration system was calculated on the basis of total cost incurred on each component and instruments employed in the manufactring of a system.

For determination of depreciation cost of a system, salvage value was taken @ 10% of total fixed cost of a system. The depreciation was calculated for expected life of 10 years (Manjarekar and Mohod 2010). Housing cost was taken @ 2% of the capital cost (BIS: 9164-1979). The depreciation cost was calculated by using Eq (2),

$$D = (C - S) / L \quad (2)$$

Where,

D = Cost of depreciation (Rs/year)

C = Capital cost (Rs)

S = Salvage value (Rs) (S = C × 10%)

L = Expected life (year)

The interest cost was calculated for average of capital cost plus salvage at rate of interest of 12.5% per annum. The interest cost was determined as Eq. (3),

$$I = [(C + S) / 2] \times r \quad (3)$$

Where,

I = Interest cost (Rs)

R = Rate of interest (%)

The actual repair and maintenance cost of the system increases with years of operation. However, for simplicity, the method of average repair and maintenance expenses per year was adopted.

$$Repair = (P \times m) / 100 \quad (4)$$

Where,

m = repair and maintenance rate (5.0%)

2.2.3 Determination of Operating Cost

Variable cost of system is the total cost involved in running of thermoelectric refrigeration system over a fixed period of time. The cost of electric energy consumed for cooling is the only operating cost involved in present refrigeration system. For measurement of electricity consumption, the cooling chamber was filled with fruits and vegetables at its full capacity and operated continuously. The electricity consumption was calculated by measuring voltage across the electric circuit using multimeter, electric current flowing in the circuit using ampere meter and number of hours the system was operated. The energy consumption of vapour compression refrigeration system was measured using energy meter connected in series to the electricity source. The power and energy consumption for the operation of system was calculated using Eqs. (5-6),

$$P = I \times V \quad (5)$$

$$E = (P \times T) / 100 \quad (6)$$

Where,

P = Electric Power (W)

I = Electric current (A)

V = Voltage across the circuit (V)

E = Electric energy (kWh)

T = Time (h)

The running cost per kg of stored commodity was calculated by dividing the total annual cost by total commodity stored per year:

Operating cost/kg = Total annual cost (Rs/year) / Quantity of commodity cooled (kg) (7)

2.2.4 Determination of Profit Generated Using Thermoelectric Refrigeration System

The increase in profit for vendor due to cold preservation of fruits and vegetables determined and compared against the profit without use of cold preservation technique. The profit was determined by taking difference of gross annual income and total annual cost.

Annual profit = Gross annual income − Total annual cost (fixed + variable) (8)

Where,

Gross annual income = Total commodity cooled (kg) × Market cost (Rs)/kg

2.2.5 Determination of Benefit to Cost Ratio, Break-even Point and Payback Period

The payback period is the length of time required for an investment to recover its initial outlay in terms of profits. The benefit to cost ratio (BCR), break-even point and payback period were determined by using following expressions, Eqs. (11-13),

B:C = Gross income (Rs/year) / Total cost (FC + VC) (11)

Table 2 Cost of major components used in thermoelectric refrigeration system

Sr. No	Description	Quantity	Cost (Rs)
1	Polyurethane sheet	2 m^2	1,000
2	Peltier module	4	1,600
3	Air cooled heat sink	3	1,800
4	Liquid cooled heat sink	4	1,600
5	Axial cooling fan	1	150
6	Heat sink paste	2	400
7	Movable cart	1	5000
8	Rechargeable battery (12V 80Ah)	2	10,000
9	Water pump (12V)	2	1,500
10	Water tubes	6 m	60
11	Fogger	1	100
12	Water tank	1	300
13	Temperature and humidity sensor	1	1,000
14	Silicon	1	150
	Total		24,660

BEP = FC (SP − VC) (12)

Payback period = BEP / Total commodity cooled (13)

Where,

FC = Fixed cost (Rs)

SP = Selling price (Rs)

VC = Variable cost (Rs)

Results and Discussion

3.1 Evaluation of Techno-economic Feasibility of the System

The techno-economic feasibility of the developed thermoelectric refrigeration system was evaluated to determine the viability of system for commercial application. The feasibility was determined on the basis of coefficient of performance (COP), fixed cost, operating cost, annual profit, cost to benefit ratio, breakeven point and payback period. The cost of instruments involved in development of the system is explained in **Table 2**.

3.2 Coefficient of Performance (COP) of the System

The COP measures efficiency of the refrigeration system. It is the ratio of refrigeration load and power consumption of a system. As 30 kg bitter gourd stored in thermoelectric refrigeration system requires 360 min for cooling, heat of refrigeration removed from the system was calculated to be 153.72 W. The power consumed by refrigeration system was calculated to be 180 W. Therefore COP of thermoelectric refrigeration system was calculated to be 0.85. COP of developed refrigeration system was found to be higher than experimental study conducted by Gökçek and Şahin (2017) which reported COP of 0.41 for 0.063 m^3 for thermoelectric refrigerator.

3.3 Fixed Cost of Liquid Cooled Thermoelectric Refrigeration System

The fixed cost of thermoelectric refrigerator consists of cost of each component incurred in system and charges paid for fabrication of system. The total cost of material and instruments used in the system was Rs 24,660. The skilled labour cost incurred for 40 h of working was Rs 1,480 at Rs 37 per hour. The fixed cost for thermoelectric refrigeration system was calculated to be Rs 33,427. The details of fixed cost are presented in **Table 3**.

3.4 Operating Cost of Liquid Cooled Thermoelectric Refrigeration System

The operating cost of thermoelectric refrigeration system was evaluated after loading the system with 10 kg per day each of bitter gourd, okra, mango and papaya. Operating cost consists of initial cost of fruits and vegetables, cost of electric power consumption and skilled labour charges. It was assumed that refrigeration system was operated during summer weather conditions of Punjab from March to August for 184 days. The total operating cost of thermoelectric refrigerator was 272,252. The details of operating cost of thermoelectric refrigeration system are summarized in **Table 4**.

3.5 Annual Profit from Operation of Thermoelectric Refrigeration System

The annual profit to the operator is difference of gross annual income and total cost (fixed and operating) of a system. As the thermoelectric refrigeration system facilitates better quality retention with extended storage life, the spoilage losses as well as physiological loss in weight of fruits and vegetables incurred in ambient storage were minimised. It was assumed that as the quality of fruits and vegetables stored in thermoelectric refrigeration system was better than those in ambient storage, the operator will fetch increased market value for commodities. The annual gross income for operator was calculated to be Rs 338,560. Therefore, total annual income for operator was Rs 66,308. The details of assumed selling price of commodity are provided in **Table 5**.

3.6 Breakeven Point of Liquid Cooled Thermoelectric Refrigeration System

Breakeven point is the point at which monetary return met with the fixed and operating cost of a system, and profit starts generating

Table 3 Calculated fixed cost of liquid cooled thermoelectric refrigeration system

Sr. No	Description	Cost (Rs)
1	Initial cost of thermoelectric refrigerator	26,140
2	Salvage value @ 10% of initial system cost	2,614
3	Life in years	10
4	Depreciation @ 10.0% / year	2,353
5	Interest cost @ 12.5%	1,797
6	Housing cost @ 2% of initial cost	523
	Total fixed cost	33,427

Table 4 Calculated variable cost of developed liquid cooled thermoelectric refrigerator

Sr. No	Description	Cost (Rs)
1	Skilled labour charges, Rs 300/day	55,200
2	Cost of bitter gourd, Rs 7/kg	12,800
3	Cost of okra, Rs 7/kg	12,800
4	Cost mango, Rs 50/kg	92,000
5	Cost papaya, Rs 50/kg	92,000
6	Electricity charges, Rs 9/unit, 4.5 units/day	7,452
	Total	272,252

thereafter. It is revealed that with daily operation of system and selling of commodity in market, the total cost of system decreases whereas profit from system increases. It can be seen from the **Fig. 3** that taking expected selling price for fruits and vegetables as shown in **Table 5**, the selling price line intersects the total cost line at 3,700 kg of fruits and vegetables sold of Rs 175,000. It means, profit will start generating after the sale of 3,700 kg of fruits and vegetables. As the selling price increased or decreased, the quantity of fruits and vegetables need to be sold decreases or increases accordingly.

3.7 Payback Period of Liquid Cooled Thermoelectric Refrigeration System

The payback period was calculated on the basis of selling price of fruits and vegetables and time period in terms of days at which returns from operation of system met with total investment on the system. It can be observed from the **Fig. 4** that at expected selling price as shown in Table 5, it takes 85 days to achieve the payback period. The payback period varies according to selling price of fruits and vegetables and as the selling price increased or decreased payback period can advance or delays accordingly.

3.8 Cost Benefit Ratio of Liquid Cooled Thermoelectric Refrigeration System

It is the ratio of gross income to the total cost (fixed + variable) incurred for development and operation of system. In the present study, the cost benefit ratio was calculated to be 1.11. The details of the cost-economics of the developed thermoelectric refrigeration system are presented in **Table 6**. The cost benefit ratio increases with increase of selling price of fruits and vegetables. It was clear from the results that application of liquid cooled thermoelectric refrigeration system for cold chain management for local vegetables vendors was economical and sustainable.

Table 5 Expected selling price of fruits and vegetables stored in the developed system

Sr. No	Description	Cost (Rs)
1	Bitter gourd, Rs 12/kg	22,080
2	Okra, Rs 12/kg	22,080
3	Mango, Rs 80/kg	147,200
4	Papaya, Rs 80/kg	147,200
	Total	338,560

Table 6 Cost economics of Liquid Cooled Thermoelectric Refrigeration System

Sr. No	Description	Cost (Rs)
1	Total fixed cost	33,427
2	Total variable cost	272,252
3	Total cost (fixed + variable)	305,679
4	Total fruits and vegetables required per day, in kg	40
5	Total fruits and vegetables required per year (184 days), in kg	7,360
6	Total gross income on selling of fruits and vegetables (184 days)	338,560
7	Profit in year (184 days)	32,881
8	Benefit to cost ratio	1.11
9	Breakeven point, in kg	3,700
10	Payback period, in days	85

Fig. 3 Breakeven analysis between selling cost and quantity of fruits and vegetables sold

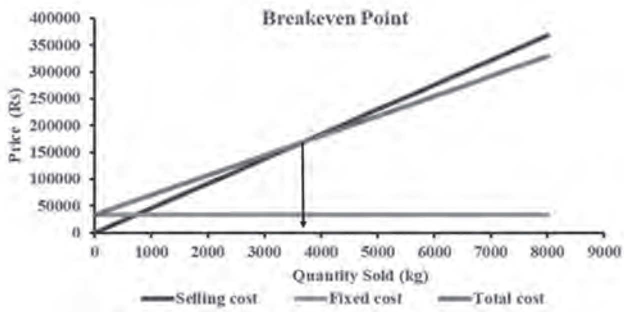


Fig. 4 Payback period analysis between selling cost and quantity of fruits and vegetables sold

Conclusions

The mobile thermoelectric refrigeration system is capable of maintaining the temperature in the range of 13 °C to 17 °C and relative humidity in the range of 75% to 85%. The system has higher coefficient of performance (COP) of 0.85, which is higher as compared to other systems available in the prior art. The invention provides a mobile thermoelectric refrigeration system useful for marketing fruits and vegetables in an efficient manner. The system is economical, has higher coefficient of performance and maintains the freshness and quality of perishable agricultural produce during marketing and transportation. Further, the refrigeration system is an eco-friendly technology and indirectly increases the shelf life of the perishable agricultural produce.

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ABSTRACTS

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2064

Specific Draft Modeling for Combined and Smple Tillage Implements Using Mathematical, Regression and ANN Modeling in Silty Clay Loam Soil: Hassan Zaki Dizaji* (hzakid@scu.ac.ir), Mohammad Esmail Khorasani Ferdavani, Nahid Aghili netegh, Mohammad Javad Sheikhdavoodi, Koroush Andekaeizadeh

Specific draft is one of the important parameters in the design of tillage tools and estimation of energy consumption in tillage operations, which makes it useful. For this reason, it’s prediction and modeling about different working conditions (depth of plowing and advance velocity) provide the possibility to determine the proper working conditions of tillage implements. In this study, two groups of tillage implements with different geometry including combined tillage implements (combined tiller and chisel packer) and simple tillage implements (moldboard plow, disk plow, chisel plow and offset disk harrow) are used. Also 3 speeds (3, 4.5 and 6 km/h) and 3 different depths (15, 20 and 25 cm) in silty clay loamy soil (47% silt, 22% sand and 31% clay) with 7% moisture content (based on dry) in the form of split twice plots design on the basis of completely randomized block with three replications was considered and the tractor’s performance parameter, including specific draft (force per unit width), was measured. empirical regression models (Linear and nonlinear), and artificial neural network (ANN) modeling were performed on each implement and were compared to other regression and mathematical models of Kheiralla, ASABE and Goryachkin. The type of tillage, depth and speed of advance showed a significant effect on specific draft. The best model was to predict the specific draft nonlinear regression developed in this study. Also, the linear regression model and ANN model obtained in this research after the nonlinear regression model were a suitable model for predicting specific draft in six types of tillage implements. Among the experimental models, ASABE was the perfect model for all simple tillage implements except for disk plow and disk harrow. Also, this model has the potential to be used for compound tillage implements.well as decrease of weight by 27.51%.

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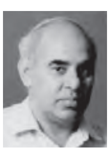
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