International specialized medium for agricultural mechanization in developing countries

ISSN 0084-5841

AMA

AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

VOL.52, NO.4, AUTUMN 2021

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Edited by

YOSHISUKE KISHIDA

Published quarterly by

Farm Machinery Industrial Research Corp.

in cooperation with

The Shin-Norinsha Co., Ltd.

and

The International Farm Mechanization Research Service

TOKYO

CIRCULATION

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Editorial, Advertising and Circulation Headquarters
1-12-3, Kanda Nishikicho, Chiyoda-ku, Tokyo 101-0054, Japan
URL: https://www.agriculturalmechanization.com/
E-Mail: ama@shin-norin.co.jp

Printed in Japan

This is the 189th issue since its maiden issue in the Spring of 1971

EDITORIAL

In Japan these days, everywhere we see nearly all people wearing masks, even when walking on streets. The same is happening in other countries; there are a lot of people wearing masks responsibly. It is heartening to see that most of us are helping to prevent the spread of coronavirus. In its long history of humankind in the world, there has never been such a sight of human beings wearing masks all over the world. Even after the end of this coronavirus turmoil, this scene would remain in human minds for long and in the history as a terrifying memory.

The relationship between humans and microbes is very complex, and such unfortunate conflict like this may happen again in the future. With the advancement of science and technology, the methods and speed of making vaccines and so on, however, have improved notably. I've read a book that says 90% of the weight of the human body accounts for several types of bacteria. You can say that the human body mostly consists of microorganisms and lives with them. There is also another report that says a human body carries about 380 trillion viruses per person. After all, human beings must coexist well with other life systems, especially microorganisms, in order to successfully survive on this earth. When it comes to the coronavirus, their evolving character means that it attaches itself to humans to proliferate easily. So if they kill humans, they will not be able to survive. Therefore, I think that by repeating mutations, they may transform into a harmless virus to humans; or at least our bodies may adapt to it.

Humans need food to survive. The food is produced from this land; and we intake many microorganisms into the body through the food. It is said that there are more than 100 trillion intestinal bacteria in our bowels. The basis of agriculture is soil, which is the world of microorganisms in itself. Better food comes from the soil that contains good microorganisms. It is said that known are only a few percent of the microorganisms in the soil. When considering the symbiosis of humans and microorganisms, the deeper research is necessary on how to make good soil with better microorganisms in it. It is sure that through these types of research, new agricultural machineries will be born.

The world population is about to exceed 8 billion and continues to increase. In order for this large number of human beings to survive on this earth, we must evolve better agriculture and better symbiosis with microorganisms that establishes strong harmony between humans and life systems. While evolving towards this better agriculture, we must conceive a more peaceful world and society without any conflict. It is worrying to image if the mankind could survive well on this planet, nevertheless we continue to grow toward 10 billion population. The amount of farmland per capita is decreasing every year. This means the most important thing is to increase the agricultural productivity. For that, the spread of new agricultural mechanization is indispensable.

On this shrinking earth, the closer cooperation among the countries of the world is needed. In addition, economic disparities are widening in various ways, which also need to be bridged.

I invite all AMA readers to work together in order to create a better world and achieve better agricultural mechanization.

Yoshisuke Kishida
Chief Editor
December, 2021

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AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

Vol.52, No.4, Autumn 2021

Evolution of Greenhouse Vegetable Cultivation in the Former USSR and Modern Russia

by

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Abstract

Russia currently prioritizes increased greenhouse vegetable production. However, limited literature is available considering the development of the industry and historical transition of technology from the USSR to modern Russia. Here, we address this research gap by identifying five distinct stages of greenhouse farming from its evolution in the 1930s in the USSR to modern Russia. We outline technologies of greenhouse heating, irradiation, irrigation, and hydroponics that were effectively utilized in the Soviet period, and analyze factors of recovery and further development of the industry, emphasizing the importance of state support for this capital-, energy- and knowledge-intensive area of agricultural production.

Keywords: USSR, Russia, protected horticulture, greenhouse heating, sanctions.

Introduction

In Russia, 33%-37% of the population's demand for vegetable products is covered by imports. During the winter-spring period, this number increases to as high as 90%-95% for certain types of products (Toropilova, 2013). Currently, ensuring food security and providing the Russian market with vegetable products is one of the main tasks faced by agricultural producers.

From 1960 to 1988, large socialist state and cooperative agricultural enterprises operated effectively in the USSR. State and collective farms were the main producers of agricultural products. Agriculture was gradually transforming from outdated, manual production to a large technically equipped industry, which played a significant role in the global economy. In 1980, the USSR ranked first in the world production of wheat, rye, barley, sugar beet, potatoes, cucumbers, sunflower, cotton and milk, second in sheep livestock, and third in the overall volume of agricultural production, livestock and grain harvest. The USSR was also a major exporter of various agricultural products such as grain, cotton, vegetables, vegetable and animal oils and fur (Tulenkova, 1980; Aliev, 1985; Bakuras, 1989; Ponomarev, 1989). As for the protected cultivation industry, in 1985, the total area of winter greenhouses reached more than 4700 ha, and the profitability of vegetable growing in greenhouse farms increased from 70% to 200% (Bakuras, 1989).

Today, the infrastructure of the greenhouse vegetable cultivation sector in Russia is represented by winter and spring greenhouses, as well as hot-beds and simple constructions such as low plastic tunnels. More than 85% of vegetables produced by protected cultivation in Russia are harvested in winter greenhouses. According to Rosstat (The Federal Service for State Statistics), the total area under greenhouse vegetable production in agricultural organizations in 2014 was 2120 ha, and the overall volume of harvested vegetables was 1.303 million tons, which is 10% more than that in 2013.

As a result of the introduction of the agricultural development program in Russia, the total harvest of vegetables grown by protected cultivation was predicted to reach 1.7 million tons by 2020 (Chekmarev, 2015).

This paper aims to examine stages of formation of greenhouse production in the USSR, to analyze main technologies used in greenhouse farming, and to determine the current state of greenhouses in modern Russia.

Stages of Formation of Greenhouse Farming in Russia and the USSR

Initial development of greenhouse production in the USSR can be divided into several stages, which are characterized by specific features and challenges.

Stage 1 (1930-1960)

The first large industrial greenhouses appeared in the country during this period. In 1930, construction of the first greenhouse complexes started in Moscow, Leningrad, Simferopol, Kislovodsk and the North Caucasus. By 1939, the total area of greenhouses in the USSR was 82.3 ha (Voronin and Bazarumbetov, 2013). Complexes located in the south of the country achieved the best results since operating costs were 40%-50% lower in the southern parts of the USSR than in the north (Ponomarev, 1989).

Greenhouse production capacity increased until 1941. In the years of the Great Patriotic War in 1941-1945, all agriculture in the USSR was severely damaged and greenhouse vegetable horticulture was practically destroyed. After the war ended, the USSR faced enormous challenges in the recovery and development of the national economy. First, in 1946, the government determined the pathways towards achieving the pre-war level of industrial and agricultural development (Voronin, 2012). The state adopted measures to strengthen potato, vegetable and livestock complexes around major cities and industrial centers, and to develop greenhouse production to supply the population with early vegetables and greens in the winter-spring period (Tulenkova, 1980). Consequently, the USSR managed to eliminate damage caused by the war to the national economy and agriculture and recover its greenhouse production within five years (Reimers, 1955).

Stage 2 (1960-1993)

In this stage, extensive restoration of greenhouse farms began across the country. The government developed and launched projects to determine standards for construction of block and arch type greenhouses using polyethylene and polyamide films and provide automatic regulation of microclimate, irrigation, and fertilization of plants (Tarakanov et al., 1982). Construction of greenhouses reached its peak during 1972-1986. Greenhouse complexes with areas of 12-54 ha were built in almost all regional centers and large cities all over the USSR, even in the northern areas such as Karelia, Chukotka and Taimir (Tulenkova, 1980; Ponomarev, 1989). During 1985?1991, several years prior to the collapse of the USSR, the largest greenhouse complexes included Yuzhniy, Moskovskiy, Leto and Belaya dacha with areas of 144, 115, 54 and 48 ha, respectively. In 1991, due to the unstable situation in the country, increased energy prices and change of ownership of agricultural organizations, 1400 ha of greenhouses ceased to exist (Bunin, Mukhortov and Rodionov, 2008). Thus, at the beginning of 1992, approximately 3200 ha of glass winter greenhouses were present in Russia (Ryzhkova, 2015).

Stage 3 (1993-2000)

This period was marked by the collapse of the USSR and the national economy. The unstable political and economic situation in the country led to a sharp deterioration of the financial and technological state of greenhouse complexes. A substantial part of the areas under the greenhouse production was disassembled or left abandoned. The volume of greenhouse agricultural production dramatically decreased and slowed down relative to foreign countries (Tarakanov et al., 2003). Thus, depreciation of fixed assets of greenhouse complexes reached 80% in 1993 and production reached its record minimum in 1996 at 459 thousand tons of greenhouse products (Voronin and Bazarumbetov, 2013).

Stage 4 (2000-2010)

Further development of greenhouse vegetable cultivation was concentrated on the reconstruction of the remaining greenhouses with the aim to reduce energy costs for heating and microclimate; however, these attempts did not have any effect on the increase in the production of vegetables (Litvinov et al., 2011).

Since 2006, Russian energy prices have been increasing annually, which has adversely affected the financial performance of greenhouse enterprises and led to a reduction of greenhouse area to 1870 ha (Detkov, 2016). At the same time, demand for flower production began to increase. Prior to this period, the flower market was 80% filled by foreign suppliers from Holland, Latin America, Ecuador, and Colombia, because the Russian flower manufacturers were unable to compete with other countries. However, the situation began to change with the formation of new flower farms, concentrated mainly in the central part of Russia (Litvinov and Shatilov, 2015).

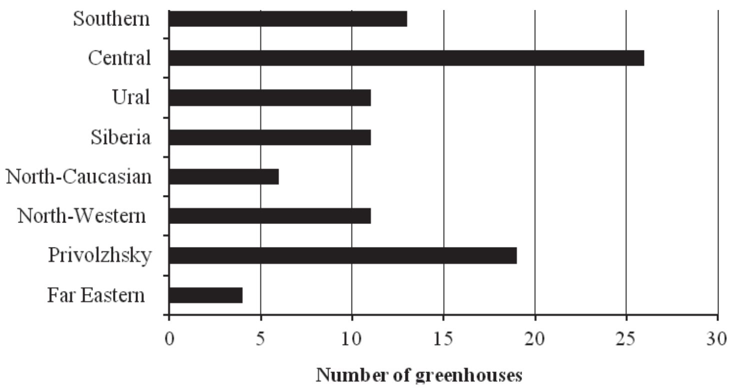
In 2010, there was a certain revival of investment activity in the greenhouse business. Many large companies started to consider greenhouse vegetable growing as the best option for diversification of production, and as a promising area for investment. This interest was caused by the implementation of the state program aimed at support greenhouse farming (Syrov, 2017).

Stage 5 (2010-2016)

In 2014, the volume of land under greenhouse production remained low at 1880 ha. The following year, the government took measures to increase production by granting state subsidies to carry out construction and modernization of greenhouse complexes. These measures increased the area of winter greenhouses to 2017 ha, and by 2016 this number reached 2376 ha. There are more than 25 greenhouse farms in the Central Federal District, about 13 farms in the Southern Federal District, and 19 greenhouses in the Privolzhsky Federal District (**Fig. 1**).

The volume of glazed winter greenhouses changed considerably in different years (**Fig. 2**). Expansion of the area of winter greenhouses is expected to continue, and the government plans to increase the extent of winter greenhouses to 4000 ha to cover the national requirement for fresh quality vegetables all year round. The total volume of greenhouse vegetable production is also planned to be increased by 1 million tons to achieve 1.7-1.8 million tons by 2020.

Fig. 1 Greenhouse farms in the regions of Russia based on members of the Association 'Greenhouses of Russia' in 2016



Source: Association "Greenhouses of Russia" 2017

Fig. 2 Volume of glazed winter greenhouses in Russia and the USSR

Source: The Federal Service for State Statistics 2016, Association "Greenhouses of Russia" 2017, Alecon, 2016

Application of Progressive Heating Technology in Greenhouses in the USSR

In the Soviet period, heating of greenhouses was one of the critical factors for improving vegetable production. Heating allowed extension of the period of greenhouse use in the winter season, and also created the necessary thermal regime, which ensured a larger and earlier harvest. Profitability of greenhouse vegetable cultivation depended directly on the reduction of the heating costs. The prices for the heating, in turn, depended on the type of fuel and the type of heating system. In 1961, the most common types of winter greenhouses heating were heat waste from industrial enterprises, condensing thermal power plants, nuclear power plants, and gas compressor stations. Technology involving heating with hot water obtained from industrial thermal power plants was applied in various ways. In some cases, after the hot water was used to heat the cultivation areas, it was returned to the enterprises partly cooled. In other cases, the entire potential of hot water was used to heat the greenhouses and then discharged into water basins or sewers (Bryzgalov, 1995). The greenhouses with water heating were set to a depth of 50 cm. Steel pipes with a diameter of 50-75 mm were mounted on brick or concrete pads at the bottom of the greenhouse with a slope for air removal and water drainage. Hot water from the boiler room or industrial enterprises was circulated through the pipes, thus heating the greenhouse (Edelstein, 1983). Since the soil on the edges of the greenhouse cooled more intensively, additional heating devices were placed around its perimeter. Lateral glazing was strengthened with plastic film (Markov, 1974).

Mixed heating of soil and air was considered to be a more effective method. A favorable temperature regime was created in the greenhouse, and air and soil were evenly heated, which enabled earlier planting of seedlings (Shefel, 1971).

Another heating technique came into practice in 1962, with the development of an electrical heating system of greenhouses, which included use of an uninsulated steel wire fed with a current of safe voltage (Ivanishin, 1963). Heating occurred when a voltage (50 V) was passed through the uninsulated steel wire (6-7 mm in diameter), which was covered with heat-resistant varnish. The wire was placed under the soil layer, thereby providing heating of the soil and air (**Fig. 3**). The use of the uninsulated steel wire in greenhouses also carried out partial sterilization of the ground, which in turn disinfected the soil (Ivanishin, 1964).

The steel wire electric heating method was applied in the construction of greenhouses in the Angarsk and Kitoy collective farms of the Irkutsk region, Kenonsky state farm in the Chita region and a number of other agricultural organizations (Ivanishin, 1960). The main disadvantages of this method were as follows: the need to use a step-down transformer, the rapid corrosion of the steel wire and the difficulty of replacing the heated material, as well as the danger of conducting maintenance while the device was switched on.

A zinc-coated wire with a cross section of 2.5-3 mm was used to make the repair process of the soil heating system convenient. The wire was twisted into a spiral and placed in asbestos cement pipes with a diameter of 50-100 mm, which were put into a layer of sand at a depth of 40-50 cm. The mains voltage amounted to 220 V. The disadvantage of this method was the laborious process of manufacturing the asphalt-concrete gutter base under the asbestos cement pipes to prevent heat loss and the absence of air heating in the greenhouse (Markov, 1974).

Air Heating of Winter Greenhouses in the USSR

In the Soviet period, various methods were used for heating greenhouses, e.g., thermal generators, gas burners and electric and gas air calorifiers. In the calorifiers, copper tubes were heated with electricity or hot water. The tubes quickly transmitted heat to the air, which was blown through the tubes by the fan, thus maintaining the microclimate inside the greenhouse (Bryzgalov et al., 1983). In thermal generators, gas combustion occurred directly within the greenhouse with subsequent conditioning and dispersal of warm air throughout the entire greenhouse volume using a fan. Due to the excessive amount of carbon dioxide and other products of combustion expelled directly into the greenhouse, this method required intermittent air infiltration and ventilation.

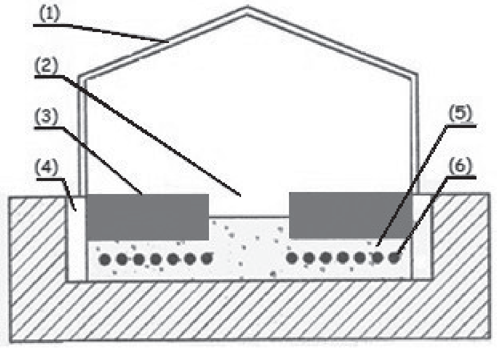
Fuel combustion in boilers was one of the most widespread air heating methods in the USSR. Hot water with a temperature of up to 100-130°C was passed through the pipes of the greenhouse. The hot water method also required adequate control of the carbon dioxide levels, which is vital for the photosynthesis of plants. In contrast to the direct-fired heating, the shortage of carbon dioxide needed to be addressed. Fresh animal manure was added to the soil with a layer of 8-12 cm to 30-50 kg/m^2, or carbon dioxide was dispensed directly into the air (Markov, 1974).

The Use of Geothermal Water as a Source of Heating in the USSR

The presence of a large number of geothermal sources in the USSR allowed the use of thermal energy reserves in the construction of greenhouse complexes. The largest thermal springs were concentrated in the North Caucasus, the Kamchatka and Magadan regions, in the area surrounding Lake Baikal, and in Western Siberia.

Geothermal water was used for heating greenhouses for the first time in 1969 in the Kamchatka region at the "Thermalniy" state farm. Water from the Sredneparatunskoye hot springs was utilized at a temperature of 780 °C for greenhouse heating (**Fig. 4**). In these greenhouses, a boiler room was used for heat exchange. A pump pushed geothermal water into large diameter pipes

Fig. 3 Schematic of the greenhouse with electric heating using an uninsulated steel wire: (1) roof, (2) passage, (3) layer of fertile soil, (4) foundation, (5) sand layer, (6) steel uninsulated wire with a diameter 5–6 mm



Source: Ivanishin, 1960

within the boiler. Inside the large pipes there were tubes of smaller diameter filled with fresh water. The heated fresh water went through the pipes to heat the greenhouse and then returned, while the used geothermal water was reinjected back to the ground. The heat consumption in such greenhouses and hotbeds was determined by the engineering characteristics and the quality of the heating and ventilation systems (Bryzgalov et al., 1983).

Currently, Russia plans to build a modern greenhouse complex with an area of 5 ha in the Kamchatka region, which will be heated by underground thermal water (Kamchatsky Krai Invest Portal).

Application of Additional Lighting in Greenhouses in the USSR

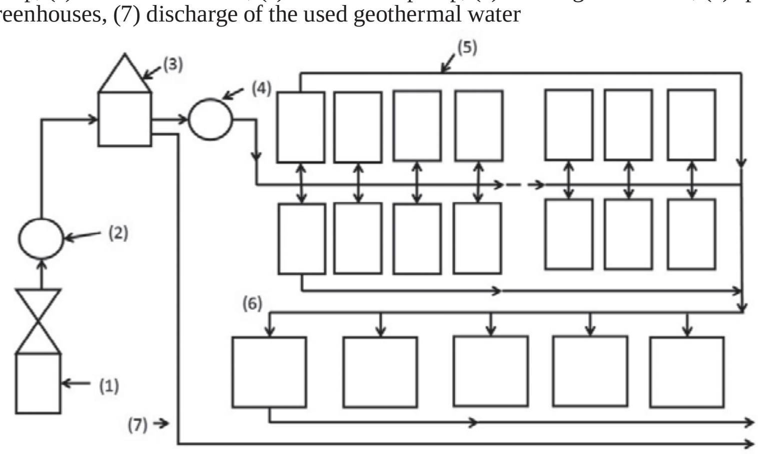
In the middle of the last century, artificial lighting in greenhouses was a widespread practice in the USSR (Prikupets, 2012). The low intensity of natural light in the greenhouses during the winter period was not sufficient for the normal vital activity of plants. In winter, artificial lighting was a crucial factor in obtaining early vegetable seedlings of good quality (Shuin and Efimov, 1960). For many years, the main type of lighting used in the greenhouse cultivation was incandescent lamps, which were inefficient and had a radiation spectrum that did not meet the needs of plants. In some cases, neon, mercury and sodium lamps of low power were used (Leman, 1952).

Another type of lamp used during the Soviet times was fluorescent lamps that were closed on top with a screen. The power of these lamps was 40-80 W and they could be heated only up to 40-45 °C. Therefore, the lamps were located close to plants at just 3-5 cm distance. Moreover, due to the low power of the fluorescent lamps, it was necessary to place up to 10-15 lamps on each frame (Markov, 1974). As the plants grew, the frames on which the lamps were mounted were raised upwards (**Fig. 5**). As a source of additional illumination, fluorescent lamps resulted in an increased rate of photosynthesis, which accelerated fruiting and increased yield. The main disadvantages of fluorescent lamps were the large dimensions of the built structures, and that the seedlings were shaded from natural daylight (Lhamazhapov, 1974).

In 1972, the first greenhouse irradiators in the country with an internal mirror surface (OT-400) were manufactured at an electrical plant in the city of Saransk. They produced a downward-directed luminous flux of about 30 lm (**Fig. 6**). The main advantage of the OT-400 irradiator compared with the previously used fluorescent lamps was the absence of shading of the seedlings, and the shading surface of the lamps was no more than 2%-4% of the illuminated area (Popov, 1986).

The OT-400 lamps were therefore used for additional irradiation of plants in greenhouses in all cold areas of the USSR. However, they also were not completely efficient and had a small luminous flux (Prikupets, 2012).

Fig. 4 Schematic of greenhouse heating with geothermal water: (1) well, (2) conveying pump, (3) boiler installation, (4) distribution pump, (5) winter greenhouses, (6) spring greenhouses, (7) discharge of the used geothermal water

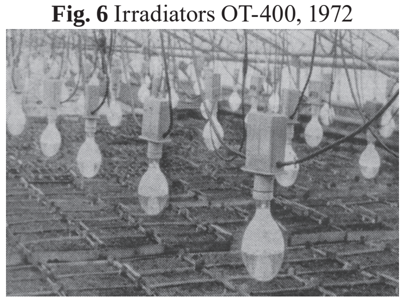


Source: Bryzgalov, Sovetkina and Savinova, 1983

Fig. 5 Plant irradiation with fluorescent lamps

Source: Markov, 1974

Fig. 6 Irradiators OT-400, 1972



Source: Markov, 1974

Plant Irrigation Technologies in the USSR

Soviet agricultural irrigation techniques included various methods: overhead sprinkling, hand watering, subsoil irrigation and impulse irrigation. The most common method of irrigation during the Soviet period was overhead sprinkling, which was used to moisten soil and air. In this method, mobile pipelines were placed at the height of 2 m from the soil surface along the perimeter of the greenhouse. Water pressure in the pipes was 1.5-2 atmospheres (**Fig. 7**). The irrigation process was adjusted to imitate the rains occurring in the summer. The sprinkling method was alternated with hose irrigation (Markov, 1974).

Subsoil watering of plants was applied in the cultivation of certain varieties of melons and beans with a lowered relative humidity. This type of irrigation included installation of asbestos-cement troughs that were placed at a depth of 30 cm at a slope and at a distance of 70-100 cm from each other. Perforated pipes were installed in the troughs. However, this method of plant irrigation did not find wide distribution because of the need for an annual installation of a watering system and the large water consumption (Markov, 1974).

Application of Hydroponics in the USSR

The development of industrial hydroponics is associated with the name of W. Gericke, a professor of the University of California. In 1929, he applied the method of aquatic culture and called the new technology "hydroponics". Professor W. Gericke managed to obtain a record harvest of 60 kg of tomatoes with one square meter. Results of his work served as the basis for improving the hydroponic method for industrial use in vegetable cultivation. Hydroponic technologies became widely used in the USA, England, Germany, France, Italy and especially in Japan, where the world largest hydroponics area of 22 ha was built near Tokyo in 1946.

Soilless plant cultivation had been studied in Russia before the USSR was created. In 1886, K. A. Timiryazev – a scientist known worldwide – organized a demonstration of experiments on soilless plant growing at Nizhny Novgorod Fair to popularize the hydroponic method. However, the first attempt to use the hydroponic method for industrial purposes in the USSR occurred in 1959 at the Moscow winter hothouses of the Teplichny state farm (Bryzgalov et al., 1983). By 1970, greenhouses covering about 1 million m^2 of land were built to use hydroponic technology. Large hydroponic plants appeared near the Moscow state farms Marfino and Belaya Dacha, near the Saint-Petersburg (then Leningrad) Leningradskiy state farm, and the Sverdlovsk state farm named after G. Ordzhonikidze. The hydroponic method was most widespread in Ukraine.

The hydroponic method was particularly effective in the far north regions, desert and mountain areas with no fertile land, and in large greenhouse farms located near large cities, where harvesting and delivery of soil were labor-intensive processes. Growing plants using artificial nutrient solutions enabled achievement of high and stable yields at low production costs (Aliev, 1985).

Waterproof tanks or concrete pools were used as water containers connected into a single unit by a channel that ran along the walls of the greenhouses and provided nutrient solution from a reservoir through the main pipeline. Containers for making and storing the nutrient solution were placed below the floor level of the greenhouse directly in the cultivation facility. The volume of the reservoir was calculated to contain 40-50 L of solution per 1 m^2 of area.

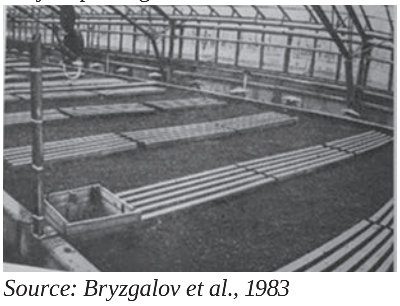
The tanks or pools had a small slope towards the reservoir, so that the solution would flow down to the reservoir. Nutrient solution was automatically fed to the plants by a flooding method using a pressure switch. When the contacts of the pressure switch were closed, a magnetic starter activated the electric motor of the centrifugal pump. When the level of the nutrients increased to 17-18 cm, the float switch became automatically activated. The solution supply would stop and the discharge started (Bryzgalov et al., 1983). At the same time, the solution acidity and its electrical conductivity were strictly controlled. The higher the concentration of the nutrient solution, the greater its electrical conductivity. When the electrical conductivity decreased to a certain value, adjustment of the solution was carried out. The advantage of this method was that it provided optimal conditions for root system growth by ensuring that plants always had sufficient moisture, nutrients and oxygen (Aliev, 1985).

Today, hydroponic methods of vegetable cultivation remain ubiquitous throughout the country. Although the basic principles of innovative hydroponics have not changed, scientifically approved well-balanced nutritious solution and modern computer-controlled feeding methods are being developed. In addition, new plastic materials covered with epoxy resin have made it possible to dispose of expensive and inconvenient metal trays, channels, and pumps. Use of durable and harmless plastic materials is safe for roots (Toropilova, 2013).

Fig. 7 Overhead sprinkling irrigation

Source: Markov, 1974

Fig. 8 A pool for placing substrate in a hydroponic greenhouse



Source: Bryzgalov et al., 1983

Conclusions on Greenhouse Vegetable Growing in the USSR

The socio-political problems that arose in the last century undoubtedly influenced the development of the greenhouse industry in the USSR. The use of technological processes, such as heating of winter greenhouses with industrial waste, hot water from geothermal power plants, natural gas and artificial heating, ensured higher vegetable production and an earlier harvest. Geothermally heated greenhouses specifically designed for the winter time constituted a unique technological method in vegetable cultivation. Finally, the hydroponic system made it possible to grow vegetables without using soil. All these important factors played an important role in the development of the greenhouse economy in the USSR (Moiseychenko et al., 1994).

Russian greenhouse complexes have not yet managed to reach the high area and production levels of the USSR. In 1985 in the USSR, the area of greenhouses was more than 4700 ha, whereas in Russia in 2017, the total area of greenhouses was 2600 ha (Agroarchive, 2017).

The Present Situation

In 2014, economic sanctions were imposed on Russia by the United States, the European Union, and some other countries to exert pressure with a view to changing the position of Russia in the international arena. One of the areas affected by the sanctions was the supply of imported vegetable products. In response, in August 2014, Russia imposed embargoed import of products from a number of Western countries. The sanctions imposed against Russia had a negative impact on various branches of trade and industry. However, they stimulated development of the national agriculture because of the lack of foreign producers on the domestic agricultural market and urgent need to fill the gap in provision of food products. Since then, the greenhouse industry has also been undergoing significant changes (Mamedov, 2014).

Because greenhouse production carries many risks, state support is crucial for an effective development of the industry. The Russian Ministry of Agriculture has developed a plan for construction or modernization of greenhouses for the period 2015-2020. According to the plan, new greenhouse areas will annually increase up to 400 ha (Chekmarev, 2015).

In order to stimulate construction of new greenhouses, the Government of Russia adopted Resolution No. 624 dated 24 July 2015 (“On Approving the Rules for Granting and Distributing Subsidies from the Federal Budget to Subjects of Russia for Reimbursing Direct Costs of Development or Modernization of Projects related to the Agro-Industrial Complex”) as an additional measure of support for investment projects. The resolution includes the following measures of state support:

- subsidizing 20% of the direct costs incurred for the construction and modernization of greenhouses and subsidizing part of the interest rate on investment loans for construction, reconstruction of greenhouse complexes and small energy facilities;
- subsidizing part of the interest rate on loans that are concluded for a period up to 1 year for purchase of fuels and lubricants; means of plant protection, mineral fertilizers and seeds (except for the elite seeds); spare parts and materials for the repair of agricultural machinery, equipment, trucks and tractors; and materials used for drip irrigation (Ministry of Agriculture of Russia, 2016).

Conclusion

Greenhouse production reached its highest level during the Soviet period using technological methods that increased the volume of production by several times. A considerable contribution to the development of the greenhouse production was made by cultivation methods, such as electric soil heating, use of geothermal water, additional artificial lighting and the hydroponic growing system.

One of the primary objectives for increasing greenhouse production in modern Russia is the introduction of innovative production technologies, as well as the development of modern resource-saving technologies that can improve the quality and quantity of greenhouse products.

Every year, new greenhouses are put into operation. In 2016, the gross harvest of vegetables grown in greenhouses reached 813.6 thousand tons. To ensure the population of Russia has access to fresh greenhouse vegetables during the winter-spring seasons, up to 1.9-2.0 million tons of vegetables is needed annually. Producers of greenhouse products will have to face many challenges on the way to achieving an effective greenhouse economy. However, notably, the area of greenhouses in Russia has been steadily growing in recent years, which suggests that it is possible for Russian greenhouse production to prosper in the future.

Acknowledgements

We thank Alex Boon, Ph.D., from Edanz Group (www.edanzediting.com/ac) for editing a draft of this manuscript.

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Specific Cutting Energy Characteristics of Cassava Stem with Varying Blade Parameters Using Impact Type Pendulum Test Rig

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Abstract

Cassava harvesting is highly labour intensive and a partially mechanized operation. The design of cutting blade needs to be optimized to obtain minimum energy requirement and high quality of cut. To obtain better performance of stem cutter this study was conducted to establish relationship between blade configurations and cutting energy requirement of cassava stem using pendulum type impact test rig. This study was carried out to investigate the effect of blade thickness, approach angle and shear angle on specific cutting energy and cutting index. The results showed that specific cutting energy increased significantly at approach angle (γ) of 30° and shear angle (β) of 20°. The effect of blade thickness on energy requirement of cassava was not significant. The combination of 20° shear angle, 30° approach angle and 6 mm thickness yielded in the minimum specific cutting energy and the best quality of cut cassava stem, respectively.

Keywords: approach angle, shear angle, specific cutting energy, cutting index

Nomenclature

T: Thickness of cutter blade (mm)
V_c: Velocity of knife (m s^{-1})
CRD: Completely Randomized design
Ω: Angular velocity of the pendulum arm (rad s^{-1})
CV: Coefficient of variance
I: Moment of inertia of the pendulum arm (kgm)
SS: Sum of square
L: Total length of the pendulum arm (m)
MSS: Mean sum of square
M: Mass of the pendulum arm (kg)
DF: Degree of freedom
ANOVA: Analysis of variance
ns: Non significant
E_c: Energy utilized for cutting the stem (J)
α: Bevel angle
g: Acceleration due to gravity (m/s^2)
β: Shear angle
γ: Approach angle
V_c: Velocity of knife (ms^{-1})
CI: Cutting Index
SV: Source of variation
SCE: Specific cutting energy (J m^{-2})
E_f: Energy lost in friction and air resistance by the Pendulum arm (J)
E_0: Energy available in the pendulum arm after cutting (J)
R: Distance between the center of

rotation and the center of gravity of the pendulum arm (m)

E_s: Energy stored in the pendulum when raised to θ° (J)

Introduction

Root and tubers crops are most vital for mankind to fulfill the ever-growing food demand after cereals and grain legumes. Cassava is called king of tuber crops having significant position in global agricultural economy and trade. It is commonly used as food thickener and as an ingredient in cassava pudding. In India, cassava is grown in more than 13 states with major share of production from southern states namely Kerala, Tamil Nadu and Andhra Pradesh. India ranks first in the world for productivity of cassava tubers with productivity of 27.92 t ha^{-1} against world average of 10.76 t ha^{-1}. In area and production, India stands 14^{th} and 7^{th} globally (Chennakrishnan, 2012).

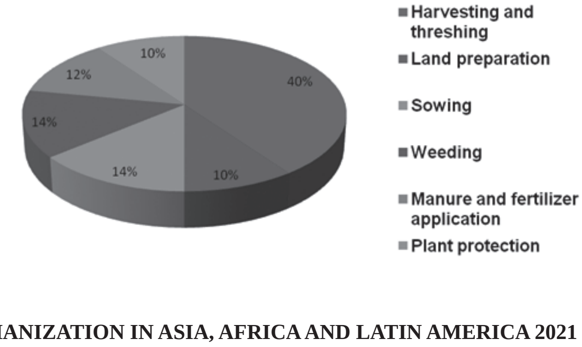
In India, cassava is mainly used for starch production in industries and is grown by small and marginal cultivars. In cassava production, harvesting operation is most labor intensive process. The conventional practice for cassava harvesting is to cut the stem upon maturity and then slightly wet the field. The cassava tubers are dug out after a week, by skilled labor with a special fork type spade/pick-axe. The conventional practice of cassava harvesting accounts for 40% for total labor used in cassava cultivation (**Fig. 1**). The conventional practice of cassava harvesting is slow, leads to drudgery and there is considerable amount of cassava tubers left in ground or damaged. Also, Untimely harvesting of cassava may lead to deterioration in quality of cassava roots and delay in sowing of next crop (Moore and Lawrence, 2003; Addy et al., 2004; CMIE, 2005; FAO, 2005).

The cassava harvesting is a two-step process, where the stem cutting is followed by tuber digging. Researchers around the globe have tried to develop various diggers as an attachment to tractors to uproot the cassava tubers. Hence, the whole process of cassava harvesting is partially mechanized as stem cutting is still done manually (Amponsah, 2014). Therefore, to fully mechanize the harvesting process, there is a need for development of cassava stem harvester. The development of such cassava stem cutter unit requires an extensive study on physical and mechanical properties of cassava stem (Persson, 1987; Dauda et al., 2015). The performance of a cutting element is a function of plant morphology, cutting energy requirement, cutting force and stress applied by cutting blade on stem surface. Hence, it is important to determine the cutting energy requirement of cassava stem for suitable design of the cutting blade and operational parameters.

Measurement of stem cutting energy has received considerable attention among researchers for successful development of harvester. The impact type pendulum test rig method for determination of stem cutting energy is widely used by researchers for establishing relationship between energy requirement and blade configurations (Koloor and Kaini, 2007; Rajpoot and bhole, 1973; Viswanathan, 1996). In impact type pendulum test rig the energy requirement of cutting is compensated by energy required for overcoming friction and stem deformation (Koloor and Kaini, 2007; Persson, 1987). The stem ruptures when the pressure of blade overcomes the threshold limit of deformation and further advancement of blade in the stem results in complete failure of stem under tension. The failure also occurs due to compression and deformation at the sides of the cutting blade (Srivastava et al., 2006; Srivastava et al., 2007). The cutting energy requirement of stem depends on the blade configuration and plays an important role in reducing the specific cutting energy by 50% for nodes and internodes (Igathinathane et al., 2010; Chattopadhyay & Pandey, 1999; Prince,Wheeler and Fisher; 1958; Womac et al., 2005, Akritidis, 1974; Dowgiallo, 2005; McRandal & McNulty, 1980; O'Dogherty, et al., 1995; O'Dogherty, 1982; Yu et al., 2003). Therefore, the blade design and its configurations significantly affect the energy requirement (Gupta & Oduori, 1992; Clementson & Hansen, 2008, Sunil et al., 2015).

The cutting energy requirement of the stem also depends on the cutting velocity and loading rate of blades (Taghijarah, Ahmadi, Ghahderijani & Tavakoli, 2011). Prasad and Gupta (1975) studied the energy requirement of maize stem and concluded that smooth cutting of stem occurred at a cutting velocity of 2.65 m s^{-1}. Yiljep and Mohammed (2005) studied the energy requirement of sorghum stem and results revealed that the stem cutting energy was minimum at 2.9 m s^{-1}, further increase in velocity resulted in higher requirement of cutting energy. Apart from the blade configuration and cutting velocity, diameter of stem and its

Fig. 1 Labor utilization in cassava cultivation



fibre content plays an major role in determining the energy requirement of blade (Prasad & Gupta, 1975; Kroes & Harris, 1996a, 1996b). The review of literature confirms that the performance of the cutting blade can be judged by their cutting energy requirements, cutting force and cutting index (Philip et al., 2012). Hence, it is necessary to determine the cutting energy requirements for suitable blade design (Yilmaz et al., 2009).

Only few attempts in past have been made to develop a cassava stem cutter as an attachment to existing cassava digger. Therefore, a study was conducted to determine the energy requirement to cut cassava stems using impact type pendulum test. The data generated from this study can be utilized for successful development cassava stem cutter with maximum cutting efficiency and minimal energy loss during harvesting.

Theoretical Considerations

The specific cutting energy and velocity of knife using pendulum test rig were determined using following theoretical consideration and derivations.

2.1 Bevel Angle (α)

Bevel angle is the angle of the bevel edge of the blade. The bevel angle of the blade decides the sharpness of the blade and the ease with which it enters the cassava stem during harvest.

2.2 Shear Angle (β)

Shear angle is the angle made between the vertical plane and the cutting plane of stem. The shear angle depends on plant height.

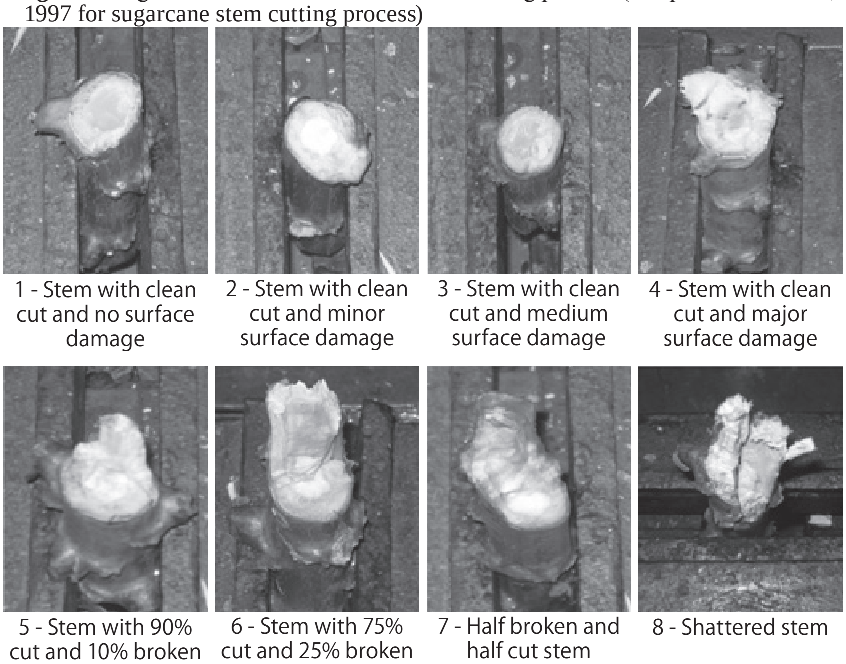
2.3 Approach Angle (γ)

Approach angle is the angle between central line of the blade and normal to the direction of motion of the blade.

2.4 Thickness of Cutter Blade (T)

The thickness of the blade affects the cutting energy at the entry point into the stem required for harvesting cassava stem. The blade of minimal thickness has no significant effect on energy requirement when cutting is done above critical speed. As the blade thickness increases, the cutting energy at entry point of the stem is affected (O'Dogherty & Gale, 1991).

Fig. 2 Damage classification in cassava stems cutting process (Adopted from Kores, 1997 for sugarcane stem cutting process)



2.5 Specific Cutting Energy (SCE)

The specific cutting energy for cutting cassava stem was computed to nullify the effect of diameter of cassava stem on cutting energy. It is expressed as the ratio of cutting energy required to cut stem to the exposed cross sectional area of the stem.

2.6 Cutting Index (CI)

The quality of cut cassava stem is an important factor in the cassava harvesting process as the cut stems are used as setts (planting materials) for cultivation of next crop. If the stem is cut at improper combination of shear angle, approach angle and thickness of blade, there is a splitting along the axial direction that causes losses. For the assessment of damage caused during cutting of cassava stem, a 8 - point damage rating scale (1 - Stem with clean cut and no surface damage, 8 - shattered stem) was used, which is an adoption of the damage classification in sugarcane cutting process proposed by (Kores, 1997) and shown in **Fig. 2**.

2.7 Conceptualisation Stem Cutting Energy Measurement (E_c)

From the measured values of θ and θ_o, the energy expenditure for cutting cassava stem was determined as detailed below and illustrated in **Fig. 3**.

At equilibrium position the potential energy stored by the pendulum arm was zero. Whereas, the potential energy stored in the pendulum arm when raised to an angle θ, was given by

$$E_s = MgL = MgR\,(1 - \cos\theta) \quad ...(3)$$

The energy lost due to friction and air resistance by the pendulum in absence of any cutting element moves through an angle θ_o from the equilibrium position was given by

$$E_f = MgR\,[(1 - \cos\theta) - (1 - \cos\theta_o)] \quad ...(4)$$

$$E_f = MgR\,[\cos\theta_o - \cos\theta] \quad ...(5)$$

When the cassava stem is placed in specimen holding unit, the pendulum arm attached with the cutting blade was allowed to fall in and move through an angle, θ_c on the upswing after cutting. The energy required for cutting cassava stem E_c was calculated by deducting initial potential energy of pendulum arm E_s with potential energy lost due to friction E_f and air resistance E_o.This was expressed as

$$E_c = E_s - (E_f + E_o) \quad ...(6)$$

$$E_c = MgR\,(1 - \cos\theta) - [MgR\,(\cos\theta_o - \cos\theta) + MgR\,(1 - \cos\theta_c)] \quad ...(7)$$

$$E_c = MgR\,(\cos\theta_c - \cos\theta_o) \quad ...(8)$$

The rotational velocity of the blade was obtained by equating potential energy with rotational kinetic energy of the pendulum arm, given by

$$Mgh = (I\Omega^2) / 2 = MgR\,(1 - \cos\theta) \quad ...(9)$$

$$\Omega^2 = 2MgR\,(1 - \cos\theta) / I \quad ...(10)$$

The peripheral velocity Vc of the cutting blade was calculated by multiplying rotational velocity of blade with length of the pendulum arm given by

$$V_c = \Omega L = \sqrt{[2MgR\,(1 - \cos\theta) / I]}\,L \quad ...(11)$$

Material and Methods

3.1 Experimental Setup

An impact type pendulum test rig was developed to determine the impact energy required for cutting cassava stem. The functional components of the test rig include main frame, swinging arm blade, stem holder and angular displacement indicator. Dead weights were placed at the free end of the swinging arm just above the blade mounting platform to change the pendulum energy. The swing arm was held at extreme upswing position (at a height of 750 mm from ground level) by means of locking arrangement. At the base of the main frame, tool maker's vice of 90 mm was fixed to hold the cassava stem. The vice was adjusted in longitudinal and transverse direction so that the cassava stem to be tested can be brought exactly below the pendulum hinge point and the blade is aligned in line with the position of the stem for cutting. The height of the vice can also be adjusted to suit the variation of the blade position for selected levels of shear and approach angle. A 200 mm diameter semicircular dial with needle was used to measure the angular displacement of the swing arm. The dial was graduated in degrees with a least count of 1°. When the swing arm was held at extreme upswing position, the angular dis-

Fig. 3 Measurement of stem cutting energy using pendulum type impact test rig

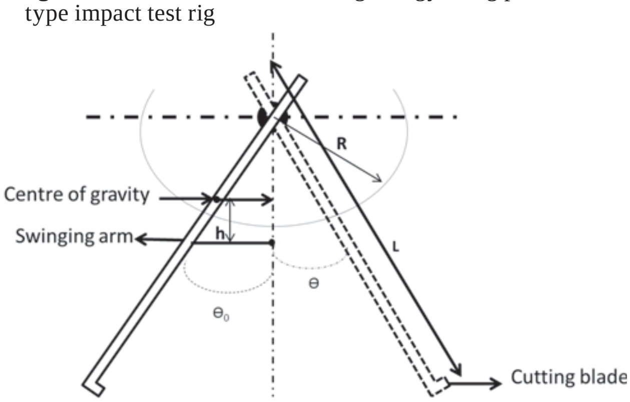


Fig. 4 Impact type pendulum test rig for cassava harvesting

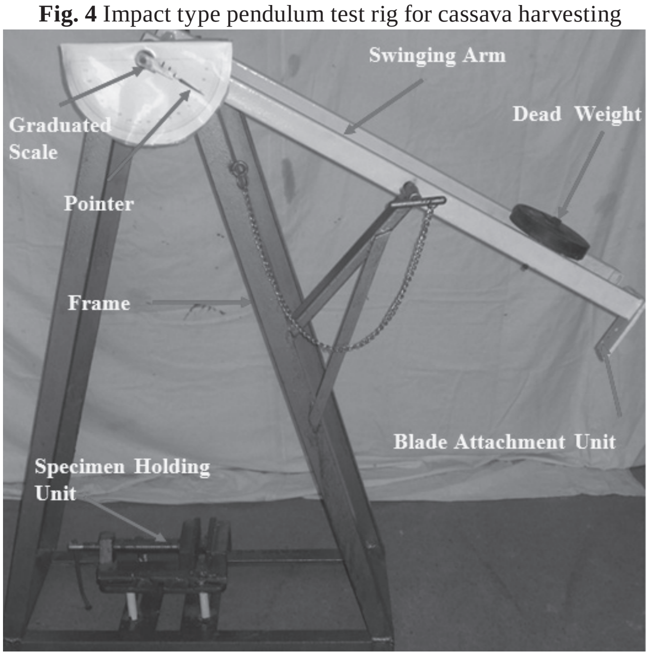


Fig. 6 Blade Setting arrangement at pendulum hinge point to get desired shear and approach angle

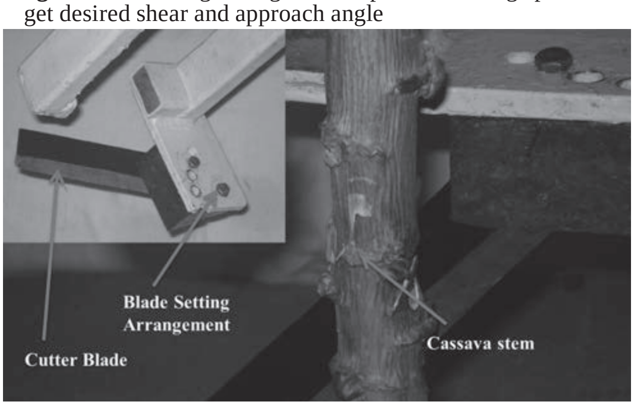
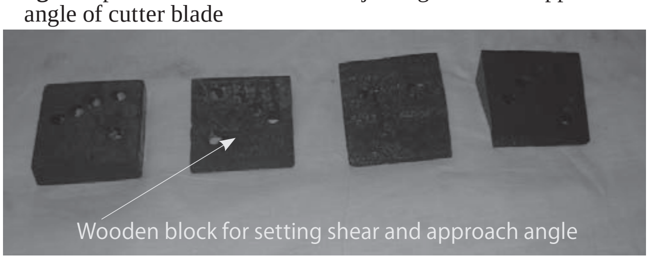


Fig. 5 Tapered wooden block for adjusting shear and approach angle of cutter blade



placement indicator makes an angle 'θ' with the dial gauge (**Fig. 4**).

Tapered wooden blocks (corresponding to selected levels of shear and approach angles) were placed on the mounting platform of the swing arm for setting selected levels of approach angle (0°, 15°, 30° and 40°) at shear angle (0°, 15°, 20° and 25°) of cutter blade (**Fig. 5**).

3.2 Cassava Cutting Energy Experiments

Freshly harvested cassava stems of CO-4 variety were collected from farmer's field of, Yethapur, Salem, Tamilnadu (India). The stems were cut close to the ground at about 15 cm from ground level as recommended in conventional cassava stem cutting. The moisture content, height and diameter of the stems were recorded. The moisture content of all the stems were maintained at almost constant level by keeping it under shade. The moisture content of each stem was recorded before placing in impact type test rig. The cassava stem was firmly clamped vertically in the vice directly below the pendulum hinge point (**Fig. 6**).

The diameter of the cassava stem at the place of cut was measured for each treatment of the investigation with vernier caliper. The bevel angle of the cutter blade was fixed at 25°. A factorial CRD experiment was designed to assess the effect of blade parameters of specific cutting energy and cutting index of cut cassava stem. The factors and their treatment levels were: (i) Thickness of blade (β): 3 and 6 mm; (ii) approach angle: (γ): 0°, 15°, 30° and 40°; (iii) shear angle (β): 0°, 15°, 20° and 25° respectively.

Results and Discussion

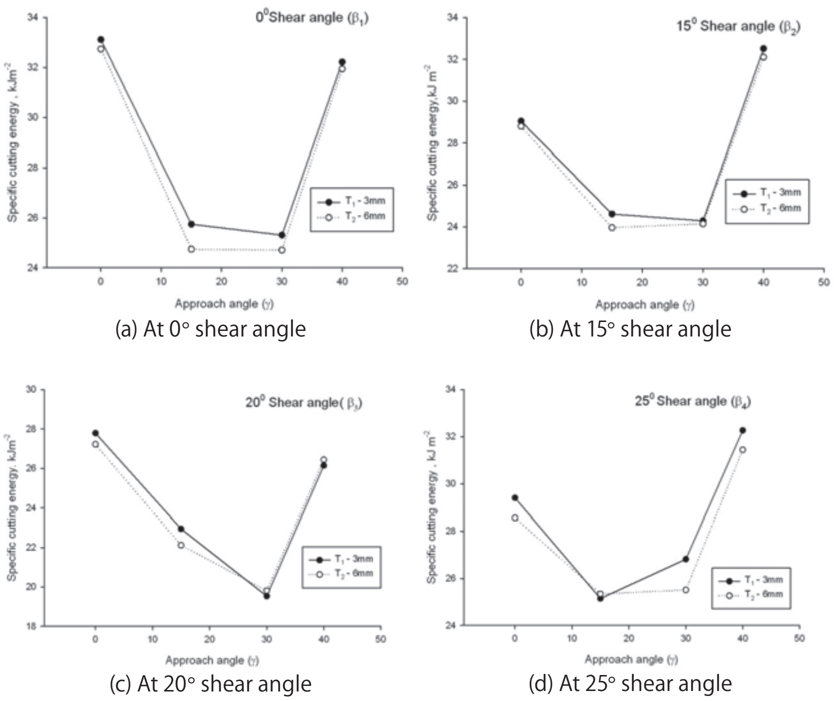
4.1 Specific Cutting Energy (SCE) at Varying Approach Angle (γ)

SCE of the cassava stem was determined using pendulum test rig at selected blade thickness, shear angle for varying approach angle as shown in **Fig. 7**.

It was inferred from the results that there was reduction of SCE for cassava stem harvesting by 22.3 and 24.4 percent for 3 and 6 mm thickness of cutter blade respectively with increase in approach angle from 0 (γ_1) to 15° (γ_2). Further increase in approach angle to 30° (γ_3) had a negligible effect on SCE. The decrease in cutting energy for small approach angles of cutter blade (up to 30°) was due to the greater wedging action of the knife edge. When the approach angle was increased from 30° (γ_3) to 40° (γ_4), an increase of 27.3 and 29.3 percent of SCE was noticed for 3 and 6 mm thickness of cutter blade respectively. The cutter blade approach angle above 40° (γ_4), resulted in sliding of cutter blade which in turn reduced the impact effect of the blade and hence higher SCE (Prasad and Gupta, 1975; Koloor and Kiani, 2007).

In general increase in approach angle from 0 (γ_1) to 15° (γ_2) led to reduction of 14.5 to 29.7 and 11.3 to 27.2% in SCE respectively for 3 and 6 mm thickness of cutter blade. It was observed that at lower approach angle (γ_1) 0° greater wedging action of the blade resulted in higher energy requirement of cassava stem. When the blade approach angle (γ) was higher, sliding occurs in turn decreases the impact effect of the blade, which increased the energy requirement of cut cassava stem. The thick outer core of cassava stem resisted the blade penetration at lower approach angle (γ), but as the blade progressed the thick spongy internal structure of cassava reduced the impact force, hence reducing the SCE. The effect of thickness of cutter blade on SCE was not significant at all selected levels of shear and approach angle. The cutter blade with 30° approach angle (γ_3) yielded minimum specific cutting energy for selected levels of 3 and 6 mm thickness of cutter blades. The cutter blade with 6 mm (T_2) thickness and approach angle of 30° (γ_3) resulted in minimum SCE of 24.7 kJ m^{-2}. As the moisture content of cassava stem were kept between 15-18 percent, the variation in SCE

Fig. 7 Effect of approach angle on specific cutting energy of cassava stem with varying shear angle and blade thickness



(a) At 0° shear angle (b) At 15° shear angle (c) At 20° shear angle (d) At 25° shear angle was non-significant with respect to the moisture content of the stem. It also indicates cutting progressed up to half of the stem diameter after which the stem failed itself under its own weight due to bending and impact of cutting arm (Liu et al., 2012; Sunil et al., 2015). The sudden rise in SCE after approach angle (γ_3) 30° is attributed to the reduction in impact cutting energy the as the blade progress from cortex to pith of cassava stem.

Table 1 ANOVA on specific cutting energy (SCE)

Sl. No.	SV	DF	SS	MS	F
i	Treatments	31	1418618313	45761881	1862.35**
ii	Thickness of blade (T)	1	3407139	3407139	138.66 **
iii	Approach angle of cutting blade (γ)	3	837777968	279259323	11364.86 **
iv	Shear angle of cutting blade (β)	3	482911354	160970451	6550.92**
v	T × γ	3	347305	115768	4.71 **
vi	T × β	3	423036	141012	5.74 **
vii	γ × β	9	90064084	10007120	407.25 **
viii	T × γ × θ	9	3687428	409714	16.67 **
ix	Error	64	1572620	24572	
	Total	95	513662562.8		

CV = 0.6%, ** = significant at 1% level

4.2 Specific Cutting Energy (SCE) at Varying Shear Angle (β)

The effect of shear angle (β) of cutter blade on specific cutting energy at varying approach angle (γ) and thickness of blade (T) is shown in **Fig. 8**.

It was inferred that there was an overall reduction of specific cutting energy by 11.2 and 12.8% with increase in shear angle from 0 (β_1) to 25° (β_4) for 3 and 6 mm thickness of cutter blade respectively. But the effect was significant with an increase of 16.1 and 16.9% of specific cutting energy when the shear angle was increased from 0 (β_1) to 20° (β_3) for 3 and 6 mm thickness of cutter blade respectively. Increase in shear angle from 0 (β_1) to 20° (β_3) of cutter blade led to reduction of frictional force of the cassava stem under impact and hence reduced specific cutting energy (impact energy). Further increase of shear angle 25° (β_4) resulted in an increase of 5.8 and 4.9% of specific cutting energy for 3 and 6 mm thickness of cutter blade respectively. This was due to the fact that the plane of least resistance coincided with optimum value of shear angle of 20° (β_3).

Though the cutter blade with thickness of 6 mm (T_2) registered lower values of specific cutting energy at all selected levels of approach angle than that of 3 mm (T_1) thickness, the effect of thickness of cutter blade on specific cutting energy was not significant. The cutter blade with 6 mm (T_2) thickness and shear angle of 20° (β_3) resulted in minimum specific cutting energy of 25.5 kJ m^{-2}.

In general increase in shear angle from 0° (β_1) to 20° (β_3) led in significant reduction of 7.2 to 23.4 and 12.8 to 19.8% in specific cutting energy respectively for 3 and 6 mm thickness of cutter blade. The specific cutting energy was maximum at 0° shear angle (β_1) of cutter blade due to maximum frictional force. The shear angle of 20° (β_3) of cutter blade resulted in lower impact cutting energy due to lesser resistance offered by the cutting plane of cassava stem. At higher shear angle of 25° (β_4) of cutter blade, the edge of the cutter blade was away from the plane of least resistance resulting in higher impact energy.

4.3 Analysis of Specific Cutting Energy (SCE)

To statistically verify the factor's influence on the SCE, an analysis of variance (ANOVA) was carried on the data. **Table 1** shows the results analysis of variance for average SCE as influenced by the stem thickness

Fig. 8 Effect of shear angle on specific cutting energy of cassava stem with varying shear angle and blade thickness

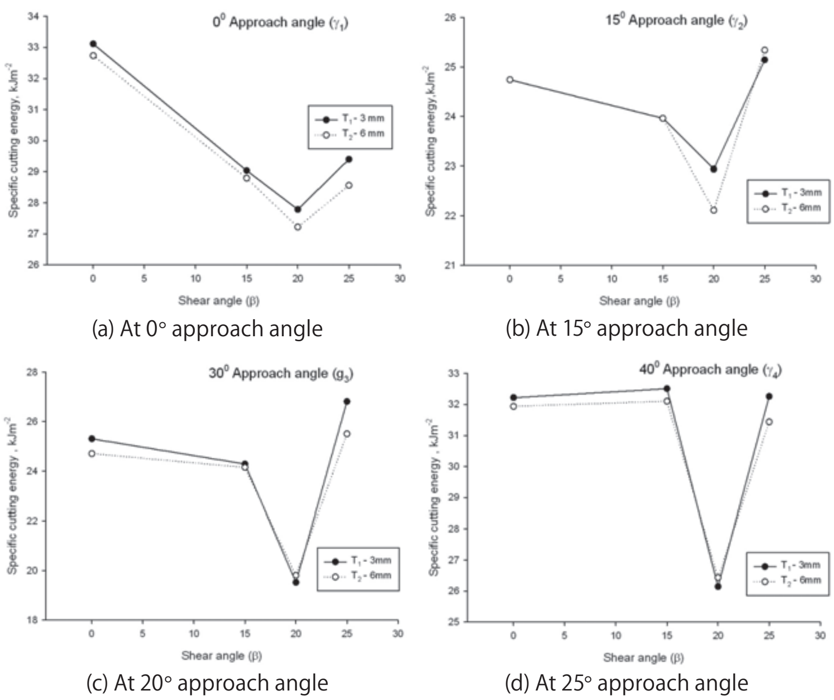


Table 2 ANOVA on cutting index

Sl. No.	SV	DF	SS	MS	F
i	Treatments	31	3.53109533	0.11390630	22.78**
ii	Thickness of blade (T)	1	0.03627038	0.03627038	7.25**
iii	Approach angle of cutting blade (γ)	3	0.64379658	0.21459886	42.92**
iv	Shear angle of cutting blade (β)	3	1.88220592	0.62740197	125.49**
v	T × γ	3	0.03893304	0.01297768	2.60ns
vi	T × β	3	0.05383904	0.01794635	3.59*
vii	γ × β	9	0.53203717	0.05911524	11.82**
viii	T × γ × θ	9	0.34401321	0.03822369	7.65*
ix	Error	64	0.31997000	0.00499953	
	Total	95	3.85106533		

CV = 11.1%, ** = significant at 1% level, * = significant at 5% level, ns = not significant

(T), shear angle (β) and approach angle (γ) at constant bevel angle (α) of the cutter blade.

All the factors significantly affected the SCE at 1% level. This confirmed that the approach angle (γ°), and shear angle (β°) of cutter blade had a significant effect on specific cutting energy (SCE). The interaction among all the factors was also shown to be significant. The trend in change of SCE with respect to shear angle (β) was not similar at different levels of stem thickness (T) and approach angle (γ). This reflects the significant interaction between the all three factors. The individual effect of the variables viz., thickness (T), approach angle (γ°), and shear angle (β°) of cutter blade on specific cutting energy (SCE) was significant at 1 percent level of probability.

Duncan's multiple range test (DMRT) was carried out for comparing the treatment means. It indicated that, approach angle (γ) of 0° the SCE requirements of cassava stem at 0°, 15°, 20° and 25° shear angle (β) were non-significant at 5% level. Similarly, the SCE means at approach angle (γ) of 150 at 0°, 15°, 20° and 25° shear angle (β) was statistically significant.

It was evident that even though for most of the treatments, the specific cutting energy values were matched for 3 and 6 mm thickness of cutter blade at selected levels of approach (γ) and shear angle (β) of cutter blade, the effect of thickness of blade on specific cutting energy was significant. This was contrary to the earlier discussion that though there was marginal variation of specific cutting energy values with increase in thickness of blade from 3 mm (T_1) to 6 mm (T_2), the effect of thickness of blade on specific cutting energy was not significant.

4.5 Cutting Index (CI) at Varying Approach Angle (γ)

The effect of approach angle (γ) on cutting index at seleted levels of shear angle (β) and thickness (T) of cutter blade is depicted in **Fig. 9**.

It was infered that with increase in approach angle from 0° (γ_1) to 30° (γ_3) of cutter blade, the value of cutting index decreased indicating enhanced quality of cut of cassava stem for 3 and 6 mm thickness of cutter blade respectively. Further increase in approach angle from 30° (γ_3) to 40° (γ_4) resulted in an increase of cutting index value indicating deterioration in cutting quality of cassava stem. The decrease in cutting index for small approach angles of cutter blade (up to 30°) was due to the greater wedging action of the knife edge. With greater wedging action, the bevel edge of the cutter blade penetrates very easily into the stem surface with minimum resistance improving the quality of cut with minimum damage. The vice provided in the pendulum test rig to hold the stem tightly might offer greater counter resistance to the blade and hence improved quality of cut. At all selected levels of approach angle of cutter blade, there was no significant variation in cutting index for 3 and 6 mm thickness of blade.

The cutter blade with shear angle

Fig. 9 Effect of approach angle (γ) on cutting index at selected levels of shear angle (β) of cutter blade in impact type pendulum test rig

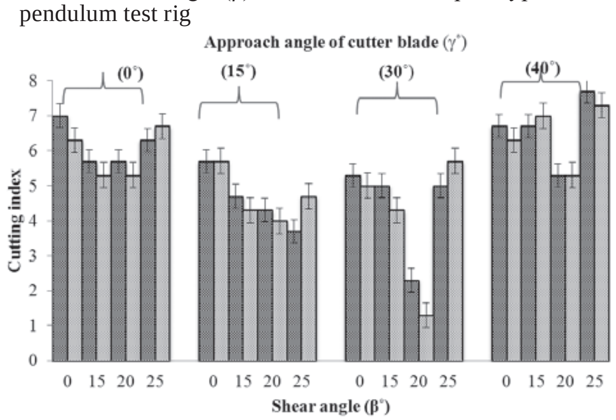
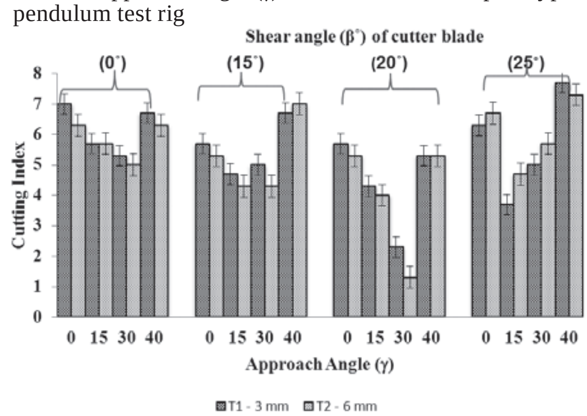


Fig. 10 Effect of shear angle (β) on cutting index at selected levels of approach angle (γ) of cutter blade in impact type pendulum test rig



of 20° (β_3) yielded the minimum value of cutting index indicating the highest quality of cut of cassava stem at all selected levels of approach angle (γ) and thickness of blade. Comparison of thickness of blade, 6 mm (T2) thickness produced the better quality of cut of cassava stem at 20° (β_3) shear angle.

The best quality of cut of cassava stem with the lowest cutting index of 1.3 was obtained for the combination level of 6 mm thickness, 20° shear angle (β_3) and 30° approach angle (γ_3) of cutter blade.

4.6 Cutting Index (CI) at Varying Shear Angle (β)

The effect of shear angle (β) on cutting index at seleted levels of approach angle (γ) and thickness (T) of cutter blade is depicted in **Fig. 10**.

There was increase in shear angle from 0° (β_1) to 20° (β_3) of cutter blade; the value of cutting index decreased indicating enhanced quality of cut of cassava stem. Further increase in approach angle from 20° (β_3) to 25° (β_4) resulted in an increase of cutting index value indicating deterioration in cutting quality of cassava stem. Similarly with increase in approach angle from 0° (γ_1) to 30° (γ_3) resulted in improved quality of cut for 3 and 6 mm thickness of cutter blade respectively. Further increase of approach angle up to 40° (γ_4) resulted in deterioration of quality of cassava stem cut. At all selected levels of shear angle of cutter blade, there was no appreciable variation in cutting index for 3 and 6 mm thickness of blade.

In general, the cutting index was maximum at 0° shear angle (β_1) of cutter blade due to maximum frictional force. At higher shear angle of 20° (β_3) of cutter blade, the lesser resistance offered by the cutting plane of cassava stem resulted in lower impact cutting energy improving the quality of cut. At higher shear angle of 25° (β_4) of cutter blade, the edge of the cutter blade is away from the plane of least resistance resulting in poor quality of cut.

4.7 Analysis on Cutting Index (CI)

The statistical analysis of the data was performed to assess the significance of the variables viz., thickness (T), shear angle (β) and approach angle (γ) on cutting index. The analysis of variance on cutting index is furnished in **Table 2**.

There was significant difference among the treatments. The individual effect of the variables viz., thickness (T), approach angle (γ°), and shear angle (β°) of cutter blade and cutting index (CI) was significant at 1 percent level of probability.

But the interaction of thickness (T) and approach angle (γ°) on cutting index (CI) was not significant and the interaction of thickness (T) and shear angle (β°) on cutting index (CI) was significant at 1% level of probability.

The cutting index values of cut cassava stem was not significant for 3 and 6 mm thickness of cutter blade at selected levels of approach (γ) and shear angle (β) of cutter blade. There was no significant variation cutting index with increase in thickness of blade from 3 mm (T_1) to 6 mm (T_2).

Conclusions

The effect of blade configurations on SCE needs to be established to design an efficient stem cutter for cassava. In order to determine the blade parameters effect on SCE, an impact type pendulum test rig was fabricated. The energy required to cut individual cassava stem at varying blade thickness (T), approach angle (γ) and shear angle (β) was determined. The combination of 20° shear angle, 30° approach angle and 6 mm thickness yielded in minimum specific cutting energy of 18.2 kJm^{-2} and minimum cutting index of 1.3. The results showed that specific cutting energy increased significantly at approach angle (γ) of 30° and shear angle (β) of 20°. Hence the treatment combination of $\gamma_3\beta_3T_2$ can be selected as the optimized combination of selected variables (specific cutting energy of 18.6 kJm^{-2} and cutting index of 1.3) for design of prototype tractor operated cassava stem harvester. The data generated from this study will serve in significant saving in energy requirement and improved quality of cut of cassava for blade design by optimizing the blade parameters. The results of this study are applicable to a selected variety of cassava; however it can serve as a reference to other varieties. Further study must be carried out to investigate the effect of peripheral velocity of cutter and forward speed of prime over on cutting energy requirement of cassava stem.

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Physiological Response of Female Farm Workers on Manually Operated Ambika Rice Weeder for System of Rice Intensification (SRI)

by

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Abstract

The system of Rice Intensification (SRI) is a method of rice cultivation. Farmers across the country are adopting SRI, as it gives equal or more yield than the conventional rice cultivation, with less water, less seed, and fewer chemicals. The major constraint farmers are facing in SRI method of cultivation is the drudgery in using mechanical-weeder. Under such circumstances, mechanization may play a key role in its large scale adoption of SRI and thereby increasing production to feed increasing population of the country. To address the recommended management issues, the farm mechanization intervention is required to make SRI technology simple to adopt. Therefore, 15 female subjects representing five age groups A1 (20-25 years), A2 (25-30 years), A3 (30-35 years), A4 (35-40 years) and A5 (40-45 years) 3 from each group were engaged for entire study to assess the physiological cost and body discomfort by manually operated rice weeder. Physiological workload based on heart rate data, energy expenditure, time of weeding in every task, recovery period of normal heart rates and work output of the subjects were studied. The heart rate of female belongs to A5, A4, A3, A2 and A1 years were 123.35, 119.07, 116.13, 108.39, 110.91 beats/min and energy expenditure were 10.88, 10.19, 9.74, 8.49 and 8.90 kJ/min, respectively. Mean overall discomfort rating of operation of manually operated weeder on a 10 point visual analog discomfort scale (0- no discomfort, 10- extreme discomfort) was 5.37 and scaled as "moderate discomfort". The study revealed that the heart rate of all the subjects during weeding operation was stabilized around 117 ± 7 beats/min within 8-10 minutes of weeding. The physiological workload of farm women in operation was within the capability of average female farm workers.

Introduction

Rice is the most important cereal food crop in India. It plays a vital role in the national food grain supply. There is a considerable increase in the productivity of rice in India during the recent past. The system of Rice Intensification (SRI) is claimed to be another viable alternative for increasing rice yield. However, farmers faced some difficulties during the on-farm evaluation and large scale adoption of SRI. Common problems faced by the farmers to follow the SRI principles are transplanting of young seedlings, grid formation to check row transplanting, mechanical weeding, formation of drainage channel etc. The adoption of SRI cultivation is adversely being affected by scare labour availability at a cheaper rate. Delay and negligence in weeding operation affect the crop yield up to 30 to 60%. In Chhattisgarh, 54% of the total workforces are engaged in agriculture. Among all agricultural activities, weeding is predominant responsibility of farm women. The performance of a weeder not only depends on the constructional features but also on the workers operating them. The performance of the man-implement system may be poor if physiological demand to implement is not given due attention.

Weed control in rice cultivation accounts for about 25% of the total labour requirement (900-1200 man hours/ha) of a cultivation season. With the initiation of mechanization in row seeding and row transplanting of rice, interest in mechanical weeder is seen amongst the farmers. Moreover, the weeders besides killing the weeds loosen the soil between rows thus, increasing the microbiological activities, air, and water intake capacity. The weeding tools available have been primarily developed for male workers. As a result, the outputs of female farm workers are low and many occupational health problems occur. The heart rate is the reliable physiological index for measurement of the stress and energy expenditure.

Mohanty et al. (2015) ergonomically evaluated physical strain of four different types of manual weeders with respect to their physiological parameter. They noticed the physical strain of different male and female agricultural workers during weeding operation. The physiological as well as mechanical performance parameters were Working Heart Rate (WHR), Oxygen Consumption Rate (OCR), Energy Expenditure Rate (EER), Relative Cost of Work Load (RCWL) was measured with all 12 subjects in the age group of 18-45 years. Four weeders including *Khurpi*, Trench, Wheel hoe and Wheel finger weeders were evaluated with male and female workers. The mean value of WHR was observed to be minimum 85.6 beats/min in case of *Khurpi* and maximum 130.8 beats/min in case of Wheel Hoe. The actual field capacity was recorded maximum 0.0311 ha/h in case of Wheel finger weeder followed by 0.0149 ha/h in Wheel hoe and lowest 0.0038 ha/h in case of *Khurpi*. The body parts feeling maximum discomfort during Wheel hoe and Wheel finger weeder was observed to be maximum in the shoulder, arm elbow, mid-back, and lower back. Kumar et al. (2013) reported that two types of manual weeder (Cono-weeder and *Mandava* weeder) for shallow water conditions were evaluated for different age group of workers (25 to 30, 30 to 35, and 35 to 40 years) at different day timings (T1 = 8.00 to 11.00 AM, T2 = 12.00 to 2.00 PM, and T3 = 4.00 to 6.00 PM). The weeding operations by different age group of workers at different working hours showed that the heart rates corresponding to Cono-weeder and *Mandava* weeder were 154.54 beats/min and 140.17 beats/min, respectively. Oxygen consumption rate was 1.76 l/min and 1.47 l/min respectively. Karhale et al. (2015) revealed that Cono weeder performed the task with comparatively higher field capacity, better performance index in the early stages of weed infestation. The field performance analyses have shown that weeding efficiency as 72.2% for Cono weeder with damage factor of 4.1% respectively. It was found that a male subject took an average of 80.8 h/ha respectively for weeding operation with Cono weeders; whereas the female subject took 125 h/ha. The performance analysis results demonstrated that weeding tools can produce large reductions in the weeding costs and significant reductions in labour time, whereas hand weeding reached the best efficiency in weed control.

Materials and Methods

The subjects designated as S1 to S15 respectively and the age groups were designated as, A1 (20-25 years), A2 (25-30 years), A3 (30-35 years), A4 (35-40 years) and A5 (40-45 years). Three female subjects each from five age groups were chosen. These subjects belonged to the 50th percentile as it was the major representative group and the measure of central tendency of the whole group of subjects. All the selected subjects were screened for normal health with medical investigations, including blood pressure, pulse rate, etc. These subjects were engaged in the field trials for weeding operation. Their physiological cost was estimated for evaluating the age groups for better performance and efficiency along with higher comfort and safety to the operator. Field experiments were carried out to assess physiological workload of the selected subjects in terms of heart rate (HR), Oxygen Consumption Rate (OCR), Energy Expenditure Rate (EER), blood pressure response during weeding operation. Details of the design of experiments for evaluating the performance of weeding operation are presented in **Table 1**.

The Experimental Procedure for Evaluation of the Physiological Cost

The following steps were followed to evaluate the physiological cost of the subjects:

1. The selected female subjects were asked to report to the field in the morning at 7:30 AM. It was ensured that they were in sound health, had sound sleep in the previous night, and had a normal breakfast.
2. The subjects were explained about the objectives of the experiment and made familiar with the operation to ensure their full co-operation.
3. The environmental temperature and relative humidity were re-

Table 1 Design of the experiment for evaluation of the physiological cost

Response	Independent variable	Levels	Description
Heart Rate (HR)	Age groups	5	A1 (20-25), A2 (25-30), A3 (30-35), A4 (35-40), A5 (40-45)
Oxygen Consumption Rate (OCR)	Timing slots in a day	3	T1 (8 AM to 10 AM) Rest - 10 AM to 11 AM, T2 (11 AM to 1 PM) Rest - 12 PM to 2 PM, T3 (3 PM to 5 PM)
Energy Expenditure Rate (EER)	Methods	1	Mechanical weeding by manual rice weeder

corded.

4. The rice weeder was put in proper test condition before conducting the test.
5. Before the start of the field operation subjects was allowed to take rest for 30 minutes.
6. The Resting Heart Rate, Working Heart Rate, Blood pressure was noted using a stethoscope and automatic blood pressure monitor for the entire work period.
7. On the first day of experiment total five subjects, one subject from each age group was selected to conduct the weeding operation.

Each subject operated the weeder in the experimental wet land rice field in between the rows shown in **Fig. 1**.

8. Observations were recorded at every 7-9 minute of continuous operation and then took rest till the heart rate returned to normal.
9. During the two hours of operation, heart rate was continuously recorded. All readings were noted and averaged to get the mean heart rate for that time. Mean HRrest and HRwork of the subject was recorded.
10. Heart Rate for all the remaining subject was taken as per above steps.
11. Increase in heart rate (ΔHR) was computed from the difference between the mean working heart rate and resting heart rate.
12. For finding recovery time of heart rate, heart rate of the subjects was measured regularly at 2 minutes of interval till the heart rate shows a constant reading at each trial of the 7-9 minute of regular operation.
13. The same procedure was repeated with other subjects to get three readings from each age group of female agricultural workers.

Table 2 Heart rate response (beats/min) during weeding operation

Factors	Resting heart rate, HR_{work}			Working heart rate, HR_{rest}			Increase in heart rate, ΔHR		
	R1	R2	R3	R1	R2	R3	R1	R2	R3
A1T1	82.40	83.76	84.61	108.80	107.61	111.75	26.40	23.85	27.14
A1T2	81.76	82.43	85.28	112.32	110.04	116.74	30.56	27.61	31.46
A1T3	78.95	84.66	86.52	107.50	108.67	114.77	28.05	24.01	28.25
A2T1	75.36	76.85	80.82	104.34	108.50	110.32	28.98	31.15	29.50
A2T2	75.61	74.47	81.63	106.50	110.64	111.45	30.39	36.17	29.82
A2T3	74.80	76.57	82.63	105.89	107.93	109.95	31.09	31.36	27.32
A3T1	78.90	82.89	82.40	114.89	115.89	116.92	35.99	33.00	34.52
A3T2	77.22	81.04	83.95	116.32	117.72	118.14	39.10	36.68	34.19
A3T3	77.52	80.90	79.81	113.20	114.27	117.89	35.68	33.37	38.08
A4T1	74.34	76.88	80.34	118.50	113.84	120.23	43.66	36.96	39.89
A4T2	74.54	80.28	82.23	122.23	118.33	123.45	47.69	38.05	41.22
A4T3	74.95	77.76	81.52	117.50	116.21	121.34	42.05	38.45	39.82
A5T1	80.43	80.47	81.90	119.54	124.34	122.50	39.11	43.87	40.10
A5T2	81.47	80.38	80.81	122.23	128.32	125.34	40.76	47.94	44.53
A5T3	78.99	79.45	79.89	120.13	126.43	121.34	41.14	46.98	41.45

Table 3 Mean working heart rate of the selected female workers

Factors	Timing slots in a day		
	T1 (8-10 AM)	T2 (11 AM - 1 PM)	T3 (3-5 PM)
A1 (20-25)	109.38	113.03	110.31
A2 (25-30)	107.72	109.53	107.92
A3 (30-35)	115.90	117.39	115.12
A4 (35-40)	117.52	121.33	118.35
A5 (40-45)	122.12	125.29	122.63

Work Rest Cycle

For every strenuous work in any field requires adequate rest to have an optimum work output. The actual rest time taken for each subject was found from the heart rate response curves of respective operations. The rest time was measured from the ceasing of the operation till the heart rate of the subject reaches resting level. The rest pause to the subject was calculated using the following formula:

$$R = T(E-A) / (E-B)$$

Where,

R = Resting time (min)

T = Total working time/day (min)

E = Energy expenditure during the working task (kcal/min)

A = Average level of energy expenditure considered acceptable (kcal/min)

B = Energy expenditure during rest (kcal/min)

Heart Rate

A stethoscope was used to measure the average heart rate during the rest and working condition (beats/min).

ΔHR (beats/min) = Average working heart rate − average heart rate during rest

Fig. 1 Physiological cost assessment of the selected subjects during weeding operation

Table 4 CD and SE values of HR_{work} of the selected subjects

Factors	CD 5%	CD 1%	SE (d)	SE (m)
Factor A (age group)	2.078	2.808	1.013	0.716
Factor T (Time slot)	1.606	2.173	0.785	0.555
Treatments / (A × T)	3.591	4.850	1.755	1.241

Table 5 Energy Expenditure Rate (kJ/min) during weeding operation

Factors	Resting energy expenditure rate, EER_{rest}			Working energy expenditure rate, EER_{rest}			Increase in energy expenditure rate, ΔEER		
	R1	R2	R3	R1	R2	R3	R1	R2	R3
A1T1	4.38	4.60	4.73	8.58	8.39	9.05	4.2	3.79	4.32
A1T2	4.28	4.39	4.84	9.14	8.78	9.84	4.86	4.39	5.00
A1T3	3.83	4.74	5.04	8.29	8.56	9.53	4.46	3.82	4.49
A2T1	3.26	3.50	4.13	7.87	8.45	8.82	4.61	4.95	4.69
A2T2	3.30	3.12	4.26	8.13	8.87	9.00	4.83	5.75	4.74
A2T3	3.17	3.45	4.42	8.12	8.44	8.76	4.94	4.99	4.34
A3T1	3.83	4.46	4.38	9.55	9.71	9.87	5.72	5.25	5.49
A3T2	3.56	4.17	4.63	9.77	10.00	10.06	6.22	5.83	5.44
A3T3	3.61	4.14	3.97	9.28	9.45	10.02	5.67	5.31	6.05
A4T1	3.10	3.50	4.05	10.04	9.38	10.4	6.94	5.88	6.34
A4T2	3.13	4.04	4.35	10.71	10.09	10.91	7.58	6.05	6.55
A4T3	3.20	3.64	4.24	9.88	9.76	10.57	6.69	6.11	6.33
A5T1	4.07	4.07	4.30	10.29	11.05	10.68	6.22	6.98	6.38
A5T2	4.23	4.06	4.13	10.71	11.68	11.21	6.48	7.62	7.08
A5T3	3.84	3.91	3.98	10.38	11.38	10.57	6.54	7.47	6.59

Blood Pressure (mm of Hg)

Blood pressure is the pressure exerted by the blood on the walls of the blood vessels. The pressure of the blood in other vessels is lower than the arterial pressure. The peak pressure in the arteries during the cardiac cycle is the systolic pressure and the lower pressure (at the resting phase of the cardiac cycle) is the diastolic pressure. A Digital Automatic Blood Pressure Monitor was used to record systolic and diastolic blood pressure and pulse rate.

Oxygen Consumption Rate (l/min)

The oxygen consumption rate (amount of oxygen consumed by the whole body per unit time) was computed from the heart rate values of the operator and is given by the following equation (Singh et al., 2008).

$$OCR (l/min) = 0.0114 \times HR - 0.68$$

Energy Expenditure rate (kJ/ min)

The energy expenditure rate (EER) was determined by multiplying the OCR Work with the calorific value of oxygen as 20.93 kJ/l (Nag and Dutt, 1979).

Results and Discussions

Heart Rate

The heart rate responses of female subject of five different age groups (A1, A2, A3, A4, and A5) in three slots of 2 hours in a day (T1, T2 and T3) during weeding operations were observed. **Table 2** shows that the mean resting heart rate HR_{rest} (beats/min), mean working HR_{work} (beats/min) and mean an increase in heart rate (ΔHR)

The resting heart rates were observed different for the different age groups of workers ranging between 74 to 82 beats/min at 8:00 to 10:00 AM, which increased from 75 to 88 beats/min at 11:00 to 1:00 PM and 74 to 87 beats/min between 3:00 to 5:00 PM. The heart rate was calculated after 7-9 minute of the continuous work period and given a rest of 4-5 minute by considering that the worker heart rates get stable after rest. **Table 3** represents the average working heart rates of different age groups in three slots of 2 hours in a day (T1, T2 and T3). The average working heart rate was lowest for subjects of age group A2 (25-30) years and highest for the subjects of age group A5 (40-45) years at all work timings. The mean value of the heart rate of the different age group of the operator on different timing in a day (T1, T2 and T3) was 114.53, 117.31 and 114.86 beats/min, respectively.

Statistical Analysis for Mean Working Heart Rate Responses of Female Workers

In order to see the significance of heart rate on different factors during weeding operations, the data were analyzed with statistical software OPSTAT and ANOVA for HR responses' is presented in **Table 4**. Analysis of variance indicates that heart rate was significantly affected for both the factor A (age group) and T (timing slots in a day). The first factor- age groups (A1 to A5) showed a significant difference in the heart rate of the operator. The age group A2, between 25 to 30 years has a low heart rate as compared with A1, A3, A4 and A5. The second factor- the timing also showed a significant effect on heart rate of the operator. The timing T1 (8:00 to 10:00 AM) was highly significant with low heart rate followed by T3 (3:00 to 5:00 PM) and T2 (11:00 to 1:00 PM) due to the change in the environmental conditions. The interaction effect A × T shows that workers aged between 25 to 30 years weeding at 8:00 to 10:00 AM and at 3:00 to 5:00 PM were having significantly low heart rate followed by workers aged group A1, A3, A4, A5 while weeding at 8:00 to 10:00 AM.

Energy Expenditure Rate

The EER responses of female subject of five different age groups during weeding operations were calculated with the help of heart rate. **Table 5** shows the mean resting energy expenditure, working energy expenditure and mean increase in energy expenditure rate, ΔEER (kJ/min) of the three subjects each of five different age groups in three slots of 2 hours in a day (T1, T2 and T3) at 15 days, 25 days, and 35 days after transplanting in weeding operations.

Mean Resting Energy Expenditure Rate, EER_{rest} and Working Energy Expenditure Rate, EER_{work} Responses of Female Workers

The resting EER_{rest} were different for the different age groups of workers ranging between 3.06 to 4.41 beats/min at 8:00 to 10:00 AM, which increased from 4.07 to 4.99 kJ/min at 11:00 to 1:00 PM and 3.65 to 4.53 kJ/min between 3:00 to 5:00 PM. **Table 6** presents the average EER_{work} at of different age groups at the different time of work with manually operated Ambika Rice weeder.

Table 6 Mean working energy expenditure rate (EER_{work}) of selected female workers

Factors	T1	T2	T3	Mean A
A1 (20-25)	8.67	9.25	8.79	8.90
A2 (25-30)	8.38	8.66	8.44	8.49
A3 (30-35)	9.70	9.94	9.58	9.74
A4 (35-40)	9.94	10.57	10.07	10.19
A5 (40-45)	10.67	11.20	10.77	10.88

The average EER_{work} was lowest for subjects of age group A2 (25-30) years and highest for the subjects of age group A5 (40-45) years at all the timings slots, this might be due to variations in the environment temperatures. The mean value of EER_{work} of the different age group of the operator on different timing in a day (T1, T2 and T3) was 9.47, 9.92 and 9.53 kJ/min, respectively. The highest EER was found to be, 10.88 for the age group A5, followed by 10.19 kJ /min for age group A4, 9.74 for A3, 8.49 for A2 and 8.90 kJ/min for A1 in manually operated Ambika rice weeder when three timing (T1, T2 and T3) were averaged.

Blood Pressure and Pulse Rate

Mean value of blood pressure and pulse rate responses of all the selected female subjects during weeding operations were observed. **Table 7** shows that the mean working blood pressure of the subjects.

Table 7 The mean working blood pressure of the subjects

Subjects	Diastolic Blood Pressure (mm Hg)			Systolic Blood Pressure (mm Hg)		
	T1 (8-10 AM)	T2 (11 AM - 1 PM)	T3 (3-5 PM)	T1 (8-10 AM)	T2 (11 AM - 1 PM)	T3 (3-5 PM)
S_1	76	75	76	120	122	122
S_2	82	78	79	129	131	131
S_3	81	78	76	127	123	128
S_4	83	80	83	120	124	125
S_5	84	83	83	129	131	135
S_6	83	81	84	130	121	132
S_7	78	76	79	122	121	120
S_8	80	78	81	123	123	124
S_9	77	76	80	124	122	120
S_{10}	76	76	76	125	128	131
S_{11}	79	78	81	129	132	133
S_{12}	77	77	82	128	128	126
S_{13}	83	78	80	124	125	130
S_{14}	82	80	78	127	131	135
S_{15}	81	81	83	126	126	127

The Recovery Time of Subjects During Weeding Operation

The mean recovery time required by female agricultural workers of five different age groups (A1, A2, A3, A4, A5) during weeding operation range of, 4, 4, 4-5, 5 and 5-6 min respectively (**Fig. 2**). The recovery time was almost the same for all female subjects, but as the age increases it shows little variation. The female workers belong to higher age groups A4 (35-40) and A5 (40-45) required a longer time to reach their resting HR as compared to A1 (20-25), A2 (25-30), A3 (30-35) year age groups. For better comfort of the subjects, the weeding tools should be operated in proper posture and proper resting as far as possible.

Assessment of Body Discomfort During Weeding by Selected Female Farm Workers

Assessment of body discomfort of the operator during continuous

Fig. 2 Mean heart rate (Beats/min) and working and recovery time (min) during weeding

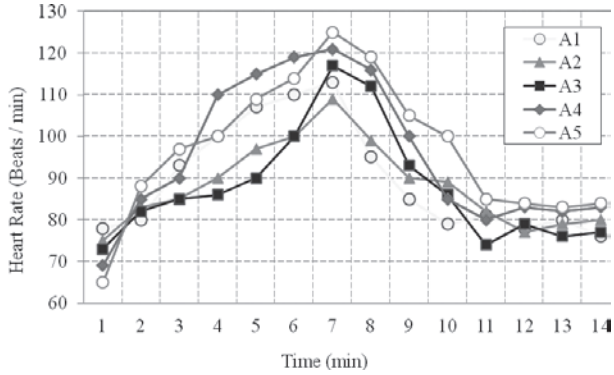

Table 8 Mean value of overall discomfort rating (ODR) for the subjects during weeding operation

Different age groups	Time slots in a day		
	T1 (8-10 AM)	T2 (11 AM - 1 PM)	T3 (3-5 PM)
A1 (20-25)	77.91	1.34	2.003
A2 (25-30)	80.47	1.26	2.064
A3 (30-35)	83.90	1.33	1.533
A4 (35-40)	78.14	1.29	1.761
A5 (40-45)	78.56	1.29	1.562

Table 9 Weeder performance and evaluation during weeding operation

Different age groups	Weeding efficiency	Damaged plant	Effective field capacity (ha/h)	Theoretical field capacity (ha/h)	Field efficiency (%)	Operating speed (km/h)
A1 (20-25)	77.91	1.34	0.014	0.022	63.6	2.003
A2 (25-30)	80.47	1.26	0.015	0.023	65.2	2.064
A3 (30-35)	83.90	1.33	0.011	0.021	63.8	1.533
A4 (35-40)	78.14	1.29	0.012	0.020	62.0	1.761
A5 (40-45)	78.56	1.29	0.012	0.020	60.0	1.562

Note: Data are average of three replications.

operation field experiments was carried out to assess overall discomfort rating (ODR) and body part discomfort score (BPDS) for female subjects of five different age groups during weeding operation for all the selected subjects. The female subjects A1, A2, A3, A4 and A5 could not conduct the weeding operation continuously for 2 hours as they experienced extreme discomfort and refused to continue the operation. The collected data were analyzed in order to see the effect of different age groups and different slot of working in a day.

Overall Discomfort Rating (ODR) During Weeding Operation

Discomfort level of farm women during weeding operation by different age groups of female farm workers was recorded on a 10 point scale, "0" for no pain, "1" for very small and "10" for the maximum discomfort level. Body parts discomfort scale is a subjective symptoms survey tool that evaluates the respondents direct experiencing with the discomfort of pain. Pain has both physical and emotional components. The overall discomfort ratings given by each of the four subjects were added and averaged to get the mean rating. The assessment of ODR was shown in **Fig. 3**.

Table 8 represents the Mean ODR of different age groups. The peak ODR was found to be, 5.62 for the age group A5.

Field Performance of *Ambika* Rice Weeder

Tests were conducted in clay loam soil. The fields were submerged with water. In order to evaluate the performance of the weeder 15 female operators of average health were used. A randomized complete block design was used in the test with 5 treatments replicated thrice. The test results indicate weeding efficiency of 78-84%. There was negligible plant damage during operation by the weeder. The field capacity of the weeder ranged between 0.011 to 0.015 ha/h (**Table 9**). This range in field capacity may be attributed partly to the subject's capabilities and partly to the moisture variation and weed density in the field. It was noticed that weeder performed better if the field is submerged with water at about 20-30 mm depth. It was observed that there is no difference in the working depth of Ambika rice weeder on female agricultural workers of different age groups at three different timing in a day was observed. The effective width of operation of Ambika rice weeder was 11.8 cm. The performance of the Ambika rice weeder is given in **Table 9**.

Conclusion

1. The mean working heart rate (HR_{work}) of female belongs to different age groups were 110.91, 108.39, 116.13, 119.07, 123.35 beats/min for age group A1 (20-

Fig. 3 Visual analogue discomfort scale for assessment of overall body discomfort

25), A2 (25-30), A3 (30-35), A4 (35-40) and A5 (40-45) respectively. Based on mean heart rate the operation was graded as "moderately heavy". The mean heart rate on different slots in a day was 114.53, 117.31, 114.86 beats/min at T1 (8:00-10:00 AM), T2 (11:00-1:00 PM) and T3 (3:00-5:00 PM) respectively for weeding with manually operated Ambika rice weeder.

2. The increase in energy expenditure rate (ΔEER) was found to be, 4.36, 4.87, 5.66, 6.49 and 6.81 kJ/min for the age group A1, A2, A3, A4 and A5 respectively
3. The female workers belong to higher age groups require a longer time to reach their resting heart rate.
4. The mean ODR and BPDR were 5.204, 72.12 respectively, the lowest for subjects of age group A1 (20-25) years and mean ODR and BPDR was 5.626, 89.02 respectively, and the highest for the subjects of age group A5 (40-45) years at all work timings. During overall field operation with manually operated Ambika rice weeder ODR was 5.37.
5. The average weeding efficiency ranges from 77% to 84 %.

Acknowledgment

The authors are grateful to Tata Trusts, Mumbai, SRI Programme-Selective Mechanization in SRI, for granting financial assistance during the course of the investigation.

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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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Prototype Manually Operated Check-row Planter for Dry Seeding of Rice: Nitin Kumar Bharti, Utpal Ekka, P. K. Sahoo, Indra Mani, Swati Nirbhavane

Direct seeding and transplanting are two methods of sowing of paddy under dry and wet land conditions. Transplanting of the seedlings in puddle fields is traditional method of sowing of paddy, followed by most of the farmers. Manual transplanting and dry seeding of paddy by a manual method is a tedious job and requires about19.23 and 23.14 man-days per hectare and cost around 34.47$.ha^{-1} and 41.49$.ha^{-1} respectively. Acute shortage of agricultural labour during the peak planting season, the farmers have to face great difficulties in timely sowing of paddy. A check row planter capable of planting two rows of paddy seeds at a spacing of 25 × 25cm was developed and evaluated. Three research plots were selected for evaluation the machine. The TFC and EFC was evaluated as 0.048 ha.h^{-1} and 0.023 ha.h^{-1}, at a speed of 0.97 km.h^{-1} with FE of 47.38%. The machinery cost per hour was measured as 0.26 $.h^{-1}, for sowing one ha of land, the check row planter required 9.76 $/ha^{-1}, which was much lesser as compared to manually transplanting in SRI and dry seeding method which required 34.47$ and 41.49$ per ha respectively. The developed machine saved 66.75% and 72.38 % in cost of transplanting over manual transplanting and dry seeding methods respectively. The machine was found to be efficient, economical and also, energy efficient. The maximum energy consumed, 362.83MJ.ha^{-1} was recorded under dry seeding by manual method of sowing followed by 301.52 MJ.ha^{-1} in transplanting manually in SRI and 97.65 MJ.ha^{-1} energy consumed by check row planter in dry seeding of rice.

Characterisation of Ventilated Multi-Scale Packaging Designs Used for Postharvest Handling of Pomegranate in South Africa

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Abstract

Ventilated corrugated packaging is the most widely used type of packaging for postharvest handling of fresh horticultural produce. The presence of vent holes facilitates fruit cooling and poorly ventilated cartons result in non-uniform cooling and a higher cooling energy demand. In this study, we investigated the geometrical design attributes of different corrugated fibreboard cartons used for handling pomegranate fruit. The carton designs can generally be classified into 'Processing-fruit' and 'Fresh-line-fruit' cartons. The '104MM' cartons are the mostly used export cartons in the industry and accounts for 48.00% of the export volumes followed by the '118MM' carton design at 15.73%. The cartons had varied ventilations along the long (4.60% to 13.82%), short (0.71% to 5.33%) and bottom (0.74% to 4.66%) faces, with largely open tops. Internal packages, especially liners and trays are also employed in the industry. The carton designs, and the use of tray/polyliner in the pomegranate fruit packages is largely a decision of the exporter in consideration of individual market requirements.

Keywords: Punica granatum, carton vent design, internal packages, ventilation area, stacking

Introduction

The global packaging market value is estimated to reach US$ 1 trillion by 2021 with an annual growth rate of 5-7% until the end of the decade (Smithers, 2019). Much of this growth will be in markets in the developing countries including the Middle East, Africa, and South America (Smithers, 2019). Food packaging accounts for over 35% of this global packaging industry in the developed markets and further growth is projected in the developing world markets with higher population growth (Rundh, 2005). Paper, corrugated board and other paperboard package materials account for 1/3 of the global packaging trade (Rundh, 2005; GADV, 2019; Opara & Mditshwa, 2013). Without packaging, supply of food from the point of production to the consumers, movement of perishables, etc. would be unmanageable (Rundh, 2005). Packaging plays roles in marketing and logistics in addition to its primary role of product protection.

Apart from corrugated paperboard, the fresh produce market also employs other package materials, including punnets, plastic crates, plastic and woven nets, (Opara & Mditshwa, 2013). Packaging used in the fresh fruit industry requires ventilation through which respiration and metabolic heat is removed from the fruit environment in the cold chain process (Berry et al., 2015). The design of the vent-holes (area, number, position) have an effect on the carton strength and cooling properties of the fruit therein (Fadiji et al., 2016; Berry et al., 2017; Mukama et al., 2017). For corrugated fibreboard cartons, increase in vent area compromises the carton strength (Fadiji et al., 2016) though it may improve fruit cooling rates. The design process of such cartons is thus normally a trade-off between achieving structural integrity and adequate and fast cooling.

The horticultural industry uses millions of paperboard cartons to move produce around the world annually. These hold produce in single or multiple layers, have different vent-hole configurations, and are made from a variety of paper materials with different flute/liner configurations. In addition to the cartons, fresh fruit are packaged in internal packages like polyethylene liners, foam nets, trays and punnets (O'Sullivan et al., 2016; Ambaw et al., 2017). These serve different functions that may include reduction of moisture loss, protection of fruit against abrasion, modification of atmosphere around the fruit, etc. However, some internal packages negatively affect fruit cooling rates, for example, poly-liners (Ambaw et al., 2017; Mukama et al., 2017).

Pomegranate fruit cultivation and demand is on the rise world over given the health promoting benefits associated with the fruit consumption (Rahmani et al., 2017). Thus far, consumption of the fruit has been linked to anti-hypertensive, anti-mutagenic and anti-cancer benefits that trace back to phytochemical, antioxidant and radical scavenging properties of pomegranate fruit components (Fawole & Opara, 2012; Opara et al., 2016). Pomegranate trees are native to the area between Iran and northern India, however, the trees are now cultivated widely in Mediterranean basin, the drier parts of Southeast Asia, Malaya, and tropical Africa. The total world production is currently estimated at 3 million tons per year (Erkan & Dogan, 2018). According to Pomegranate Industry overview (2018) by HORTGRO (South Africa), the total area planted by pomegranates increased by 13% from 826 ha in 2017 to 932 ha in 2018. The report projected 1.4 million 4.3 kg equivalent cartons of fruit pack out by 2023 (POMASA, 2019). Total exports have been increasing since 2012 but dropped by 19% between 2017 and 2018 probably due to drought in the Western Cape, the main growing region in South Africa. Most South African pomegranate fruit export is destined to the European market (PPECB, 2019). Europe is a net importer of fresh pomegranates, their total import volume increased from 67,000 tons in 2013 to 95,000 tons in 2017 (CBI, 2019).

There is a growing trend in the use of pomegranates as an ingredient in food, cosmetic, and pharmaceutical industries given their bright red colour, sweet-sour flavour and nutraceutical properties (Fawole & Opara, 2014). However, pomegranates are vulnerable to moisture loss, fungal infections, bruising and decay if the fruit is not properly handled, packaged, and stored after harvest (Kader, 2006; Caleb et al., 2012; Munhuweyi et al., 2016). Pomegranate shelf life can be prolonged up to 4 months if fruit is kept at temperature and relative humidity (RH) − (4 to 8) °C and 90% to 95%, respectively. Rapid loss of moisture and the associated shrivelling are the most common challenges after harvest (Fawole & Opara, 2013; Arendse et al., 2014). Most tree fruits lose moisture at considerably high rates until attainment of storage temperature. Packaging, cooling, and humidification could greatly avert this loss (Delele et al., 2009; Montero-Calderon & Cerdas-Araya, 2012).

Cartons used in the fresh fruit industry are of different designs majorly decided by the exporters, importers, and the consumers (Opara & Zou, 2007; Pathare & Opara, 2014; Berry et al., 2015). Berry et al. (2015) did a survey of the ventilated fibreboard cartons used in the apple and pear industry in South Africa and found 11 different export cartons that were divided into two major designs: the 'telescopic' and 'display' cartons. These had different vent-hole designs and the packaging procedure made use of different internal packages: thrift bags, punnets, trays, and poly-liner bags. However, there is a dearth of knowledge on the packaging designs currently used in the pomegranate industry which would guide future package designs to meet the demands of the global competitive market. Therefore, the objective of this study was to survey and characterise the packages used in the pomegranate industry in terms of geometric configuration, ventilation and internal packages.

Materials and Methods

Carton Survey

A survey of the current packaging used in the pomegranate industry was done between February and June, 2019 in two major pack-houses in Wellington, Western Cape, South Africa and in the fresh produce section in the major supermarkets within the Western Cape Province. This province is South Africa's major pomegranate growing area accounting for >60% of the total annual production (POMASA, 2019). Each of the packages were assessed for: a) Geometry (length, width, height), b)

Ventilation area, and c) Presence of internal packages (trays, poly-liner bag). Up to 3 cartons of each design were assessed to for the dimensions and ventilation area.

Pomegranate Cartons Trade Data Analysis

Pomegranate fruit export data in the different cartons used in South Africa was obtained from Perishable Products Export Control Board (PPECB, 2019). Each package design had a local 'Pack code' linked to the 'Global Trade Item Number' of fruit exports. Similar to findings by Berry et al. (2015) on pome packages, different pack codes were used to describe similar ventilated package designs from different manufacturers and fruit exporters. The number in the 'Pack code' is meant to represent the weight of fruit in the carton (Muller, J.C., 2019, General Manager, Sonlia Pack house, Wellington, South Africa, personal communication, 20 July). However, this is not consistent, for example, 76 kg of fruit is unrealistic for carton 'OPEN TOP - 82 MM' with 'Pack code' D76N just like D82N, and D64A (**Table 1**).

Results and Discussion

Pomegranate Cartons Export Statistics

All packages used in the South African pomegranate fruit export between 2015 and 2018 are shown in **Table 1** (PPECB, 2019). The ambiguity in the 'Pack names' is clearly visible. Standardisation of the 'Pack names' is necessary to reduce confusion in future. The majorly used export cartons characteristics (geometry, loading, ventilation) and their suggested 'Pack names' are described in **Table 2**. The '104MM' cartons are the mostly used export cartons in the industry accounting for 48.00% of the export volumes, followed by unnamed cartons at 22.27%, the '118MM' at 15.73%, '170MM' cartons at 7.67%, the '82MM' cartons at 3.53% and then the '190MM' cartons at 1.69% (**Table 1** and **Table 2**). However, the volume of the '82MM' cartons exported in 2018 dropped sharply from 48, 955 cartons in 2017 to only 260 cartons in 2018. This is because this carton takes smaller diameter fruit in counts 18 and 20 which are slowly being phased out of the export market (Muller, 2019a). Additionally, data for the '105MM' cartons that are used to export a

Table 1 Cartons of pomegranate fruit exported from South Africa between 2015 and 2018 by carton type (PPECB, 2019)

Pack name	Pack code	2015	2016	2017	2018	Total	%
DOUBLE 4.75KG INTR 400 × 300 × 104	D04I	388501	581421	545143	466389	1981454	43.26
NULL	NA	170944	259102	387351	174043	991440	21.65
DISPLAY 64 170MM	E15D	80612	39642	77122	133719	331095	7.23
MULTIPLE 4.75KG INTR 400 × 300 × 118	M04I	74986	110836	75005	60521	321348	7.02
4.5KG INTR 120 Extra Large Carton	B04I	116258	133260	60680	5400	315598	6.89
4.5KG CARTON 400 × 300 × 82	C04I	42334	65452	48955	260	157001	3.43
4.0KG SUPERVENT CARTON	B04S	0	0	10080	132710	142790	3.12
4.0KG DISPLAY 216	D04D	0	16983	46180	10960	74123	1.62
F14D	F14D	38605	13260	14814	6426	73105	1.60
MULTIPLE 5.25KG INTR CARTON	M05I	14378	15580	16994	7740	54692	1.19
MULTIPLE 5.25KG DISPLAY	M05D	0	7577	17550	3612	28739	0.63
NOT AVAILABLE	NULL	1010	11951	8211	7160	28332	0.62
6.09KG CARTON	C15A	25365	0	0	0	25365	0.55
E14D	E14D	0	0	0	19269	19269	0.42
4.00 DISPLAY 228	C04D	0	3120	5860	0	8980	0.20
DOUBLE 5.25 INTR	D05I	3710	0	4760	200	8670	0.19
Display 15 KG	F15D	397	2088	5033	137	7655	0.09
OPEN TOP - 82 MM	D76N	1820	2460	0	0	4280	0.09
DOUBLE 5.25 KG DISPLAY CARTON	D05D	0	2600	170	154	2924	0.06
5KG COMPOSITE 150MM CARTON	B05C	0	1260	0	0	1260	0.03
4.00 COMP 110MM	A04C	0	840	0	0	840	0.02
E12D	E12D	195	130	0	0	325	0.01
OPEN TOP -76 MM	D82N	250	0	0	0	250	0.01
TELESCOPIC 170MM	E15C	100	150	0	0	250	0.01
DOUBLE 5.25KG COMPOSITE CARTON	D05C	200	0	0	0	200	0.00
15KG CARTON	C15, AI5C	95	0	0	1	96	0.00
DISPLAY 10KG	E10D	0	90	0	0	90	0.00
DISPLAY 64 122MM	D64A	0	0	0	3	3	0.00
Total		**959760**	**1267802**	**1323908**	**1028704**	**4580174**	**100**

significant amount of fruit (Muller, 2019a) could not be traced in the statistics using the ‘Pack code’ or ‘Pack name’. These could be among the ‘NULL/NOT AVAILABLE’ group of cartons in **Table 1**.

Carton Designs

The survey found 10 different carton designs in use in the pomegranate fruit industry. These were manufactured by different companies in South Africa. The different cartons can be grouped into two major carton types: the cartons that are used to package ‘Fresh-line-fruit’, and cartons used to package ‘Processing-fruit’. The dimensions, ventilation, and loading of these cartons are shown in **Table 2**. ‘Processing-fruit’ is fruit meant for industrial processes like juicing, aril extraction, and extraction of other pomegranate products, while ‘Fresh-line-fruit’ are sold individually or on weight basis to retailers. The ‘Fresh-line-fruit’ cartons hold fruit in single layers while in the ‘Processing-fruit’ cartons, the fruit are jumble packed or place packed.

In the ‘Fresh-line-fruit’ cartons, there were four main groups of cartons, the ‘82MM’, the ‘104MM’, ‘105MM’, and the ‘118MM’ cartons. The ‘82MM’ carton is used for smaller diameter (< 60 mm) fruit packaged in counts 18 and 20, gross weight (3.5-4.5) kg, fruit in 105MM and 104MM cartons is packaged in counts 10, 12, 14, and 16, gross weight (3.0-4.5) kg (diameter (> 60 < 100) mm), while the ‘118MM’ cartons that hold larger fruit with diameter (> 100 mm) in counts 6 to 8, gross weight (4.3-5.5) kg. The ‘104MM’ and ‘118MM’ cartons have variations including the ‘Bini’, ‘*Agri-lock-A*’, and ‘*Agri-lock-B*’ cartons, mainly differentiated by their ventilation and make of the carton tops (**Fig. 1**). The ‘*Agri-lock-A*’ and ‘*Agri-lock-B*’ cartons (**Fig. 1**) have similar design with top flaps locked in carton material overlaps on the top of the carton, however, the ‘*Agri-lock-B*’ cartons have different bottom and top ventilation configurations with semi-circular vent-holes that are continuations of the ventilation along the long side of the carton in addition to the vent-holes at the bottom. This ventilation configuration is achieved by placing oblong vent-holes along the folding line of these cartons. The ‘*Bini*’ cartons have the top flap glued on the long side of the cartons (**Fig. 1**).

The International Fibreboard Class Code (IFCC) document is the internationally applied system in corrugated and solid board design that assigns codes and numbers to most common box types to facilitate communication between manufacturers and customers (FEFCO & ESBO, 2007). Under this categorisation, the cartons used in the pomegranate industry are within descriptions: 0432-M, and 0436-M, category: 04 − Folder-type boxes and trays (trays with one piece of

Table 2 General carton design characteristics of cartons used in the South African pomegranate industry

		Fresh-line-fruit cartons								Packaging-fruit cartons	
Carton name		82MM	105MM	104MM			118MM			170MM	190MM
Pack code		C04I, D76N, D82N	D03I	D04I, D04D, B04S			M05D, M05I, M04I, B04I			E15D, E15C, E10D, E12D, E14D	F14D, F15D
Carton make				Bini	Agri-lock-A	Agri-lock-B	Bini	Agri-lock-A	Agri-lock-B		
International fibreboard class code		0436-M	0436-M	0436-M	0432-M	0432-M	0436-M	0432-M	0432-M	0436-M	0436-M
Dimensions (mm)	Length	395	325	395	395	395	395	395	395	600	490
	Breadth	295	295	295	295	295	295	295	295	390	390
	Height	82	105	104	104	104	118	118	118	170	190
Long carton side (mm^2)	Total area	32390	34125	41080	41080	41080	46610	46610	46610	102000	93100
	Vent area	1490	3481	4780	3733	3733	4780	3733	3733	14100	11610
	Vent area (%)	4.60	10.20	11.64	9.09	9.09	10.25	8.01	8.01	13.82	12.47
Short carton side (mm^2)	Total area	24190	30975	30680	30680	30680	34810	34810	34810	66300	74100
	Vent area	700	1651	900	707	1410	900	707	1410	1050	525
	Vent area (%)	2.89*	5.33*	2.93*	2.30	4.60	2.59*	2.03	4.05	1.58	0.71
Bottom side (mm^2)	Total area	116525	95875	116525	116525	116525	116525	116525	116525	234000	191100
	Vent area	2945	3662	5345	3507	5427	5345	3507	5427	6750	1414
	Vent area (%)	2.53	3.82	4.59	3.01	4.66	4.59	3.01	4.66	2.88	0.74
Internal packages		Tray & polyliner	Polyliner	Tray & polyliner	Tray & polyliner	Tray & polyliner	Tray & polyliner	Tray & polyliner	Tray & polyliner	Polyliner	Polyliner
Fruit count per carton		18, 20	10, 12, 14, 16	10, 12, 14, 16	10, 12, 14, 16	10, 12, 14, 16	6, 8	6, 8	6, 8	Jumble/place pack	Jumble/place pack
Weight of fruit packed carton		3.5-4.5	3.0-3.8	3.5-4.5	3.5-4.5	3.5-4.5	4.3-5.5	4.3-5.5	4.3-5.5	14-15	14-15
Cartons per pallet layer		10	12	10	10	10	10	10	10	5	6

*Vents act as interlocking spaces and are thus blocked by subsequent carton in stack board hinged to form side walls and cover with locking tabs). Berry et al. (2015) found codes 0773-M, 0200-MA and 4032-M, under which were over 11 different corrugated fibreboard carton designs used for commercial handling of apples and pears. The pomegranate cartons largely had open tops with small fold over flaps.

Ventilation Characteristics

The studied cartons had different ventilation areas (**Table 2**), varying between 4.60% to 13.82% on the long carton face/side, 0.71% to 5.33% on the short face, and 0.74% to 4.66% on the bottom face. However, for the '105MM', '82MM' and '104MM − Bini', and '118MM − Bini' cartons, the vents on the short side are used for locking purposes on stacking and are thus not useful as air passages in the cooling process. Most of the cartons had the recommended 5%-7% carton face ventilation to enable compromise between efficient fruit cooling and carton mechanical integrity (Mitchel, 1992; Thompson et al., 2008; Delele et al., 2013), but, only on the long side. The short side of the cartons largely had ventilation below 5% and so did the bottom faces of the cartons. The 'Bini' cartons had higher bottom ventilation area compared to their 'Agri-lock' counter parts. Thus, these cartons would perform better in facilitating vertical airflow in refrigerated containers (Getahun et al., 2017).

Fig. 1 Schematics showing the majorly used cartons in the South African pomegranate industry: (a) '105MM', (b) '104MM/118MM – Bini', (c) '104MM/118MM – Agri-lock-B', (d) '104MM/118MM – Agri-lock-A', (e) '190MM', (f) '170MM', and (g) '82MM'

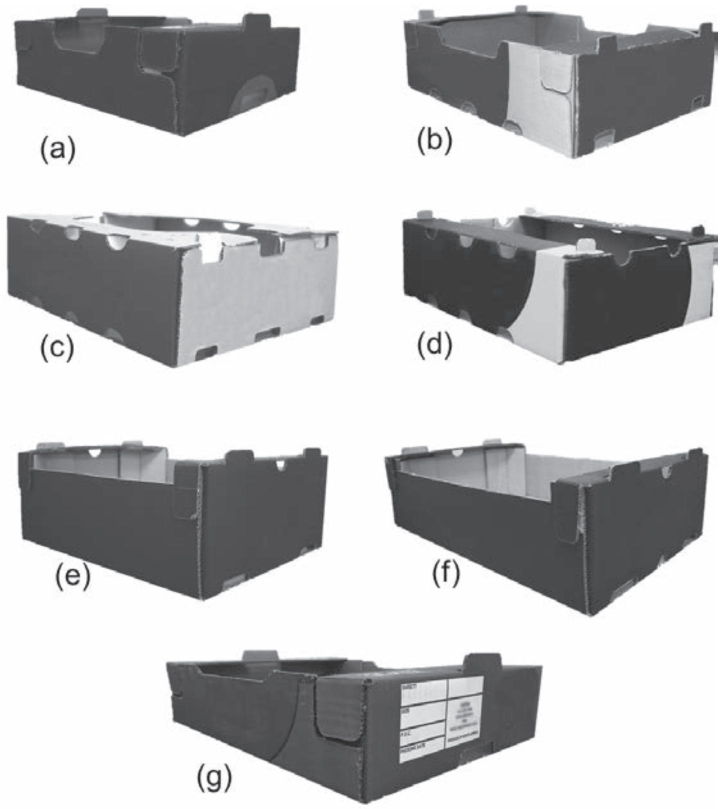
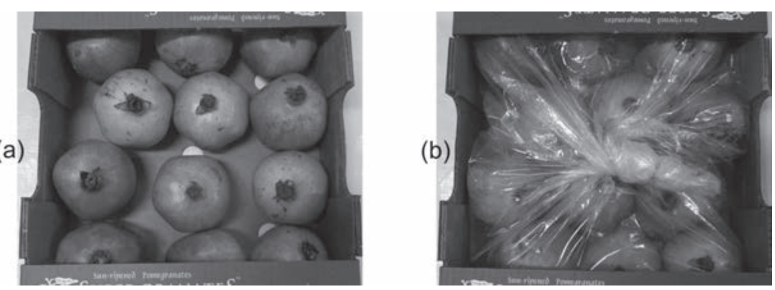


Fig. 2 Schematic showing pomegranate fruit packaging without (a) and with polyliner (b)



The shapes of the vent-holes on the studied cartons were largely semi-circular or oblong along the length and breadth of the cartons (**Fig. 1**) and circular at the bottom. While Jinkarn et al. (2006) reported that oblong vent-holes on the vertical carton faces reduced carton mechanical integrity more compared circular vent-holes, Han & Park (2007) found that circular vents reduce the CFC mechanical strength more compared vertical oblong vents. The 'Processing-fruit' cartons largely have large rectangular open areas along the long side of the cartons with very poor or no ventilation along the short side of the cartons. Therefore, stack orientation that predisposes the short side as the airflow inlets for this carton would result into large pressure drops and inefficient fruit cooling rates (Ambaw et al., 2017). The '190MM' carton had the poorest bottom (0.74%) and short side (0.71%) ventilation areas.

Internal Packages

The use of successive layers of packaging including internal packages is termed multi-scale packaging (Ngcobo et al., 2013; Berry et al., 2015). All the studied cartons are packaged with/without polyethylene liners (poly-liner) (**Fig. 2**). The poly-liners are employed to minimise moisture loss from the fruit and to modify the environment around the fruit (18%-19% O_2; 1% CO_2; 98% relative humidity–RH). The use or no use of poly-liner is determined by the exporter and market destination. Given that the fruit is waxed with carnauba wax, some exporters of the waxed fruit package their produce without poly-liners (Muller, 2019b). This is probably because poly-liners delay fruit cooling (Ambaw et al., 2017; Mukama et al., 2017).

Trays, made from pulp paper (**Fig. 3**) were used in all the 'Fresh-line-fruit' cartons, except the '105MM' carton that uses no trays. Trays are not also used in the 'Processing-fruit' cartons. Fruit in these cartons were simply jumble or place packed without or within a poly-liner. In the '105MM' fruit are placed in the carton with/without poly-liner in a single layer without tray. For cases where the poly-liners were used, the bags surrounded both the tray and fruit and were tied off at the top with rubber bands. The trays used in the industry exhibited staggered and straight fruit arrangements designed to accommodate different fruit numbers (fruit counts) according to fruit diameter (**Fig. 3**). Given the tray and carton designs, there was blockage of lower vents along the short and long sides of the carton by the trays.

Studies have shown the effect of internal packages on pomegranate fruit cooling and quality, for example, in a study by Mphalele et al. (2016), commercially ripe pomegranate fruit packaged in ventilated cartons with poly-liner (passive modified atmosphere packaging) lost significantly lower amount of water in comparison to non poly-liner packaged fruit. A similar observation was made by Mukama et al. (2019) in a study on moisture loss during forced air precooling of pomegranate fruit in poly-liner and no poly-liner. However, Mukama et al. (2017) and Ambaw et al. (2017) found that poly-liners increase the energy demand of the forced air cooling process of pomegranate fruit, using up to 3-fold more energy compared to stacks with no poly-liners, and increase the pressure drop of the system as well as cooling time by >6 hours compared to no liner packaging. Internal packages are also used in packaging other horticultural produce, for example grapes (Ngcobo et al., 2013), apples, pears (Berry et al., 2015), kiwifruit (O'Sullivan et al., 2016), etc.

Stacking Configurations

The stacking configurations of the pomegranate fruit cartons on a standard ISO2 pallet (1.0 × 1.2) m are shown in (**Fig. 4**). Four stack configurations were found in this survey: 5, 6, 10, and 12. The '105MM' cartons are stacked into 12 cartons, the '82MM', '104MM', and the '118MM' cartons are stacked in 10, the '170MM' cartons in 5, and the '190MM' cartons are stacked in 6 cartons on the pallet per layer (**Fig. 4**). Berry et al. (2015) found stack configurations 5, 7 and 10 on a standard ISO2 pallet for cartons used in the apple and pear industry.

The orientation of the pallet stack in relation to airflow (1.0 m or 1.2 m) may affect the overall cooling efficiency especially in stacks where the vent-holes along the short carton face have been blocked by interlocking action on stacking (Mukama et al., 2017) (**Table 2**). Vent-hole alignment on stacking is very important to prevent obstruction of airflow during cooling which creates high temperature zones within the stack of cartons, with negative implications on the energy requirements of the cooling process and fruit quality (Ambaw et al., 2017). It is thus necessary that both the long and short carton faces are ventilated and that vent-holes align especially for stacking configurations where the cartons orientation may change (**Fig. 4 (a)** and **4 (b)**).

Retail Display

Under retail display, pomegranate fruit were found to be bulked out with other fruit on shelves under ambient condition (**Fig. 5**) where they were sold individually or on weight basis. This type of marketing could possibly have negative effects on the fruit quality. Mukama et al. (2019) monitored quality of pomegranate fruit stored under ambient conditions (20 ± 0.36 °C 65 ± 6.79 %RH) over a 30-day period. The authors reported excessive weight loss (up to 29.1% on day 30) which led to shrivelling, deformed appearance and considerably reduced overall fruit visual quality, with signs of shrivel beginning to appear on storage day 6. Display of fruit at 20 °C, 95% RH keeps pomegranate fruit quality for 30 days and beyond.

Fig. 3 Schematic showing some of the trays used in the pomegranate industry in South Africa: (a) count-8 fruit tray, (b) count-12, (c) count-16, and (d) count-14

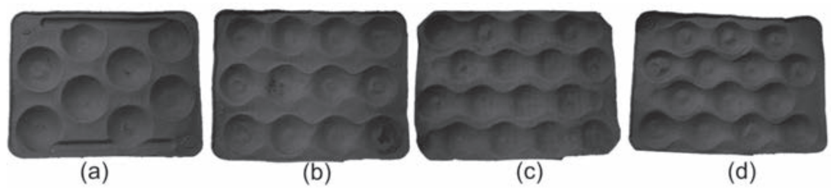
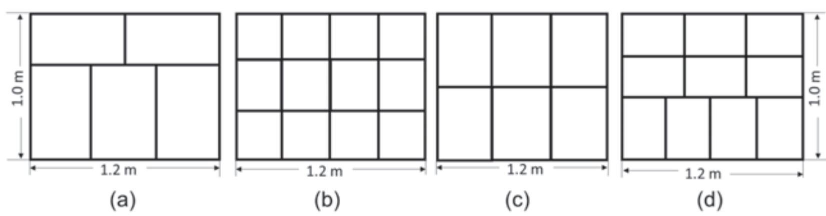


Fig. 4 Schematic showing different pallet stacking configurations of cartons used in the South African pomegranate industry: (a) 5, (b) 12, (c) 6, and (d) 10



Therefore, pomegranates should preferably be displayed in low temperature environments (5 to 7) °C (Arendese et al., 2014) or high relative humidity environments (90% to 95%) (Mukama et al., 2019) or both.

Conclusions

Efficient fresh produce distribution and marketing requires well designed and efficient packaging and cold storage systems. The survey of ventilated packaging used in the pomegranate industry in South Africa found 10 corrugated fibreboard carton designs predominantly used in the commercial handling of the fruit. These could be largely divided into 'Freshline-fruit' and 'Processing-fruit' cartons. The carton ventilation areas varied between 4.60% to 13.82% on the long carton face, 0.71% to 5.33% on the short face, and 0.74 to 4.66% on the bottom face. The cartons were largely poorly ventilated on the short faces that leads to poor carton venthole alignment and vent hole blockage in stacking configurations that involve change of carton orientation (long side/short short) on the pallet. Additionally, some cartons were found to have poor bottom ventilation area which has negative effects on vertical airflow in the refrigerated container. The trays and liners also largely block the bottom vent holes, and trays block the lower vent-holes along the vertical faces (long and short sides) of the cartons in which they are used further worsening the cold chain efficiency. Therefore, studies towards optimisation of cartons applied in the cold chain handling of pomegranate fruit are warranted.

Fig. 5 Pomegranate fruit display in a supermarket in Western Cape, South Africa

Acknowledgements

This work is based on the research supported wholly/in part by the National Research Foundation of South Africa (Grant Numbers: 64813). The opinions, findings and conclusions or recommendations expressed are those of the author(s) alone, and the NRF accepts no liability whatsoever in this regard. We acknowledge the DAAD (German Academic Exchange), the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM), THRIP, and Agri-Edge for support. We thank Mr. JC Muller of Sonlia Pack house for his generosity, invaluable support, and assistance throughout this study.

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Wheel Slip Measurement Methods and Development of Novel Technique for Its Measurement to Improve Tractive Performance of Off-road Vehicles

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Abstract

In this article, several attempts made by the various researchers for measurement of wheel slip in off-road vehicle are discussed. Various methods and the importance to measure wheel slip and its effect on tractive performance of vehicle are presented. A hall sensor based simple technique was introduced to measure wheel slip, and a microcontroller based digital system was developed to display wheel slip data and warn the operator with audible and visible warnings if the optimum range is exceeds. Hall sensor slip measurement system was validated on tarmacadam surface and in actual field condition, and compared with the manually measured values. The developed system is simple in construction and can be mounted to any make and model of agricultural tractors by entering the appropriate rolling radius via the computer interface.

Keywords: Hall Effect sensor; Actual speed measurement; Display unit; Wheel slip.

Introduction

The primary purpose of agricultural tractors is to perform drawbar work. This is defined by pull and travel speed. Research shows that about 20-55% of the available tractor energy is wasted at the tyre-soil interface (Burt and Bailey, 1982). This energy wears the tires and compacts the soil to a degree that may be detrimental to crop production. Efficient operation of farm tractors includes: (i) selecting an optimum travel speed for a given tractor-implement system (ii) maximizing the tractive advantage of the traction devices, and (iii) maximizing of fuel efficiency of the engine and drive train. Among these, the maximizing the fuel efficiency could be done with little efforts.

Increasing costs of petroleum products, most possible efforts are needed to improve the fuel efficiency and better environmental concern. Especially in agricultural tractors, matching size of implement and load to a given size of tractor place a vital role in optimizing the fuel efficiency. Wismer and Luth (1972) and Brixius (1987) suggested that wheel slip has a dominating role in improving the tractive performance. The tractors operate at peak efficiency if their slip is maintained in a certain optimum range (Zoz, 1972). In general wheel slip occurs when the tires are turning faster than the ground speed of the tractor.

As a result, less than 60% to 70% of the power that a tractor engine develops is used to pull an implement through the soil, also it may be even drop to 50% on soft and sandy soils.

The past studies have recommended that tractors and tires should be maintained to optimize wheel slippage at 10% to 15% to get better tractive performance and less slippage than this results in the expenditure of too much fuel energy to move the wheels, whereas too much slippage (greater than 15%) can result in excessive tire spin and energy loss through the tire, which is nonproductive.

Wheel slip is one of the major key indicators of efficient tractor operation. The level of wheel slip serves as a proxy to indicate whether the right combination of tire pressures, tractor weight (ballast) and tractor operating speed is selected, resulting in the correct traction required to perform efficiently and fuel save.

Further, wheel slip can determine the wear and expected lifetime of a tractor's drive train and tyres. A wheel slip that is too low may be a sign that the drive train is being strained and excessive weight is being hauled. Conversely, a very high wheel slip suggests that the tyres are wearing excessively and wasted rotations are likely wasting fuel.

Land preparation is one of the most energy consuming operations in the field. The energy utilized by a tillage practice depends on many factors such as soil type and condition, operating depth, travel speed, and hitch geometry. Optimizing the tractor performance in the field depends on the proper matching of the tractor and the implements, and wheel slip which could help in minimizing the fuel consumption and energy loss (Abbouda et al., 2001). The tractive effort can be basically enhanced by increasing the area of contact between the tractor wheels and the soil surface, and reducing the abnormal slippage.

By keeping all the above statements in mind, an attempt was made to study and present the past research on wheel slip measurement technique and to develop a simple technology and embedded system to measure and display wheel slip digitally along with audible and visible warnings.

Review of Literature

2.1 Wheel Slip Measurement and Control

Knowing the importance of wheel slip, several attempts have been made to measure this parameter. Researchers have used different techniques like Doppler/microwave radar device (Stuchly et al., 1976; Freeland et al., 1988; Wang and Domier, 1989; Khalilian et al., 1989; Grisso et al.,1991; and Reed and Turner, 1993) and electronic circuits using photo-transducer (Zoerb and Popoff, 1967; Lyne and Meiring, 1977; Clark and Gillespie, 1979; Jurek and Newendorp, 1983; Grevis-James et al., 1981; Erickson et al., 1982; Shropshire et al., 1983; and Musonda et al., 1983) for accurate measurement of slip. Most of these techniques were tractor specific, costly and of unproven reliability for instantaneous measurement of slip. These techniques were based on calculation of theoretical velocity on test bed instead of operating on a hard surface which is essential for defining zero condition.

Further, only a few researchers have worked on dynamic wheel slip control, out of which, the dynamic ballasting is important one (Tan et at., 1994). However, ballasting increases the overall weight of the tractor which increases the rolling resistance of the tyre and compaction of the soil. This compaction leads to the reduction in crop yield. Skotnikov (2001) suggested a slip control system by controlling the inflation pressure in the traction tires. This, on the other hand, increases the contact area when tire inflation pressure is reduced. Another method of controlling the slip is by adjusting the depth of operation (Ismail et al., 1981) or by regulating the forward speed. In the field, the change in slip due to variation in soil conditions is better managed by manually altering the depth of operation with hydraulic control lever. These adjustments, however, do not achieve desired results but cause unacceptable depth variations in the field. This calls for an auto-depth control device to be incorporated to automatically adjust the depth of implement for maintaining slip in a specified range throughout the duration of field operation.

2.2 Slip Measurement Methods

On-farm slip measurement methods can be classified in three groups: manual distance or wheel revolution counting, automatic slip measurement, and visual inspection of the tyre track in the soil.

2.2.1 Manual Slip Measurement

The manual slip measurement is based on either counting the number of revolutions of the drive wheels at load and at no load for a fixed distance of travel, or measuring the distance travelled for fixed number of revolutions of the drive wheels at load and at no load. The slip, by these two methods, is calculated as follows

i. Fixed distance method:

$$S = [(n_l - n_o) / n_o] \times 100 \quad ...(1)$$

ii. Fixed revolution method:

$$S = [(d_o - d_l) / d_o] \times 100 \quad ...(2)$$

Out of the two manual methods mentioned above, the method based on fixed number of revolutions is widely used, because of less error involved in measuring the distance than counting the number of revolutions (which may not be integer).

2.2.2 Automatic Slip Measurement

Parther and Schafer (1969) used general purpose analog computer to make continuous calculation of slip during each test run for performance evaluation of tractor tyres and other traction devices. The initial balance of the computer, representing the initial value of slip was manually set during each test in the field. The procedure adopted had two major disadvantages: (1) only a small portion of computer's capability was used in the calculation, and (2) the manual initial balance adjustment was subjected to human judgment, which often resulted in undesirable error and waste of valuable test soil area.

Lyne and Meiring (1977) developed a versatile instrument which indicated the wheel slip on a tractor by means of a panel meter to assist the operator in promoting efficient tractor operation. The design, calibration and accuracy of an electronic instrument for measuring, recording and displaying instantaneous tractor wheel slip were described. Photoelectric transducers were used to monitor ground speed and wheel speeds. Individual wheel speed readings were accurate to within 1% over the range of normal tillage operating speeds. The front wheels of a rear wheel drive tractor were used for ground speed indication. This feature required to monitor each of the front wheel speeds and had an output equal to the faster of the two front wheels. This speed was then compared with the rear wheel speed to get slip value by using the comparator circuit.

Thansandote et al. (1977) developed a non-contact technique like modern solid-state microwave Doppler radar to measure true ground velocity of tractor and circumferential velocity for drive wheel to determine slip. Slip measurement following this method provided higher accuracy but was very costly.

Grevis-james et al. (1981) developed a tractor power monitor to measure ground speed, wheel slip, drawbar pull and drawbar power to improve the overall efficiency of the tractor/implement combination. The developed power monitor system comprised three transducers, processing electronics, display and controls. Transducers used for ground speed and wheel speed were magnetic pickups positioned close to slotted steel discs attached to the wheels. On 2WD tractors, a front wheel was used for measuring ground speed. A fifth wheel unit was used to measure ground speed for 4WD tractor. An amplifier located within each magnetic pickup housing was used to shape the output signal from the pickup and to increase the pulse amplitude to 6 V. A strain gauge based transducer was used for measuring pull. The level of accuracy achieved with the prototype instrument was sufficient for the intended application.

Tompkins and Wilhelm (1982) developed a tractor mounted data acquisition system to measure and record axle power, drawbar power, drive wheel slip and fuel consumption of a tractor. For the measurement of slip, a fifth wheel similar in function to those used by Lyne and Meiring (1976) was used. This was mounted with 72 teeth gear and 120 teeth gear in rear axle. Magnetic sensor provided in each teeth shaft, counted the wheel rotation. The average of the rear wheel voltages (Vr) was fed into the slip calculating circuit and slip was calculated according to the equation.

$$i = (V_r - V_f) / V_r \quad ...(3)$$

where

i = wheel slip;

V_r = rear wheel voltage; and

V_f = front wheel voltage

Grogan et al. (1987) developed a microcomputer based tractor performance monitoring and optimization system. A 2WD diesel tractor was instrumented to measure engine load, engine speed, wheel slip, fuel consumption, draft and hitch forces. The microcomputer was able to optimize tractor performance by recommending the operator, the optimum gear and throttle setting to achieve maximum fuel efficiency. Analysis indicated that the farmers could reduce the fuel consumption by 15-27% by practicing shift-up, throttle-back; i.e by shifting to a higher transmission gear and reducing the engine speed to maintain the nearly constant forward speed. The actual fuel consumption could be dropped from 11.3 to 20% in controlled field tests using a tractor operated information feedback system.

Jesurajan (1988) developed an indirect slip sensing device by sensing the distance travelled by the front and the rear wheels of the tractor using an electronic device comprising photoelectric transducer, preset up and down decay counter and digital display units. A fifth wheel was used as a reference wheel to get the accurate results. The actual value of slip turned out to be much higher than the sensed values because of difficulty in sensing the distance accurately.

Behera (1989) and Prasad (1990) developed a microprocessor based slip measuring device by comparing the rear wheel revolutions with the front wheel revolutions. A disc having 16 holes at an interval of 20°, was fitted inside the rim of the front and rear wheel. A continuous light emitter and detector sensor were fitted in either side of the disc to measure the number of revolutions of wheel. The slip was calculated using a microprocessor by comparing the wheel revolutions of the front wheel and rear wheels. It was reported that some minor problems such as accumulation of dust on the light source and disc hole led to the faulty slip value. Further, when the front wheels skidded, this system did not indicate accurate results.

Saleque and Jangiev (1990) installed an instrumentation system on a 4WD, 10 kW farm tractor to monitor operational parameters during field work. The principal parameters monitored were drive wheel axle torque and rotational speed for predetermined tilling depth and soil conditions. Using a microcomputer to process data from the field experiment, the optimal operational parameters were calculated for the tractor during field work. These parameters included wheel slip, travel speed, tractive efficiency and area tilled per unit energy to achieve the best compromise value across the spectrum of typical theoretical speeds.

Reed and Turner (1993) reviewed current and past slip measurement techniques, both in experimental work and in common farm practice, and described a single method of obtaining accurate slip values on a tractor by using a pair of radar guns. The radar units transmitted a known frequency of radiation towards a surface and received reflections of the radiation from the surface. The Doppler frequency, the difference in frequency between the transmitted radiation and received radiation, was proportional to speed (**Fig. 1**). The system is universal, portable, quickly attachable and requires no modifications to the tractor. The radar sensor installation on a tractor is shown in **Fig. 2**.

Mclaughlin et al. (1993) developed a general purpose instrumentation and data logging system for a 97 kW agricultural tractor for use in field research on tractor and implement performance. The tractor was fitted with a set of transducers to measure fuel consumption, engine speed, wheel speed, ground speed, front and rear axle torque, and forces in the three point linkage. Transducer signals were isolated, amplified and filtered by signal conditioners, and recorded by a microcomputer-based data logger. A flexible software was developed to control the data logger. The software had provision for a wide range of sampling rates and real time graphic display of up to eight data channel. The system hardware and software were designed to accommodate future expansion with additional transducers on the tractor or implement. A cab extension was built on the side of the existing tractor cab to house the instrumentation system and data logger.

Sinha (2001) designed and developed a microprocessor based slip indicating device. For measuring the theoretical speed, a steel wheel with square spokes at an interval of 20° was attached to the rear wheel of a 2WD tractor along with a proximity sensor. When these spokes passed by the proximity sensor, a voltage pulse was generated which was detected by the microprocessor kit. For actual forward speed, a potentiometer was mounted on the throttle linkage mechanism. A relationship between throttle position and rear wheel rotation was developed at no load condition. At load condition, the rotation of rear wheel was compared with the corresponding value of wheel rotation at no load by the microprocessor kit. The difference of two rotations was used to calculate and display the wheel slip. A microprocessor program was written for this purpose. The sensed slip was compared with manually calculated slip to validate the system.

Raheman and Jha (2007) developed a microcontroller-based slip sensor for a 2WD tractor to indicate slip values during on-farm use. The 'zero condition' considered for the development of slip sensor was − tractor supplied with a driving torque to propel any device across a tarmacadam surface while delivering zero net traction (self-propelled condition). This sensor comprised four components: power supply; sensing of throttle position, gear position, and wheel revolution per minute; processing of collected data; and display unit. Power was taken from the tractor battery. Rotary potentiometer and proximity switches were installed on the tractor to measure throttle position and wheel revolution respectively. The performance of developed slip sensor was evaluated both on tarmacadam surface as well as in the field. The variations between indicated and actual slip were found to be within 0-5% for both the surfaces, thus indicating the accuracy of slip measurement by the developed slip sensor.

Pranav et al., (2010) developed a microcontroller based digital slip meter was developed for agricultural two wheel drive (2WD) tractors. The actual and theoretical speeds of tractor were calculated by measuring the revolutions per minute (RPM) of front wheel and rear wheels, respectively, using optical slot sensors. The slip meter was fabricated in such a way that it could be mounted on any make and model of 2WD tractor. A maximum of ±2 percent variation was observed between measured and indicated wheel slip. This system has own

Fig. 1 Working principle of Radar (Reed and Turner, 1993)

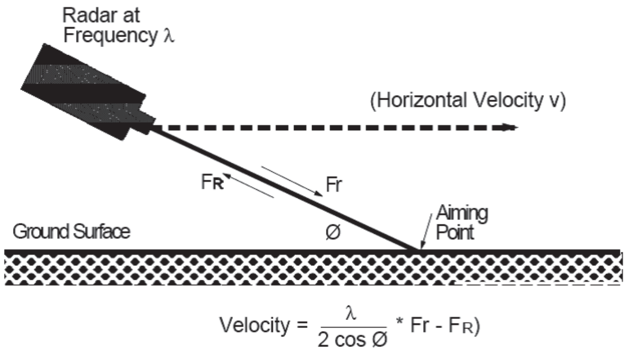
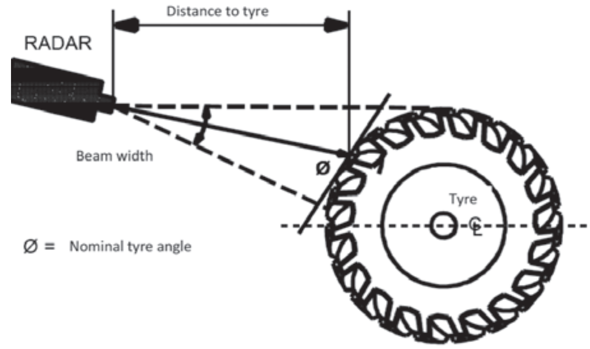


Fig. 2 Installation of radar sensor on a tractor



limitations, the life of optical encoder has less life and construction difficulty.

On the basis of the above literature survey, it is observed that the following three methods have been used to measure the actual speed of the tractor for slip computation.

a. A non-powered vehicle wheel

The method is quite simple and easy to adopt, but the actual speed depends on soil conditions, weight transfer, skid of front tyre etc. The error in slip measurement is not more than ± 2%.

b. Additional or fifth wheel device

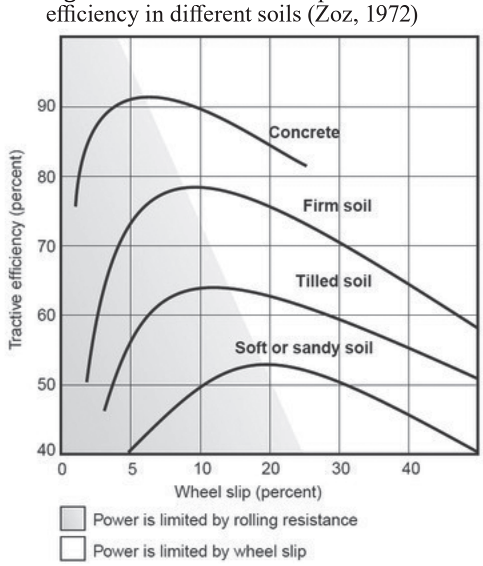
The actual speed measurement is independent of weight transfer, soil condition and skidding of front wheel. However, the use of fifth wheel poses difficulty in negotiating on undulating and rough terrain.

c. Doppler effect device or using microwave radar

The method provides an accurate reading of actual speed but the device is very expensive, has unproven reliability and cannot be used when speed is less than 0.5 km/h.

Considering the ease of measurement and low cost, the non-powered tractor front wheel was considered a better method of actual speed measurement of rear wheel driven tractors in the present study.

Fig. 3 The effect of wheel slip on tractive efficiency in different soils (Zoz, 1972)



2.3 Effect of Slip on Tractive Performance

Wheel slip is defined as the relative movement in the direction of travel at the mutual contact surface of a traction device and the support surface (ASAE, 1983). Slip has, therefore, a greater role in determining tractive effort. Tractive efficiency is the fraction of power available at the axle that is actually delivered to an implement through the drawbar. Zoz (1972) has shown that for each soil condition, there is an optimum range of slip where tractive efficiency is the highest (**Fig. 3**).

During the field operation of tractors, a significant portion of the energy is lost due to rolling resistance as well as the slippage of the traction wheels. Maximum tractive efficiency results from a compromise between minimizing rolling resistance and optimizing slip of the wheels. Tyres and tracks operate at their maximum efficiency within a certain range of slip. Therefore, the slip could be used as an indicator of the tractor performance on site for a particular condition. Operating the tractor in an optimum slip range would in turn help in conserving the fuel and thereby increasing the field capacity.

The efficient use of agricultural tractors include optimizing engine fuel efficiency, maximizing the tractive performance of the traction device, and appropriate matching and selection of the forward speed for a given tractor-implement system. Tractive performance of agricultural vehicles is characterized by the tractive efficiency and the dynamic traction ratio (ASAE, 1993). The tractive efficiency is a parameter that defines the percentage of tractor axle power that is transformed into drawbar power. It is influenced by the traction ratio, the rolling resistance (Bashford, 1984) and the wheel slip (Bashford, 1984; Brixius and Wismer, 1978). Several factors affect the traction ratio and the rolling resistance including soil mechanical properties (Dwyer et al., 1974), tyre size (Gee-Clough, 1980) and inflation pressure (Gee-Clough, 1980; Bashford et al., 1993), the dynamic wheel load (Self and Summers, 1988) and the wheel slip.

The empirical equations for predicting the drawbar performance developed by Wismer and Luth (1973), Gee-Clough et al. (1978) and Brixius (1987) contain a common parameter, wheel slip along with soil-wheel parameters. From all these relationships, it has been found that the maximum tractive efficiency occurs when the drive wheel slip lies between optimum slip ranges. Tractive efficiency falls rapidly from the maximum value if the slip is too high or too low from the optimum range. Zoz (1970) also found that for different soil condition, there is a range of wheel slip, where tractive efficiency is highest.

Thansandote et al. (1977) observed that wheel slip at a given operating load is an important parameter when optimizing the tractor performance for a particular field operation. Tyres and tracks operate at their maximum effectiveness within a certain range of slip, so operator could use the slip as an indicator of the tractor performance on site for a particular condition. Therefore, controlled wheel slip of the tractor results in better tractive efficiency, conserves fuel, increases field capacity, reduces tyre wear and capital cost.

Qaisrani et al. (1992) reported that proper ballasting reduced wheel slip, fuel consumption, tyre wear and cost of tractor operation. They observed wheel slip reduction and fuel saving up to 33% and 26% respectively with proper ballasting in some cases.

Byerly et al. (1989) and Jenane et al. (1996) observed that a tractor operating near the maximum tractive efficiency resulted in significant fuel saving. Minimum specific fuel consumption was found to occur over a wide range of slip from about 10% to 30%. Operating the tractor outside this range reduces the tractive efficiency and increases the specific fuel consumption.

Grisso et al. (2006) developed an empirical model for tractive performance of rubber-tracks in agricultural soils and validated with the experimental results. They compared the performance of 406 mm rubber-track in untilled and tilled sandy loam soil. In general, there was good agreement between the predicted and experimental results. As expected, the track performance in untilled soil with higher CI was slightly better than in tilled soil with lower CI value. The maximum tractive efficiencies (TE_{max}) in both cases occurred at slips between 6% and 7%. The predicted TEmax values were 0.831 and 0.815 for untilled and tilled soils respectively.

Hence by keeping above facts in mind, a simple digital system was designed and developed to measure the real time wheel slip of agricultural tractors and warn the operator if exceeds the optimum range on farm.

Materials and Methods

The above said methods are costly and bulky in construction with their own limitations and could not be able to display and warn the operator with audible and visible warnings, if the wheel slip exceeds the optimum values, hence a simple digital system was developed to measure the wheel slip precisely and warn the operator with simple, cheap and reliable materials. A microcontroller, Hall Effect sensor based system was developed to measure the wheel slip of tractors on farm use. The overall system comprises of three Hall Effect sensors, magnetic pins, and LCD display unit. The detailed description of developed device as follows:

3.1 Development of Wheel Slip Measurement System

Slip is not a directly measured value. It is calculated from two other measurements, that is actual forward speed and theoretical speed of the tractor, which can be measured either directly or computed from the rotational speed and the rolling radius of the wheels. In this study, the theoretical speed of the tractor was calculated by measuring the average revolution per minute (RPM) of the rear wheels, while the actual speed was computed by measuring the RPM of the front wheel. These RPM values were sent to a microcontroller for calculating the wheel slip.

3.1.1 Development of Hall Sensor System

Hall effect sensor is a simple device which can be activated with a magnetic field. It consists of a thin piece of p-type semiconductor material passing continuous current through it. The effect of generating a voltage by using magnetic field is called Hall Effect. The output of Hall effect sensor is the function of magnetic flux density. Three Hall effect sensors were mounted close to the magnetic pins, which are mounted on front and rear wheel rims for proximity switching while encountering the magnetic field. The used Hall sensor in present study could be able to detect the magnetic field up to the distance of 2 cm.

3.1.2 Measurement of Actual Speed and Theoretical Speed

For measurement of wheel slip of tractor, a test tractor MIT SUBISHI SHAKTI MT 180D is used for the present investigation which is available in the workshop of Dr. NTR CAE, Bapatla (**Fig. 4**). The actual speed of operation was measured by mounting magnetic pins directly on the front wheel rim of the tractor as shown in **Fig. 5**. Initially the rim diameter was measured and the magnets were mounted by drawing a circle of 24 cm diameter on the wheel rim. 28 small pieces of magnets were fixed to the front wheel rim at an angle of 12° to facilitate the actual RPM measurement. As per the geometry of the front wheels, magnetic pins were mounted at inner side of the wheel rim as shown in **Fig. 5a**. Similarly thirty four magnetic pins were mounted on the rear wheel rim outer side at an angle of 10° as shown in **Fig. 5b**.

3.1.3 Mounting of Hall Effect Sensor

To generate number of pulses for proximity switching of the sensor, three Hall effect sensors were mounted closed to the magnetic pins in perpendicular direction (**Fig. 6**). Two hall effect sensors were mounted close to the two front wheel rim mounted magnetic pins (**Fig. 6a**), whereas two sensors were mounted close to the rear wheel mounted magnetic pins for proximity switching while encountering to magnetic field. The reason for mounting two Hall effect sensors on the front wheels is to measure the wheel slip of the test tractor while in 4WD model. In 2WD mode, the speeds of both the front wheels are uniform where as in 4WD mode the speed may vary. Due to lack of time, the wheel slip of test tractor in 4WD mode is not performed. The used Hall sensor could be able to detect the pin up to the distance of 2 cm. In the present investigation a clearance of 0.5 cm was placed between sensor and magnetic pins. Both the rear wheel Hall sensors were mounted on a L-shaped flat iron piece which was connected to the rear wheel mud guard assembly using nut and bolt arrangement as a frame to avoid the vibrations on farm use. At the

Fig. 4 Selected test tractor

dead end of the L-shaped iron flat, a hall sensor was mounted and faced towards the magnetic pins in perpendicular direction using double bonded plaster and tape, then it was covered fully using cello tape. Similar procedure was followed for both the rear wheels.

The front wheel senor was mounted on an iron flat piece which was welded to the stub axle of the wheel assembly. Since the front wheel is a directional wheel, according to inclination of the wheel to the ground surface, sensor also should rotate. Hence an iron piece was connected to the stub axle using nut and bolt arrangement, therefore, while changing the rotational angle of the wheel, the orientation of the sensor mounted iron piece also change accordingly. The location of Hall effect sensor for proximity switching of front wheel is shown in **Fig. 6b**.

3.1.4 Interfacing and Computation of Slip in Microcontroller

The tractive performance of tractor-implement system can be evaluated by measuring various operating parameters like wheel slip, actual speed, draft force and depth of operation. For proximity switching of Hall effect sensor, the magnetic field must be applied in perpendicular direction to the flow of electronics. The output of the hall sensors were connected to the selected microcontroller via three interrupt pins 2 (interrupt-0), 3 (interrupt-1), and 21 (interrupt-2). These sensors generate the number of pulses while encountered the magnetic pins. The number of generated pulses of front and rear wheels sensors were counted using Aurdino Mega 2560 microcontroller. The potentiometer output was also connected to the same microcontroller using Analog pin A0. The microcontroller was connected to the laptop using USB and logged the data using putty software.

The front and rear wheel radius were measured by measuring the distance travelled in one complete revolution of the wheel to the circumference of the wheel. A line was marked on the wheel at the wheel soil interface as a reference point, and then the tractor was allowed to make one complete revolution of the wheel. The distance travelled in one revolution of wheel was measured using a synthetic tape. Similar procedure was followed for both the front and rear wheels.

3.1.5. Development of Digital Display Unit

A 16 × 2 Liquid crystal display (LCD) was interfaced to the microcontroller to display the measured parameters like actual speed (Va), theoretical speed (Vt) and wheel slip, %. To read and process the signals of Hall Effect sensors, a simple microcontroller based system was developed. It mainly consists of an ATMEGA 2560 microcontroller to count the number of pulses, thereby calculating wheel slip. It has 54 digital input/output pins 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button and a LCD screen to display the calculated actual speed, theoretical speed and percentage slip. The outputs of Hall sensors were fed to microcontroller unit to process and calculate the wheel slip according to the program and display it on the LCD screen, also send data to the laptop via USB cable/stores the data in SD card module. It also provided with two LEDs, namely red, green and a buzzer to alert the operator when the slip exceeds the optimum range on farm use. The green led glows continuously to indicate the working of developed system, red LED glows and buzzer on when the slip value exceeds the optimum range. In this design, as per the reviews, the optimum value considered as 10-15% i.e when the slip exceeds the 15%, red led glows along with continuous loud buzzer sound to alert the operator to reduce slip by reducing depth and speed of operation to increase the fuel efficiency.

Validation of the Slip Indicating Device

For validation of the developed Hall effect sensor based technique for slip measurement, the front mounted magnetic disc and rear wheel mounted discs were validated on tar macadam and field surface for actual speed measurement by mounting a commercial non contact type radar sensor.

4.1 Validation of Actual Speed Measurement on Tar Macadam Surface

The measurement of actual speed

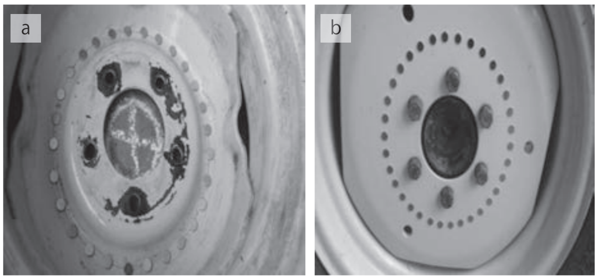


Fig. 5 a: Front wheel rim with mounted magnetic pins; b: Rear wheel rim with mounted magnetic pins

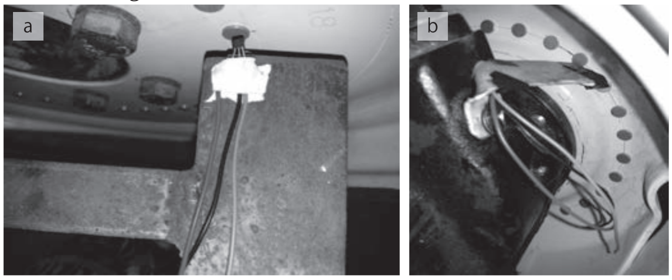


Fig. 6 a: Location of hall effect sensor for proximity switching of rear wheels; b: Location of hall effect sensor for proximity switching of front wheel

by using the front wheel of tractor depends on dynamic weight on the front axle and skid of the front wheel. The actual speed measured with Hall effect sensor was compared with the speed measured by the manual method. The actual speed was measured in different gears at different throttle positions on tarmac surface. The procedure for manual speed measurement was based on measuring the distance travelled for fixed number of revolution and time taken to complete the fixed revolutions. The actual speed measured through front wheel was compared with that measured by the manual method to observe the effect of skid and deflection on the front tyre.

During actual speed measurement, the velocity values obtained from the manual method and the developed device were found to vary from 0.15 to 1.90 m/s with an average reading of 0.67 m/s, whereas those values obtained from Hall effect sensors were found to vary from 0.17 to 1.97 m/s with an average reading of 0.68 m/s with maximum deviation of +5.37% at different gears and throttle position of tractor. This shows the suitability of Hall effect sensor and mounted magnetic pins to measure the actual speed over the costly devices like Radar sensor and other devices. Further, the average actual speed measured by the Hall effect sensor and the manual method on tarmac surface have been shown in **Fig. 7**. It clearly shows that, the indicated speed by the Hall effect sensor is very close to the one measured by the manual method.

Similar tests were also conducted in actual field conditions at different loads with cultivator. During actual speed measurement under actual field condition, the velocity values obtained from manual method and developed device were found to vary from 0.12 to 1.21 m/s, whereas those values obtained from Hall effect sensors were found to vary from 0.11 to 1.31 m/s at different gears and various depths of tractor-implement combination.

From the **Fig. 7**, it is concluded that, the actual velocity in field condition obtained by the both the sensors are very close. Therefore, the front wheel revolutions were used to measure the actual speed for calculation of the wheel slip of the tractor. A very good correlation (R^2 = 0.99) was observed in between the manual measured actual speed values and actual speed values obtained from the hall sensors.

4.2 Testing of Wheel Slip Measurement System

The wheel slip measurement system was also validated on actual field condition with two different implements namely 5 tyne cultivator and rotavator. The results obtained from the developed wheel slip measurement system were compared with the manual method measured values. The developed wheel slip measurement system was also tested in actual field condition to know it's suitability. It was observed that, the wheel slip values of the developed system were seen to vary from 3.6 to 13.4% during tillage operation with cultivator, whereas the manual method of measured slip values were seen to vary from 3.46 to 12.41 % as depth of operation changed from 5.5 to 10.3 cm, This variation could be attributed for error in manual recording of the data.

Similarly during tillage with rotavator, it was observed that, the wheel slip values of the developed system were seen to vary from -1.70 to -2.53%, whereas the manual method of measured slip values were seen to vary from -1.29 to -2.87 % as depth of operation changed from 4.8 to 9.2 cm. This variation could be attributed to error in manual recording of the data. This emphasis the importance of the developed wheel slip measurement system using Hall effect sensor. The comparison of manual method of measured wheel slip values and observed wheel slip values on actual field condition during tillage with cultivator is shown in **Fig. 8**. A maximum deviation of 7.18% was observed between the slip values measured by developed system and manual method during tillage operation with cultivator.

4.3. Validation of Slip Indicator on Actual Field Condition

A field of one hectare fallow land was selected and subdivided into

Fig. 7 Comparison of actual speed measurement on tarmac surface

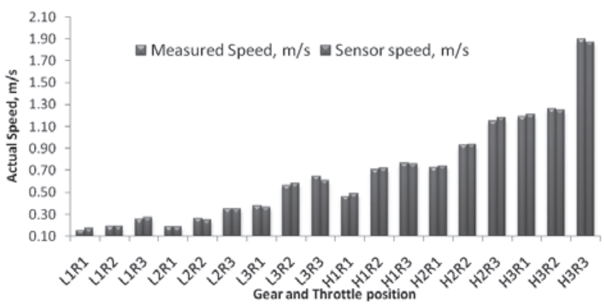
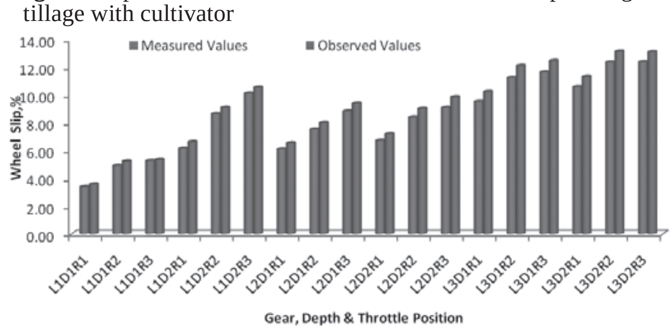


Fig. 8 Comparison of observed and measured wheel slip during tillage with cultivator

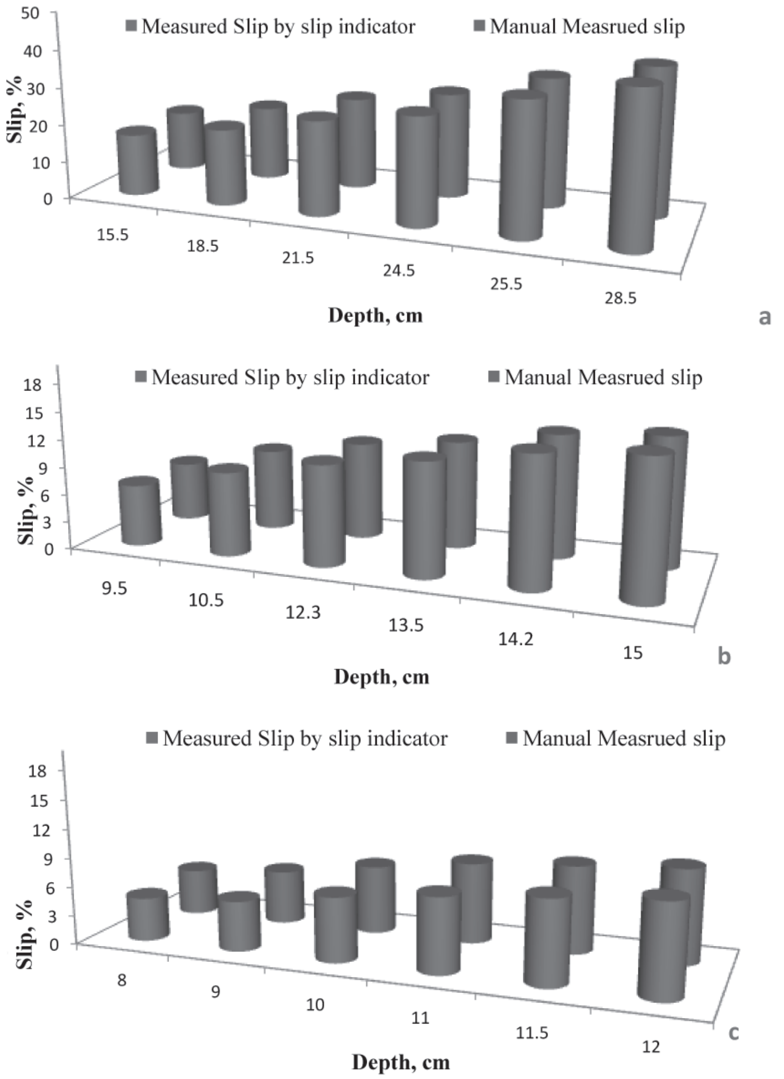


L1 = 1st low gear; L2 = 2nd low gear; L3 = 3rd low gear; H1 = 1st high gear; H2 = 2nd high gear; H3 = 3rd high gear; R1 = 1000 RPM; R2 = 1500 RPM; and R3 = 2000 RPM two plots to validate the developed slip sensing device in actual field condition. The cone index of the soil was measured with help of cone penetromer at various places of selected field. Several tests were conducted with test tractor with three implements, namely, mould board (MB) plough, cultivator and disc harrow. The depth of operation was varied from 15 to 30 cm for MB plough, 9 to 15 cm for cultivator and 8 to 12 cm for harrow. Manual slip measurement was based on measuring the distance traveled for fixed number of revolution of the drive wheels at load and no load conditions. During ploughing operation it was observed that, the slip values ranges between 13.5 to 41.68% as the depth varies from 15 to 30 cm measured by the slip indicator where as the slip values ranges between 12.9 to 42.37% measured by the manual measurement. The comparison of slip values indicated by the slip indicating device and manually measured slip under ploughing, harrowing and tillering operation is shown in **Fig. 9a**, **b** & **c**.

Conclusions:

1. The simple technique involving a Hall effect sensor and magnetic pins was found suitable for wheel slip measurement of tractor on tarmac surface and field condition.
2. The developed digital system is able to display measured parameters like wheel slip, actual speed and depth of operation without any malfunction.
3. The developed digital system is simple in construction, cheap and accurate.
4. The developed wheel slip measurement system is interchangeable among the tractor by uploading the rolling radius of the front and rear wheels via the computer interface.
5. This system helps the researchers and engineers in traction studies of different tractor-implement combination.
6. This system can be used for measurement of actual speed of operation of tractor under tarmac and actual field over the costly devices like radar sensors.
7. This system can also be used for measurement of wheel slip of tractor in 4WD mode by mounting magnetic pins and Hall effect sensor on remained front wheel.

Fig. 9 Comparison between measured and obtained slip values: a. tractor with MB plough, b. Tractor with cultivator, c. Tractor with disc harrow



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Performance Evaluation of KAU Manure Pulverizer

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Abstract

In order to assist organic farming, the effective utilization of manures is required. Recognizing the need and importance of pulverization of manures, the Department of Farm Power Machinery and Engineering developed and tested the manure pulverize and optimized the manure parameters. The machine consists of pulverizing drum, pulverizing blades, sieve, feeding hopper and supporting frame. Dried manures were fed into the pulverizing drum from the machine hopper through its feeding chute and it gets pulverized due to the rotation of the pulverizing blade. The average capacity of the pulverizer was 500.00 kg h^{-1}. Efficient moisture content values obtained for cow dung, goat fecal pellet and neem cake were 20.93%, 16.70% and 14.20%, respectively. The complete testing analysis of the machine indicated that KAU manure pulverizer performed efficiently with the use of 5 mm sieve with 15 mm clearance for all types of dried manures tested.

Keywords: KAU manure pulverizer; Manures; Fineness modulus

Fig. 1 KAU Manure Pulverizer

Introduction

Manures are plant and chemical waste that are used as a source of plant nutrients. There are number of organic manures like farmyard manure, green manures, compost prepared from crop residues and other farm wastes, vermin compost, oil cakes and biological wastes − animal bones, slaughter, house refuse etc. Organic production methods are based on specific standards precisely formulated for good production and aim to achieve an agro ecosystem, which are socially and ecologically sustainable. It is based on minimizing the use of external inputs through the use of on farm resources efficiently compared to industrial agriculture.

As manure dries, nutrients are not only concentrated on a weight basis, but also on a volume basis due to structural changes. Compared to the fresh manure, it is easier to handle and transport the dried manure because of decreased volume and weight (Salikutti, 2006). Furthermore, dehydrated manure has a consistent texture and is easier to apply to gardens. Dehydrated manure has a lower pathogen and weed seed content than the fresh manure. When manure dries up to 10-17% of moisture and is applied into a fine soil, nutrients are more concentrated and the soluble salt level is probably higher in dehydrated manure than in locally available farm manure (Babu et al., 2008). Thus the evaluation of pulverizer becomes inevitable. While recognizing the importance of the need for powdering the dried manures, Kerala Agricultural University (KAU) has developed a machine named “KAU Manure Pulverizer” to pulverize the dried organic manures such as cow dung, neem cake, biogas slurry, and goat and rabbit fecal pellets etc.

Table 1 Efficiency of pulverizer with different moisture content of manures

Item	Sample	Moisture content (%)	Input (kg)	Output (kg)	Time (sec)	Efficiency (%)
Cow dung	1	28.00	10.00	9.67	86.30	96.70
	2	16.36	10.00	9.71	78.80	97.10
	3	20.93	10.00	9.81	67.60	98.10
Goat fecal pellet	1	16.70	10.00	9.85	71.00	98.50
	2	24.48	10.00	9.75	84.33	97.50
	3	10.82	10.00	9.65	56.32	96.50
Neem cake	1	14.20	10.00	9.85	61.31	98.50
	2	26.90	10.00	9.79	120.80	97.90
	3	20.70	10.00	9.61	84.32	96.10

Materials and Methods

2.1 Description of the Machine

The KAU manure pulverizer mainly consists of a prime mover, pulverizing drum, feeding chute, power transmission unit, pulverizing blade, sieve and supporting stand as shown in **Fig. 1**. A single phase electric motor (1.5hp, 1440 rpm, 230V, 10A and 50Hz) was used as the prime mover for the developed pulverizer. Two double V-belt pulleys were used for power transmission from the electric motor to the main shaft. One of the main parts of the machine is the pulverizing drum which is made of M.S sheet of 52 cm diameter and 30 cm height in which dried manures are pulverized by impact and cutting forces of the pulverizing blades. A trapezoidal feeding chute of 565 cm length is provided to feed the dried manures. The rotary shaft is fitted with four blades that are fixed inside the pulverizing drum. It has a length of 22 cm and width of 4 cm and is made up of EN8 flat of 6 mm thick. The blades are fitted to the bottom of the shaft using a nut. It is sharpened on one side at an angle of 45°. A 5 mm square mesh or 10 mm opening mesh was provided at the bottom of the pulverizing drum. It was supported by a MS sheet of size 52 cm × 2 cm × 0.4 cm that was welded to the supporting frame located below the pulverizing blades. A clearance of 1.5cm is provided between sieve and pulverizing blade to easily collect the pulverized manures. The supporting stand was made with four angle irons of size 5 cm × 5 cm × 0.6 cm that were of height 65 cm. **Fig. 2** presents the orthographic projection of the KAU manure pulverizer.

2.2 Working Principle of the Machine

The dried farmyard manures are filled in the drum through feeding chute. The feed rate was controlled through the means of a cap provided at the top cover. Upon starting the electric motor, the main shaft rotates along with the blades inside the drum. Due to the rotation of the blades, the dried manure gets crushed within the small clearance provided between the sieve and the pulverizing blades (Nwoguet al., 2013: Etamaihe and Iwe, 2014). Power from the electric motor was transmitted to the main shaft by means of double V-belt pulley. Effective crushing is achieved by providing a tapering at one side of the blade (Gbabo and Ndagi, 2014). The powdered manures pass through the sieves which were collected at the bottom part of the machine. The dried manures will remain inside the drum until it attains a size smaller than the size of the holes in the sieve.

2.3 Moisture Content

Moisture content is the percentage of water present in a given manure sample. The oven dry method was used for the determination of moisture content. Pulverizing manure is collected in a clean container and is placed in an oven under controlled temperature conditions of 105-110 °C for a period of 24 hours.

$$\text{Moisture content, \%} = [(M_1 - M_2) / M_2] \times 100\% \quad ...(1)$$

where,

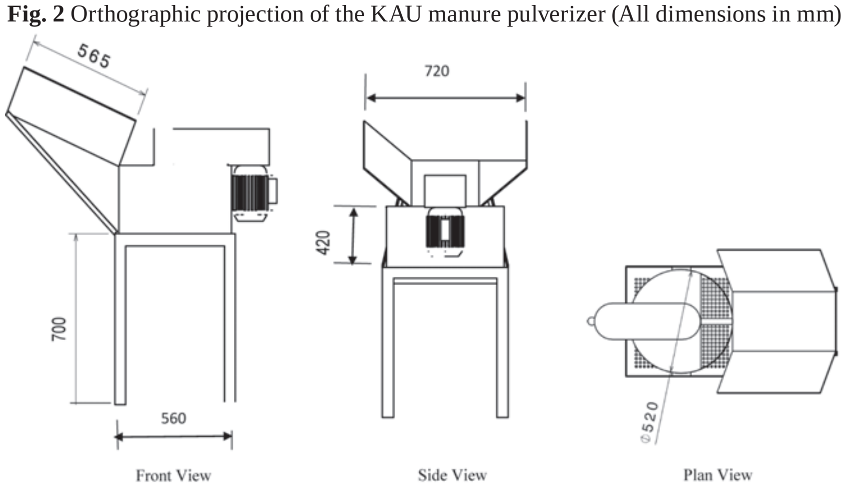
M_1 = initial weight of the manure, g

M_2 = final weight of the manure, g

2.4 Capacity of the Pulverizer

The capacity of the machine is

Fig. 2 Orthographic projection of the KAU manure pulverizer (All dimensions in mm)



considered as the amount of pulverized manure per unit time (Nwaigwe et al., 2012). In order to calculate the machine capacity, manure was fed into the machine for six known period of time viz. 10, 20, 40, 50 and 60 seconds. The time taken was observed using a stopwatch and the weight of the pulverized manure in each period was recorded. Knowing the time required and weight of the pulverized manure, the machine capacity was calculated as:

Capacity, kg h^{-1} = (weightofpulverizedmanure, kg) / (timeofoperation, h) ...(2)

2.5 Efficiency of the Pulverizer

The efficiency of the pulverizer was considered as the amount of pulverized manure per kg of dried manure as feed.

2.6 Fineness Modulus of the Powder

Fineness modulus is an index number which represents the mean size of particles in pulverized manure. It is calculated by performing sieve analysis with standard sieves (Thomas, 2006). The sieves used for the fine sieve analysis are 2 mm, 1 mm, 600μm, 425μm, 300μm, 212μm, 150 μm and 75 μm IS sieves. The sample weights retained on each sieve were recorded. The cumulative weight retained on each sieve was used to determine the cumulative percentage retained on each sieve. Adding all the cumulative percentage values together and dividing it by 100 will give the value of fineness modulus (Opath, 2014).

Results and Discussion

The test was carried out to determine the capacity of pulverizer, efficiency of operation and optimization of manure parameters according to pulverizer efficiency. The average capacity of the pulverizer was observed to be 500.00 kg h^{-1}. **Table 1** presents the efficiency results obtained for the pulverizer using different moisture contents of manures.

From **Table 1**, it can be deduced that increase in moisture content of cow dung from 16.36% to 20.93% increases the efficiency from 97.10% to 98.10%. However, further increase in moisture content beyond an optimum limit causes further decrease in efficiency due to adhering nature of manure. This is evident in the case of increasing the moisture content of cow dung to 28% which brought down the efficiency value to 96.70%. The result of using goat fecal pellet as shown in **Table 1** was almost similar to that of cow dung except for the highest moisture content involved which produced an efficiency whose value fell in between that of the efficiency values corresponded to 10.82% and 16.70% moisture contents. But in the case of cow dung the highest moisture content of input produced an efficiency below the efficiency values obtained for 16.36% and 20.93% moisture content. Whereas in the case of pulverizing neem cake, efficiency value decreased from 98.50% to 96.10% when the moisture content of neem cake increased from 14.20% to 20.70%. Further increase in moisture content to 26.90% from 20.70% increased the efficiency value to 97.90%.

Fig. 3 shows the relationship between efficiency and moisture con-

Fig. 3 Efficiency – Moisture content relationship

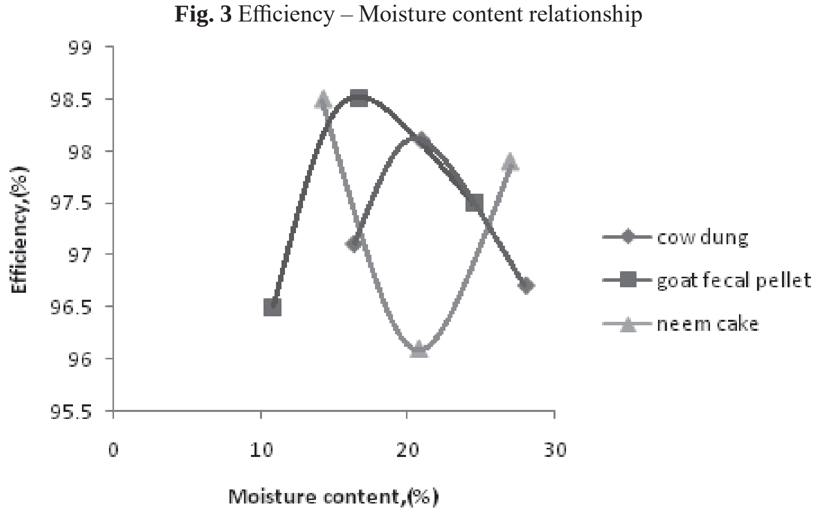


Fig. 4 Variation of efficiency with clearance at 5 mm sieve size

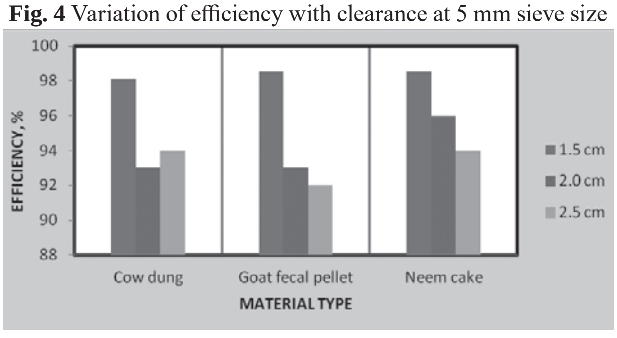
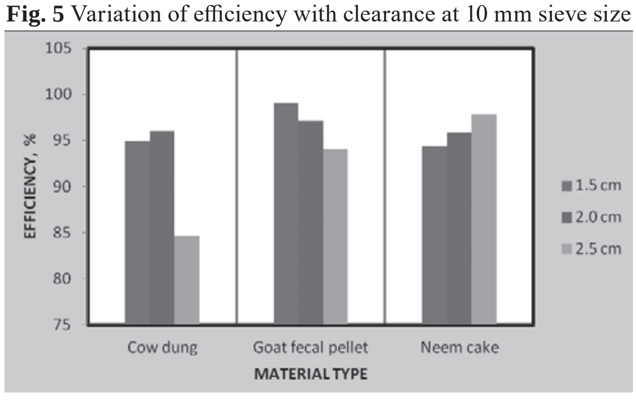


Fig. 5 Variation of efficiency with clearance at 10 mm sieve size



tent for the different manures used to evaluate the machine. It can be seen that the goat fecal pellets produced the highest efficiency value of 98.50% while neem cake produced the least efficiency value of 96.10%.

Also presented in **Figs. 4** and **5** are the bar charts showing the relationship between efficiency and the material type with the corresponding values of sieve size of 5 mm and 10 mm, respectively. Test was carried out in both 5 mm and 10 mm sieves at 1.5, 2.0, 2.5 cm clearance respectively. In the 5 mm sieve size higher efficiency was obtained at 1.5 cm clearance for all manures whereas in 10 mm sieve variations were observed in the efficiency values obtained with respect to the type of manure and clearance used.

For the determination of fineness modulus, different pulverized manures with different moisture content from different sieve sizes and clearances were collected and it was carried out in the laboratory. The pictorial views of the powdered form obtained for cow dung, goat fecal pellet and neem cake during machine testing are presented in **Figs. 6**, **7** and **8**, respectively.

Conclusions

A KAU manure pulverizer was developed and tested for its performance. Results showed that the KAU manure pulverizer was highly efficient in pulverizing goat fecal pellets with less time of operation. It works efficiently with a clearance of 1.5 cm between sieve and the pulverizing blade and is mostly suitable for goat fecal pellet.

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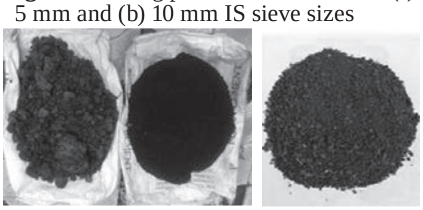
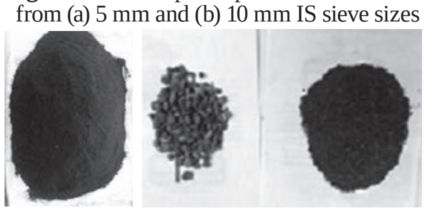
Fig. 6 Cow dung powder observed from (a) 5 mm and (b) 10 mm IS sieve sizes



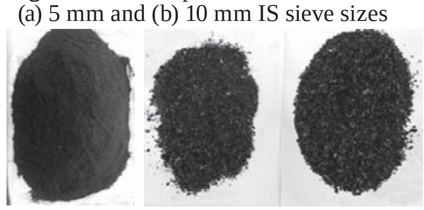
(a) (b)

Fig. 7 Goat fecal pellet powder observed from (a) 5 mm and (b) 10 mm IS sieve sizes



(a) (b)

Fig. 8 *Neem* cake powder observed from (a) 5 mm and (b) 10 mm IS sieve sizes



(a) (b)

Development and Evaluation of a Walk Behind Engine-operated Weeder for Upland Crops

by

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Abstract

Weeding is one of the critical operations in crop production. Weed control is a major problem in Indian agriculture and needs intensive efforts to mechanize the weeding operation. Weeds are serious threat to all crops. A self-propelled weeder, propelled by a 4.1 kW petrol engine, was developed with vertical axis weeding rotor having "L" shaped blades attached to its periphery. The major machine parameters influencing the performance of mechanical weeders, namely number of blades, depth of operation and rotational speed of weeding rotor were analysed for their effects on weeding efficiency, and the operational parameters were optimized to carryout field performance evaluation. The results of field evaluation of developed prototype weeder revealed that the maximum weeding efficiency was 88.29%, plant damage was 6.63%, actual field capacity, theoretical field capacity and field efficiency were 0.0327 ha/h, 0.0378 ha/h and 86.50% respectively. The performance index was determined to be 65.82. Fuel consumption and cost of operation of the developed weeder were 0.85 l/h and Rs. 3618/ha, respectively.

Introduction

Weeds are plants that grow where they are not wanted and negatively impact on main crop growth. Their undesirable qualities are considered to outweigh their good points. Weeds can be classified in numerous ways. Sometimes weeds are classified as broadleaves (dicotyledonous plants) and grasses (monocotyledonous plants). Another common way to classify weeds is by their lifespan – annuals, biennials, and perennials. Weed control is major problem in Indian agriculture and needs intensification to overcome the problem of labour availability and high labour wages. Weeding is an important operation in crop production. Weeding is an important practice to be carried out during the initial stages of crop growth especially for controlling the weeds competing with the crop, stirring the soil for aerating the crop root zones and for burying the weeds into the soil. Mechanization level of weeding and interculture operation in India is very low compared to other field operations (Mehta et al., 2019). Weeding operation requires high labour input. In present scenario, the shortage in labour availability results in untimely operations leading to loss of crop yield. The high cost of weeding can be understood from a comparative study of the losses in farm due to various causes.

Historically there have been numerous efforts to control and manage the weeds to avoid negative impact on the crops. Common weed management practices in upland cultivation include soil tillage, flame weeding, hand weeding, mechanical weeding, and herbicide application. These are often used in combination (Ramamoorthy et al., 2004). Chemical weed control method involves the use of herbicides to kill/ eradicate/ inhibit the growth of weed species by changing their chemical environment. Herbicides change the chemical environment of plants, which can be more easily manipulated than the climatic, edaphic, or biotic environment. Biological control is usually thought of as requiring intentional introduction of a parasite, predator or pathogen to achieve control but it is also a natural phenomenon. Flame weeding refers to use of gaseous flames to burn the weeds. Flaming is considered to be one of the effective methods of weed control in terms of physical damage caused to the weed plants. The differentiation in burning depends upon the weeds being small and tender and upon the crops having stems that are resistant to the intense heat and being tall enough so that the flame directed at the ground in the row will not strike the leaves or other tender parts.

Weeding is commonly carried out manually by woman labour in small and marginal farms using small hand tools such as Khurpi. Manual weeding requires large labour force i.e., about 25% of the total labour requirement which sums up to 200 to 1200 man-h/ha. The drudgery involved in the operation results in fatigue and pains in muscles and joints. Though manual weeding is considered to be the best, the undependable labour availability and escalating wages have given impetus to the development of mechanical weeding tools and machines. Hence, long handled weeders were introduced to relax the difficulty involved in manual weeding. Long handled cono-weeder, star weeder and peg weeders have gained good response from farm labours due to their ease of operation and versatility. However, it consumed more time and needed more effort to uproot the weeds completely. Hence, the weeders with suitable tools to cut, bury and uproot the weeds and propelled by a prime mover were found most suitable keeping in view the filling of mechanization gap as well as to completely avoid drudgery of manual weeding. The prime mover operated weeders were examined for their feasibility and were found efficient both in terms of rate of area coverage and weed mortality rate.

Mechanical weed control is an effective weed management method in row crops, organic farming, and minor crops (like vegetables, fruits, or some seed crops). Mechanical weeding is effective and leaves no chemical/herbicide residues on crop plants or soil. Modernized mechanical weed control, particularly when using precision weeding systems, can be a highly effective substitute for chemical weed control. Mechanical weeding can provide effective weed management even when other methods are not possible and can outperform them in some situations. There are several forms of mechanical weed control ranging from handheld tools to the most advanced vision-guided hoes.

Parida (2002) developed a modified IRRI star cum cono-weeder for wet land. He reported that the weeder consisted of a frame, a handle, a float, star wheels and a serrated cone. The average field capacity and weeding efficiency of the weeder were 0.02 ha/h and 80% respectively. The cost of the unit and operating cost were calculated as Rs. 600 and Rs. 480/ha respectively.

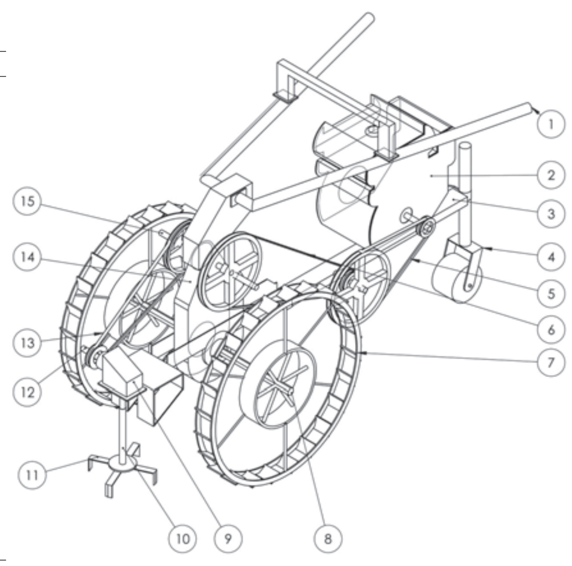
Victor and Verma (2003) developed a power-operated rotary weeder for wetland paddy. A 0.3 kW petrol engine was used with a reduction gearbox. Power transmission from engine to traction wheel and to the cutting unit was provided by means of a belt, pulley, chain and sprocket. four L-shaped standard blades were used on the hub fitted on a rotary shaft. The spacing between the blades was 200 mm. They reported that the field capacity of the machine varied between 0.04 and 0.06 ha/h with a field efficiency of 71%. The weeding efficiency of the machine was 90.5%.

Shridhar (2013) designed and developed a mechanical weeder consisted of two cutting mechanisms viz., primary cutting which is in front to loosen the soil and secondary cutting which is behind to accomplish weed cutting and lifting of weeds. He reported that field efficiency of the weeder was 81.2%.

Singh and Kumar (2008) designed a self-propelled rotary weeder for wide row crops. A three stage speed reduction of the prime mover has been incorporated. A V-belt and chain transmit engine power to the weeding unit. The 100 kg weeder used a 2.2 kW engine. The rotational speed of the weeding rotor has been achieved at 70 rev/min. and the vibra-

Fig. 1 Conceptual drawing of developed prototype weeder depicting all the components

S. no.	Particulars
1.	Handle
2.	Engine
3.	Base frame
4.	Depth control wheel
5.	Belt pulley drive (1st reduction)
6.	Belt pulley drive (2nd reduction)
7.	Ground wheel
8.	Hexagonal shaft
9.	Bevelled gear box
10.	Weeding rotor
11.	Weeding blade
12.	Bevelled gear input shaft
13.	Belt pulley drive (3rd reduction)
14.	Main gear box housing
15.	Main gear box housing shaft



tions are within manageable limits.

Tajuddin (2009) developed a 2.2 kW petrol start kerosene run engine operated weeder for low land rice. The weeder was field tested in silty loam soil. The design forward speed of the weeder was 2.5 km/h. The theoretical field capacity and actual field capacity were 0.09 and 0.075 ha/h respectively with field efficiency and weeding efficiency of 83% and 89% respectively. The cost of the machine was determined as Rs. 31,500. Cost of operation was calculated as Rs. 1,060/ha.

Keeping in view the above facts and figures, the present research was carried out with an objective to develop a walk behind engine operated weeder and conduct the field evaluation for upland crops.

Materials and Methods

Description of Machine

The walk behind engine operated weeder consisted mainly of prime mover, ground wheels, depth control wheel, speed reduction gear box, power transmission system, beveled gear box and a weeding rotor. Different views of the weeder with overall dimensions are depicted in **Figs. 1** and **2** through conceptual drawings.

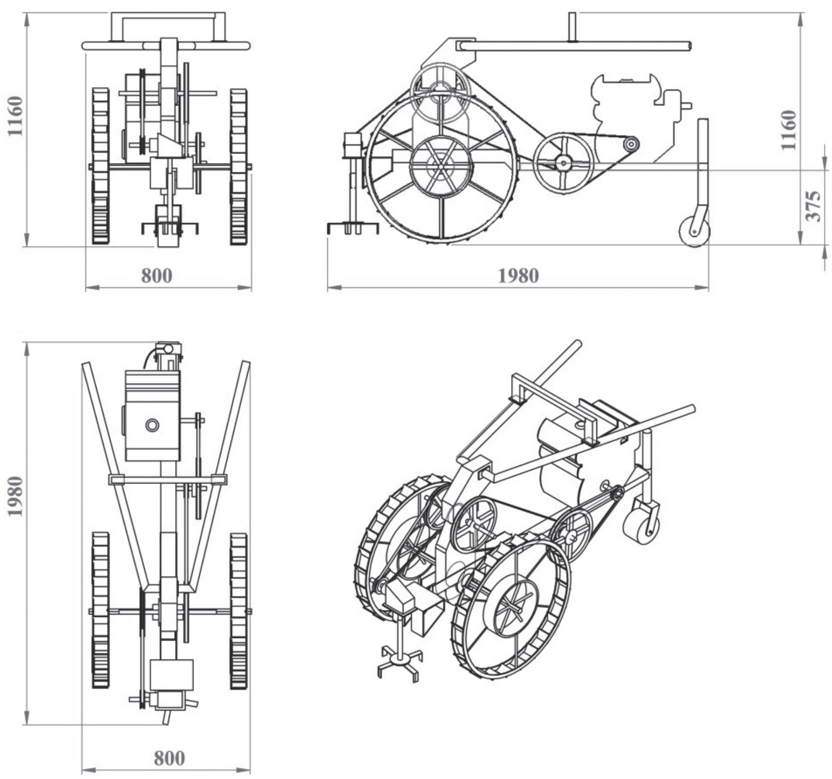
Prime Mover

Prime mover was selected based on the optimized power requirement of the weeding rotor to perform field operation. The selected engine was 750 series Briggs & Stratton petrol engine. It produces maximum output power of 4.1 kW at a rated speed of 2400 rev/min.

Ground Wheels

Lug type ground wheels were fabricated taking into the account the dry land conditions and plant spacing. Rizaldi et al. (2014) studied the tractive performance of lug wheels and they found that the highest efficiency was obtained when the lug wheel had 24 lugs with a lug angle of 30 degree. Hence the lug type ground wheels were fabricated. Ground wheels were mounted on a common hexagonal shaft. The distance between the ground wheels was adjustable to match the row to row spacing of different crops.

Fig. 2 Overall dimensions of the developed prototype weeder (All dimensions are in mm)



Depth Control Wheel

It was a drum type wheel to control the depth of operation. Provision was made to adjust the height of the wheel for varying field conditions. It was fabricated such that it travels within the row spacing without causing damage to the plants. A pivot joint was provided between ground wheel frame and the adjusting rod to ensure easy turning of the prototype weeder.

Speed Reduction Gear Box Housing

The speed reduction gear box selected was chain and sprocket type. It was used to reduce the engine rotational speed so that the ground wheels get correct rotational speed to match the walking speed.

Belt and Pulley Transmission Drive

Belt and pulley transmission was used to provide drive to ground wheels as well as to the weeding rotor by means of three intermediate steps. B-type single grooved V-pulleys made of cast iron were used for power transmission.

Bevel Gear Box

Bevel gear box is used to impart change in direction of rotation to the vertical weeding rotor and also to reduce the speed to design rotor speed for weeding.

Weeding Rotor

A vertical axis rotating type weeding rotor was developed with blades attached at the periphery. This is the main component of the weeder which has four "L" shaped weeding blades attached at the lower end of a mild steel pipe. The pipe was inserted into a weeding shaft rotating in vertical axis. Adjusting nut was provided to change the pipe position on the weeding rotor shaft. The shaft was mounted on the front end and was supported by a self-aligning bearing.

Experimental Design to Determine the Effect of Operational Parameters on the Weeding Efficiency of the Developed Prototype Weeder

The weeding operation was carried out by the developed prototype weeder.

The width of blade was provided according to the spacing of Okra crop. The weeder was run at 10 mm depth by adjusting the depth control wheel provided at the back. Weeding rotor was run at 150 rev/min. The throttle lever in the prototype was set to have 1.5 km/h forward speed. Then the weeder prototype was operated for 10 m distance. All necessary readings were recorded and the average value of readings was calculated. The time taken to span the distance was also noted. The weeding efficiency was determined. The above procedure was replicated thrice for the selected levels of variables and all the readings were tabulated.

The above experiment was repeated for the rotor speeds of 200 and 250 rev/min. Similarly for the remaining selected operating depth levels the above procedure was repeated and the observations were recorded and tabulated.

An experiment with Factorial Randomized Block Design (FRBD) was laid out. The factors considered and their levels are furnished in **Table 1**. “AGRES” statistical software was used to analyse the data in order to obtain the necessary analysis of variance of the main and interaction effect of factors on weeding efficiency. The treatment, which gave the maximum weeding efficiency, was selected as the best.

Field Performance Evaluation

To study the performance of prototype, tests were conducted with optimized levels of number of blades, depth of operation and weeding rotor speed. The weeder was operated in the field at a predetermined speed i.e., 1.5 km/h and time taken to cover a given area of land was noted. It also included time taken for turning, repairs and rest periods. Performance of the machine was evaluated in terms of weeding efficiency, plant damage, theoretical field capacity, actual field capacity, field efficiency and performance index.

Weeding Efficiency

The weeding efficiency was calculated by weed count method. To determine weeding efficiency, a quadrant of 300 × 300 mm was placed in the field at random and the number of weeds inside the quadrant was counted before and after weeding by machine.

The weeding efficiency was calculated using the following equation (Remesan et al., 2007).

$$e = [(N_1 - N_2) / N_1] \times 100$$

where,

e = weeding efficiency, %

N_1 = number of weeds in the quadrant area before weeding

N_2 = number of weeds in the quadrant area after weeding

Plant Damage

The percentage of damaged plants was calculated from the following equation (Srinivas et al., 2010).

$$q = (Q / P) \times 100$$

where,

q = plant damage, %

Q = Number of main crop plants in the 10 m row length after weeding

P = Number of main crop plants in the 10 m row length before weeding

Theoretical Field Capacity

The theoretical field capacity was worked out from the operating speed (0.42 m/s) and width of operation (0.25 m) using following equation

$$C_t = (W \times S) / 10000$$

where,

C_t = Theoretical field capacity, ha/h

W = Width of operation, m

S = Speed of operation, m/s

Actual Field Capacity

The selected plot was marked and the time consumed by the weeder for weeding was noted and the field capacity was calculated. The effective field capacity is the actual average rate of area coverage by the weeder based on the total field time and is given by the equation.

$$C_e = A / t$$

where,

C_e = actual field capacity, ha/h

A = area covered, ha

t = time taken, h

Field Efficiency

Field efficiency (E_f) was worked out as the ratio of theoretical field capacity (C_a) and actual field capacity (C_t), expressed in percentage.

$$E_f = C_a / C_t$$

Performance Index

The power available to operate the weeder (P) was 4.1 kW. Performance of the prototype weeder was assessed through performance index (PI) using the following equation (Srinivas et al., 2010)

$$PI = [a \times (100 - q) \times e] / P$$

where,

Table 1 Levels of variables selected for performance evaluation of weeder

Independent variables	Levels
Number of blades (N)	Three (2, 3, 4)
Depth of operation (D), mm	Three (25, 50, 75)
Rotational speed of weeding rotor (S), rev/min.	Three (150, 200, 250)
Dependent variable	
Weeding efficiency, %	

PI = Performance Index
a = Actual field capacity of weeder, ha/h
q = Plant damage, %
e = Weeding efficiency, %
P = Power available to operate the weeder, kW

Cost Economics of the Developed Weeder

The fixed and variable costs incurred for weeding with the prototype weeder per hour was calculated as per the procedure described in IS: 9164-1979. Fuel consumption of the weeder per hour was determined by refilling method. From the field capacity of the weeder, the cost of operation per hectare was calculated.

Results and Discussion

The 4.1 kW power rated petrol engine was used to propel the prototype weeder. The lug type ground wheels with 24 lugs, each lug having a lug angle of 30 degree spaced uniformly were fabricated. Each ground wheel had a diameter of 750 mm and width of 75 mm. The depth control wheel was fabricated with diameter of 150 mm and width of 100 mm using 3 mm thick mild steel sheet. The International Rice Research Institute (IRRI) design self propelled vertical conveyor reaper gear box housing was used by making required modifications. The gear ratio of the selected gear box housing was 22:1 through two steps of chain and sprocket arrangement to match the walking speed of the operator. The bevel gear box was used to impart drive to the weeding shaft at right angles. It consisted of two bevel pinions with 10 teeth on input shaft pinion and 14 teeth on output shaft pinion. Hence, the selected bevel gear box had a speed reduction ratio of 5:7. Weeding rotor was of vertical axis rotating type with four “L” shaped blades attached to the periphery of central hub. The pulleys having standard diameters of 75, 90, 200 and 300 mm were selected for transmission. The engine output shaft has a rated rotational speed of 2400 rev/min (N_1) and a 75 mm (D_1) diameter pulley was mounted on this shaft. The intermediate pulleys (D_2 and D_3) were mounted on a common shaft rotating with same speed (N_2 and N_3). Two more pulleys having diameter of 300 (D_4) and 200 mm (D_5) were mounted on main gear housing shaft (N_4 and N_5). Another pulley having diameter of 90 mm (D_6) was mounted on bevel gear input shaft rotating at speed N6. The overall technical specifications of the prototype weeder are given in **Table 2**.

Table 2 Technical specifications of the developed prototype weeder

S. no.	Particulars	Values
1.	Overall length of the machine, mm	1980
2.	Overall height of the machine, mm	1160
3.	Overall width of the machine, mm	800
4.	Size of the engine, kW	4.1
5.	Diameter of the ground wheels, mm	750
6.	Ground clearance, mm	375
7.	Speed ratio from engine to ground wheels	300:1
8.	Speed ratio from engine to weeding rotor	9.6:1
9.	Working width, mm	250
10.	Working depth, mm	75
11.	Number of blades on weeding rotor	4

The factorial analysis of the measured data was performed to assess the influence of the variables viz., number of blades (N), rotational speed of weeding rotor (S) and depth of operation (D) on weeding efficiency. The analysis of variance (ANOVA) on weeding efficiency for the operation of weeder is furnished in **Table 3**.

Table 3 ANOVA for weeding efficiency

S. no.	SV	DF	SS	MS	F
i.	Treatments	26	2237.20	86.04	49.23**
ii.	Number of blades (N)	2	1690.17	845.08	483.52**
ii.	Rotational speed of weeding rotor (S)	2	231.48	115.74	66.22**
iii.	Depth of operation (D)	2	41.68	20.84	11.92**
iv.	N × S	4	168.59	42.14	24.11**
iv.	S × D	4	14.81	3.70	2.11 NS
v.	N × D	4	44.23	11.05	6.32**
vi.	N × S × D	8	46.21	5.77	3.30**
vii.	Error	52	90.88	1.74	1
viii.	Total	80	3050.75	38.13	21.81

CV = 1.81%, CD (0.05) = 0.82, CD (0.01) = 1.13
** Significant at 1% level; * Significant at 5% level; NS = Non Significant

The main effects of number of blades (N), rotational speed of weeding rotor (S) and depth of operation (D) were significant at 1% level of probability. But the effect of combination of rotational speed of weeding rotor (S) and depth of operation (D) was non-significant.

Effect of Operational Parameters on Weeding Efficiency of Developed Weeder

The weeding efficiency of the weeder was measured at selected levels of number of blades (N), rotational speed of weeding rotor (S) and depth of operation (D).

Effect of Operational Speed (S) and Number of Blades (N) on Weeding Efficiency at Depth of Operation of 25 mm (D_1)

The relationship between weeding

efficiency of weeder and rotational speed of the weeding rotor (S) with selected number of blades (N) at 25 mm depth of operation (D_1) is depicted in **Fig. 3**. From the figure, it was observed that the weeding efficiency increased from 70.06 to 72.55% at rotational speeds of 150, 200 and 250 rev/min when 2 blades were implied for weeding. The observation was mainly due to increase in rotational speed of weeding rotor which applied more shearing force to the soil as a result the weeding efficiency increased. The values of weeding efficiency for rotational speeds of 150, 200 and 250 rev/min at 3 blades were 72.3, 72.54 and 73.86% respectively. Similarly the values of weeding efficiency with 4 blades were 76.25, 80.27 and 83.25% respectively. As the number of blades increased the weeding efficiency also increased because the area covered for weeding per rotation of the weeding rotor will increase with increase in number of blades.

Effect of Operational Speed (S) and Number of Blades (N) on Weeding Efficiency at Depth of Operation of 50 mm (D_2)

The relationship between weeding efficiency of weeder and rotational speed of the weeding rotor (S) with selected number of blades (N) at 50 mm depth of operation (D_2) is depicted in **Fig. 4**. From the figure, it was found that the values of weeding efficiency were 70.2, 72.01 and 73.25% respectively for rotational speeds of 150, 200 and 250 rev/min with 2 blades. Weeding efficiency however interestingly decreased from 73.98 to 73.22% at rotational speeds of 150 and 200 rev/min and then increased to 74.31% at rotational speed of 250 rev/min with 3 blades in operation. Values of weeding efficiency at 150, 200 and 250 rev/min with 4 blades in operation were found to be 78.12, 85.1 and 86.39% respectively. The significant increase in the values of weeding efficiency were observed at 50 mm depth of operation compared to 25 mm depth of operation due to increase in number of weeds uprooted as the depth of operation increased.

Effect of Operational Speed (S) and Number of Blades (N) on Weeding Efficiency at Depth of Operation of 75 mm (D_3)

The relationship between weeding efficiency of weeder and rotational speed of the weeding rotor (S) with selected number of blades (N) at 75 mm depth of operation (D_3) is depicted in **Fig. 5**. From the figure, it was observed that weeding efficiency increased from 71.2 to 73.08% at rotational speeds of 150, 200 and 250 rev/min with 2 blades employed in weeding. The lower values of weeding efficiency were observed at rotational speed of 150 rev/min because of the increase in soil resistance with increase in depth of operation. Similarly the values of weeding efficiency observed at 150, 200 and 250 rev/min rotational speeds with 3 blades were 73.29, 74.25 and 76.05% respectively. Weeding efficiencies of 79.26, 87.35 and 88.29% were observed at 150, 200 and 250 rev/min rotational speeds with 4 blades in operation. The selected depth of 75 mm would uproot almost all the weeds as the depth of operation is more than the maximum root length of weeds observed in the field.

From the analysis of weeding efficiency, four blades (N) at 250 rev/min. of rotational speed of weeding rotor (S) with 75 mm depth of operation (D_3) were selected as optimized levels.

Field Performance Evaluation

The developed prototype weeder was tested in a farmer's field having cone index range of 0.03 to 0.18 kg/mm^2 and moisture content of 13 to 23% and planted with Okra crop.

Fig. 3 Relationship between weeding efficiency and rotational speed of weeding rotor (S) for selected numbers of blades (N) at 25 mm depth of operation (D_1)

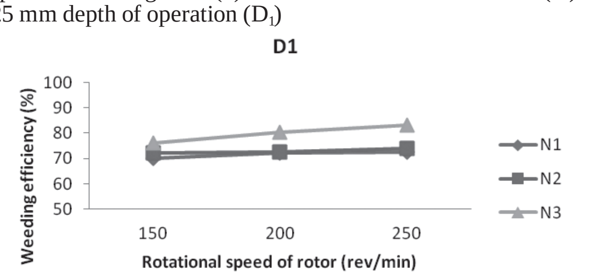


Fig. 4 Relationship between weeding efficiency and rotational speed of weeding rotor (S) for selected numbers of blades (N) at 50 mm depth of operation (D_2)

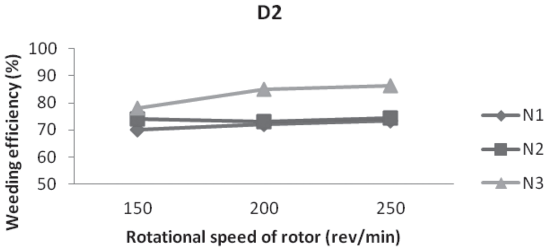
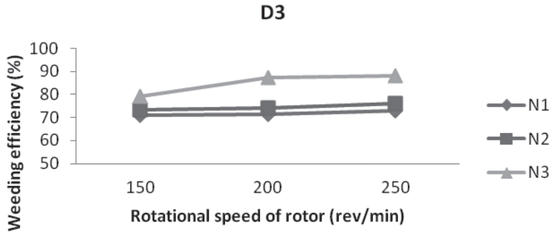


Fig. 5 Relationship between weeding efficiency and rotational speed of weeding rotor (S) for selected numbers of blades (N) at 75 mm depth of operation (D_3)



Weeding was done on 15th DAP. The spacing of crop was 350 × 200 mm. The size of the plot was 75 × 135 m. The operational view of walk behind engine operated weeder is shown in **Fig. 6**.

The maximum weeding efficiency of 88.29% was recorded with an average value of 82.56%. The average values of plant damage, theoretical field capacity, actual field capacity, and field efficiency were found to be 6.63%, 0.0378 ha/h, 0.0327 ha/h and 86.50% respectively. The performance index was worked out to be 65.82.

Bill of material was prepared and the cost of the weeder was calculated considering the material cost, costs incurred in fabricating all the components of the machine and fabricator wages. The cost of weeder was Rs. 45000. Fuel consumption of the weeder was observed to be 0.85 l/h. The cost of operation was worked out considering fixed cost and variable cost. It was determined as Rs. 3618/ha for the given field capacity.

Conclusions

Mechanical weeding, although found to be the best method of weed control, there is a lacuna in availability of traditional as well as improved machinery for carrying out weeding operation in upland crops. Self propelled weeding units have been found most suitable for small and marginal farms. Hence, the present study aimed at developing a walk behind engine operated weeder with vertical axis rotating weeding rotor to carry out weeding operation in upland crops. Analysis of weeding efficiency was carried out with three operational parameters viz., number of blades (N), rotational speed of weeding rotor (S) and depth of weeding (D). From the analysis, it was found that four blades at 250 rev/min. rotational speed of weeding rotor with a depth of 75 mm was the optimum condition to carry out the weeding operation. Various performance parameters such as field capacity, plant damage, field efficiency and performance index were determined for optimized conditions. The developed weeder was found suitable to use in small and marginal upland fields with a cost of operation of Rs. 3618/ha which is very less compared to the manual weeding method.

Fig. 6 Field operational view of developed prototype weeder

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Smartphone Application Development for the First Generation Selection of Sugarcane Clones

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Abstract

Selection of an individual plant or mass is commonly used in Thailand for selecting sugarcane clones in the early stages. Breeders find it challenging to manage information of a large amount of hybrids derived from true seeds every year. Bias from visual appraisal is still a major constraint in the first stage of selection process. Losing data during sugarcane breeding procedure is another major problem of Thailand sugarcane breeding programs. Based on the Simple Additive Weighting (SAW) in Multi-Criteria Decision Making (MCDM) technique, and using QR code technology and protocol design, we developed an application "*TSBC-1st Selection of Sugarcane*" for Android-based smartphones, which uses 18 criteria that are derived from breeders' knowledge. An appropriate scoring system is also incorporated to make the task easier with increased accuracy of data collection and faster data processing of the selected prominent clones – over the conventional manual method. The data flow of the systematic selection is visually explained to it's user with the data flow diagram. The application is developed on Visual studio code. The JavaScript and html programming language are used with Ionic Framework as a library for programming the app. Clones with total score greater than 300 units, indicating high yield component, are selected (132 selected clones (3.57%) from 3,703 clones, which promptly propagated and planted for second selection field). The capacity of the field test was obtained as 96.18 clones/h/12 people. The users were convincingly satisfied with overall performance of the developed mobile application. The weighting method and new scoring system were well accepted by the breeders. The *TSBC-1st Selection app* could assist breeders and selectors to enhance data processing and selection of prominent clones in real-time system with reduction of selection bias, duplication of work and error from data recording. Information collected and processed by the mobile-app will be available on the database for further improvement of sugarcane breeding efficiency in Thailand.

Keywords: weighting method, Multi Criteria Decision Making (MCDM), Simple Additive Weighting (SAW), Android, QR Code, yield productivity

Introduction

Sugar from sugarcane is an important agricultural product of Thailand, which generates 8 billion US$ of income accounting to about 21% of Thailand GDP in agricultural sector and about 48% in food industry section (Preecha et al., 2018). In 2018, Thailand became the world's leading white sugar exporter and ranked second in export of raw sugar, after Brazil (ISO, 2020). The milling process always demands highly productive sugarcane from the field that determines both quality and quantity of sugar. Growers, therefore need high productivity sugarcane varieties with desirable characteristics including high cane yield and sugar content, resistances to diseases and insect pests, reasonable requirement of nutrients and irrigation as well as high ratooning ability – all of which can be derived from the intensive sugarcane breeding program.

However, the conventional sugarcane breeding program is a lengthy process and moreover it is laborious. In early stage of selection, a very large population of seedlings derived from a wide range of parental crosses is evaluated by breeders based on visual appraisal. This visual clues-based method is relatively subjective and greatly depends on breeders' skill, eventually affecting plant characteristics and sucrose content (Kimbeng and Cox, 2003). Collecting data associated with such characteristics at this critical stage is usually time consuming, requires intensive labor, and is prone to excessive human error. As a result, very few commercial sugarcane varieties are grown in Thailand, and the same old varieties have been used for more than 10 years. Availability of skilled sugarcane breeders in Thailand are currently insufficient, some of which have already retired and transfer of knowledge is not happening due to generation gap between young and old sugarcane breeders. Shortage of labor in the breeding program is another limitation. Therefore, having technology that assists breeders and their team to speed up the sugarcane varietal improvement is necessary (OCSB, 2017). Thailand Sugarcane Breeding Center (TSBC) has introduced multiple technologies in all the stages of sugarcane breeding procedure. To leverage these technological interventions while addressing the challenges of skilled-labor scarcity, and to reduce the human drudgery, it was necessary to develop a smartphone-based suitable application with an intention to support and coordinate different tasks of the breeding program. The mobile-app developed and described in this article is '*TSBC 1st Selection of Sugarcane*'. This app aims to support the evaluation and selection of sugarcane progenies in the critical first stage of selection. Therefore, the objective of this research was to undertake the development of an app for smartphones to select the first generation of sugarcane clones, which is based on a newly-developed scoring system of the selection criteria obtained by brainstorming with the expert sugarcane breeders. The app feature, data flow diagram creation, system architecture, operation procedure, utilization protocol, the results of sugarcane selection obtained from this app and satisfaction of users are also presented.

The Simple Additive Weighting (SAW) from Multi-Criteria Decision Making (MCDM) technique and the QR code technology are employed to develop this mobile-app on smartphone with Android® operating system. All data associated with various criteria of plant characteristics can be analyzed in real time and saved at TSBC server for further uses by the smartphone app. Evaluation of plants is more systematic and is based on the predetermined score to minimize selection bias. Data handling is more accurate and efficient while errors such as typing and manual rerecording of data are reduced.

Theoretical Consideration

2.1 Multi-Criteria Decision Making (MCDM) Technique and Weighting Method

Selection of prominent clones of sugarcane is based on various plant characteristics. Without a systematic approach to evaluate such characteristics, the final decision tends to be subjective, depending on breeders' experiences and preferences. One of the relevant approaches to support complex decision making is the multi-criteria decision analysis. There has been a considerable increase in literature on the MCDM technique over the past 50 years where tools and methods under MCDM technique have been widely developed to aid various decision problems (Mela et al., 2012). The main purpose of MCDM is not to find the solution but to create something to assists the actor to make the decision in accordance with the goal (Munda, 2004). Available data are synthesized in order to identify the selection criteria and their levels of importance, as scoring or ranking are usually required (van der Meer et al., 2019). The accumulated scores are then used to describe the result of this decision analysis where the most preferred solution is the alternative that obtains the highest score (Keeney, 1988). To create an assessment for criteria, weighting method is applied for solving an MCDM model (Odu, 2019a). The applications of this technique on diverse fields of research such as public economics (Munda, 2004), tourism (Morgan, 1999), and urban sustainability (Amasha, 2018), industry, energy and agriculture (Gan et al., 2017) disciplines have been reported.

The SAW from MCDM is generally known as weighted linear combination or scoring methods, likely to be the most popular method, which is widely applied by many researches. The scores are derived from summing of the values from the calculation between the weights of each criterion, which is given by the decision maker and each alternative of the attribute (Afshari et al., 2010; Chou, 2013).

2.2 Agricultural Apps on Smartphone and Barcode Technology

The demand for mobile app development services in the market is rising in the field of research and development, and especially in the agronomy sector. In particular, there are requirements of app about measurement and traceability for many reasons, such as reduced risk of data losing, avoiding errors in entry data, saving time and improving personnel efficiency (Doriane Research Software & Consulting, 2016). For example, the *AgroDecisor EFC* app on android operating system was developed with multi-indicators and scoring system to support decision on suitable fungicide app for disease control of late-season soybean (Carmona et al., 2018). The fuzzy inference system was used on android mobile device with communication in local language to forecast, predict and diagnose various diseases in cotton and wheat in Pakistan (Toseef and Khan, 2018). *BioLeaf* is the app that uses image processing to measure foliar damage caused by insect pests in soybean as correctly as damage quantified by specialists (Machado et al., 2016).

Nowadays, QR codes are used in the most fields of research to minimize errors due to manual data recording into a notebook and miss-identification of treatments. (Bunrojchanawong and Praporntrakan, 2017). Using any simple QR code reader (usually a free software), camera of a smartphone is capable to read QR code printed on any surface at high speed at low cost (Shiang-Yen et al., 2010; Tarjan et al., 2014). The advantages of QR code consists of encoding a large amount of data with a small code, printable on a small area, readable regardless of the scanning angle, and resistant to dirt and damage (Denso Wave Inc., n.d.). In agricultural sector, QR code is applied in various tasks such as directly opening websites, providing information of target plants in a botanical garden, and handling a traceability system of horticultural commodities (Varallyai, 2012).

Review of the conventional sugarcane breeding method shows that the selection knowledge is transferred from seniors to junior breeders, by keeping a huge sugarcane selection data and information. But in the modern age and in paucity of time, it is difficult for breeders to continue with the same method. Moreover, the conventional (manual) data management has serious limitations in terms of its accuracy. However, in this current study, the new method is more organized with the SAW, which is applied for origination and accumulation of the scoring to assist the sugarcane breeders and expert decision by translating explicit knowledge into scoring. This makes the decision making easier and more precise than that of the conventional method to select the prominent sugarcane clone. Therefore, in this study the QR code is used to identify sugarcane information to ensure the highest accuracy of data and information which helped reducing error by eliminating manual data entry and thereby wrong selection by user bias. Data losing is a one major problem of the first sugarcane selection in the conventional method. In this study we used smartphones to address these challenges related to promotion of technology for improving yield in the commercial production of the sugarcane in Thailand breeding program.

Methodology

3.1 Design of the Scoring System for the First Generation Selection of Sugarcane Clones

Selection of the first generation sugarcane clones is the critical step that primarily decides success of the entire breeding program. Thai sugarcane breeders focus on visual appraisal and Brix measurements as main selection criteria for the first generation hybrid clones. This selection system requires skill and experience of breeders and selection team. Such skill and experience must be translated into numeric scale − leading to the decision to select a certain hybrid clone- which can be made based on more systematic scoring system. Brainstorming with 21 experienced participants including breeders, researchers and staff involved in sugarcane breeding program was conducted at TSBC to identify the important characteristics or criteria that determine the acceptance or rejection of the clones in the first selection.

The SAW was applied to develop a suitable scoring system. Characteristics were ranked based on their relative importance. The more weight percentage a criterion receives, the greater its relative importance is; in which 100 per cent allocation is made across all the criteria under consideration and the total of all criterion weights must sum up to 100 (Odu, 2019b). Depending on nature of the characteristics (qualitative or quantitative), variation within each characteristic such as number of stalk/clone, Brix or clump shapes are grouped into different classes and five fuzzy numbers, ranking from very poor to very good, sometime called performance rating values were assigned for each class. The score of each characteristic is the product of performance rating value times it's weighting value and sum of the score of all characteristics yields the total score or ranking (V_i) shown as the equation below (Setiawan et al., 2018). A hybrid clone receiving a total score above the predetermined value was selected according to the eq (1).

$$V_i = \sum_{j=1}^{n} W_j r_{ij} \qquad ...(1)$$

Where

V_i = total score or ranking from all characteristics

W_j = weighting value of each characteristic (transformed percentage value)

r_{ij} = normalized performance rating value

3.2 Development of an App for the First Generation Selection of Sugarcane Clones

This app was developed based on the inputs received from previous step on selection criteria and the scoring system; then programmed according to the step-wise operation of first selection procedure system where the sugarcane breeders are involved. In the system, QR code was used to specify the information of selected clone and to record data. TextView® was performed for displaying the result after scanning value in QR code. The application was developed on Visual Studio®

by using various Android Studio® plugins to make it functional on Android operating system. phpMyAdmin was useful for database management through web browser. The JavaScript and html programming languages were used for developing the app. Ionic Framework® was selected to be a library for programming. The data processing of the clones comes from coded formula, which is derived from the scoring system. Further, the app was developed corresponding to the protocol. User interface (UI) was designed emphasizing on simplicity and ease of operation. The number of users are not limited but must be authorized by the TSBC with given username and password.

3.3 Field Evaluation of the Application

The app was tested in the field conditions of the first selection plot at TSBC to evaluate 3,703 sugarcane hybrid clones from 72 crosses (families). The plot size was 0.5 ha with row spacing of 2.0 m and 0.6 m between plants in a row. Hybrid seedling of each family was planted in a row in order starting from seedling no. 1 until the last seedling. Numbers of clones in each family varied and more than one family can fit in a row. The check varieties

Table 1 Summary of 18 characteristics, classes, weighting percentage, rating number and scores proposed as selection criteria for the first generation selection of sugarcane clones

No.	Characteristic	Class	Rating (r_{ij})	% Weight (W_j)	Score ($W_j r_{ij}$)
1	Number of stalks per clone	≥9	5	17	85
		7-8	4		68
		5-6	3		51
		4	2		34
		3	1		17
		<3	0		0
2	°Brix in cane juice* (3 stalks sample, measure at the middle of internode)	≥22.0	5	16	80
		21-21.9	4		64
		20.0-20.9	3		48
		18-19.9	2		32
		17-17.9	1		16
		<17	0		0
3	Stalk height (cm)*	≥290	5	10	50
		250-289	4		40
		210-249	3		30
		180-209	2		20
		150-179	1		10
		<150	0		0
4	Stalk diameter (cm)*	≥3.0	5	10	50
		2.90-2.99	4		40
		2.80-2.89	3		30
		2.60-2.79	2		20
		2.50-2.59	1		10
		<2.5	0		0
5	Flowering	[1] None	5	5	25
		[2] Found	0		0
6	Clump shape	[1] Erect (<10 degrees)	5	5	25
		[2] Semi-erect (10 to <30 degrees)	5		25
		[3] Less decumbent (30 to 45 degrees)	3		15
		[4] Decumbent (>45 degrees)	0		0
7	Clump stand	[1] Upright	5	5	25
		[2] Fall due to heavy rain or wind or improper soil preparation	3		15
		[3] Fall	0		0
8	Internal firmness of stalk pith	[1] None hollow	5	5	25
		[2] Least hollow (< 2 mm.)	4		20
		[3] Medium hollow (2-5 mm.)	2		10
		[4] Large hollow (> 5 mm.)	0		0

No.	Characteristic	Class	Rating (r_{ij})	% Weight (W_j)	Score ($W_j r_{ij}$)
9	Leaf sheath adherence	[1] Easy	5	3	15
		[2] Natural loose	5		15
		[3] Semi-loose	4		12
		[4] Tight	0		0
10	Leaf sheath hair and located	[1] None	5	3	15
		[2] Few at middle: 57	3		9
		[3] Many at middle: 57	3		9
		[4] Few at side: 60	3		9
		[5] Many at side: 60	0		0
11	Stalk crack (Consider only one main stalk)	[1] None	5	3	15
		[2] Few & shallow	3		9
		[3] Deep in one internode	2		6
		[4] Deep in more than one	0		0
12	Whitefly**	[1] None	5	3	15
		[2] Found	0		0
13	Tip borer**	[1] None	5	3	15
		[2] Found	0		0
14	Stem borer (Consider number of hole from destruction per stalk)	[1] None	5	3	15
		[2] Found 1 point	4		12
		[3] Found 2 points	3		9
		[4] Found 3 points	2		6
		[5] >3 points	0		0
15	Crown disease**	[1] None	5	3	15
		[2] Found	0		0
16	Leaf diseases in overall** (Rust, Spot, Stripe and others)	[1] None	5	3	15
		[2] Found	0		0
17	White flies, Aphid, Mealy bugs**	[1] None	5	2	10
		[2] Found	0		0
18	Internode length (cm.)	[1] >13.0 (Long)	5	1	5
		[2] 10.0-13.0 (Medium)	3		3
		[3] <10.0 (Short)	0		0
		Total weighting %		100	
		$V_i = \sum_{j=1}^{n} W_j r_{ij}$			500

* No. 2-4; collected 3 samples and averaged

** The characteristics related to pests and diseases were simply evaluated as absent and present

LK92-11 and KK3 were planted at the beginning and the end of each family and there was a 2.0 m distance between each family. Each plant was assigned with a unique QR code to indicate whether it was a check variety or a hybrid clone, its running number and the actual position in the experimental field and parents (in case of a hybrid clone). Information associated with those QR codes were prepared during planting and stored in the database. A team of 12 members including at least one breeder involved with various measurements and observations in the selection activities. Data were not taken from dead clones with very poor growth. Results of the first generation selection of sugarcane clones and the selection capacity of the sugarcane selection team with the app were presented.

3.4 Users' Satisfaction of the App

Satisfaction of the app was evaluated by 16 users, by means of a structured questionnaire, who were involved in the first generation selection of sugarcane clones. Half of the users were sugarcane breeders and experts, and the rest were officers and staff with work experience varied from less than 5 year to more than 20 years. Most of them have practiced and used the application more than thrice before providing their opinions regarding the application. Questionnaire was used for evaluation. Open-ended questions were also included to obtain suggestions and opinions.

Results

4.1 Design of Selection Criteria and Scoring System

From the brainstorming of experienced breeders, researchers and staff involved with the sugarcane breeding program, a total of 18 characteristics were proposed as selection criteria for the first generation selection of sugarcane clones. Weighting percentage (W_j) for each characteristic was defined according to its significance using the weighting score method as previously described. The variation in each characteristic was grouped into classes with assigned performance rating value (**Table 1**). The first 53% of weighting derived from characteristics associated with the yield component where number of stalk per clone, which is the most important yield component, had the highest weighting percentage (17%). The second highest weighting percentage (16%) was assigned to °Brix which represents the commercial cane sugar (C.C.S.), a price indicator of sugarcane in sugar industry (Buaphuan, 2010). Stalk height and diameter (10%) were equally important (Yana et al., 2014) and came at the third rank in weighting percentage (**Table 1**). Depending of the nature of each characteristic, class number varied from 2-6 and the rating number of 0-5 was applied. In certain characteristics, different classes were equally important and the same rating number was assigned to those classes. For example, there were four classes of clump shape where erect and semi-erect were equally desirable and both classes had the rating number of 5 similarly. Characteristics related to pests and diseases were simply evaluated as absent and the rating number of 0 and 5 were assigned, respectively (**Table 1**). The cumulative weighting percentage was 100 and the maximum score was 500 in total.

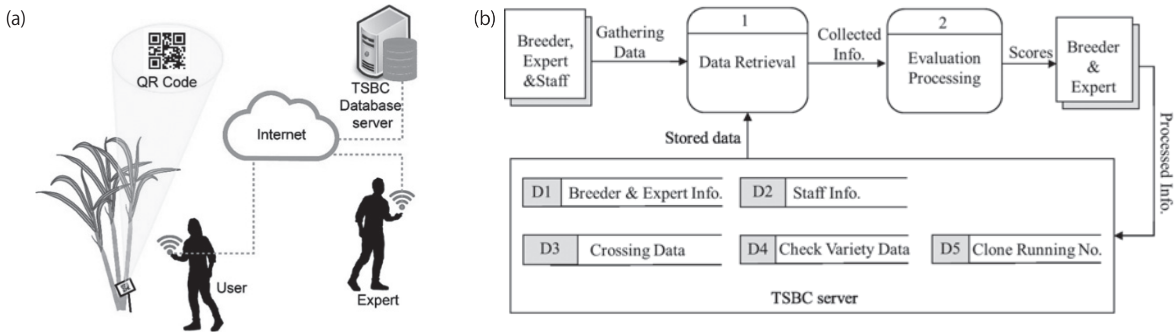
The clones receiving a total score

Table 2 An example of the accepted and rejected clone

Characteristic	No. of Stalk	°Brix	Stalk height (cm)	Stalk diameter (cm)	Flowering	Clump shape	Clump stand	Stalk pith	Leaf sheath adherence	Leaf sheath hair and located	Stalk crack	Whitefly	Top borer	Stalk borer	Crown disease	Leaf diseases in overall	Aphid	Internode length (cm)	Total score
Example: Accepted Clone																			
Data entry*	20	20.7	191.7	2.5	1	1	1	3	3	2	1	1	1	1	2	2	1	9.7	
Rating (r_{ij})	5	3	2	1	5	5	5	2	4	3	5	5	5	5	0	0	5	0	
%Weight (W_j)	17	16	10	10	5	5	5	5	3	3	3	3	3	3	3	3	2	1	100
$W_j r_{ij}$	85	48	20	10	25	25	25	10	12	9	15	15	15	15	0	0	10	0	**339**
Example: Rejected Clone																			
Data entry*	4	16.3	90	2.4	1	1	1	1	4	2	1	2	1	2	1	2	2	6.3	
Rating (r_{ij})	2	0	0	0	5	5	5	5	0	3	5	0	5	4	5	0	0	0	
%Weight (W_j)	17	16	10	10	5	5	5	5	3	3	3	3	3	3	3	3	2	1	100
$W_j r_{ij}$	34	0	0	0	25	25	25	25	0	9	15	0	15	12	15	0	0	0	**200**

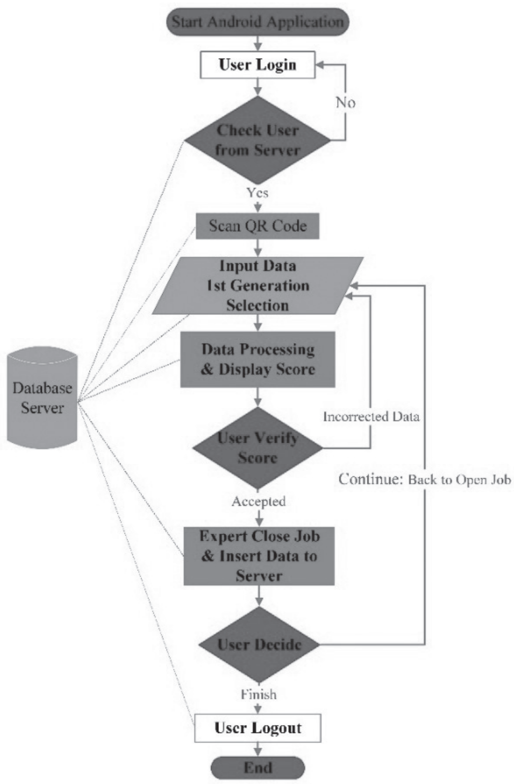
*Measurable data were presented as the actual value or its average and qualitative data are presented as class number

Fig. 1 System architecture (a), and data flow diagram (b) of the first generation selection



of 300 and above were accepted and those with a total score less than 300 were rejected. The threshold score of 300 was based on the selection results that more than 90 percent of clones selected by this new scoring system which was identical to those selected by breeders using the traditional selection protocol. An example of selection results and scoring system of an accepted clone with the total score of 339 and a rejected clone with total score of 200 are shown in **Table 2**.

Fig. 3 Operation procedure of TSBC-1st Selection app



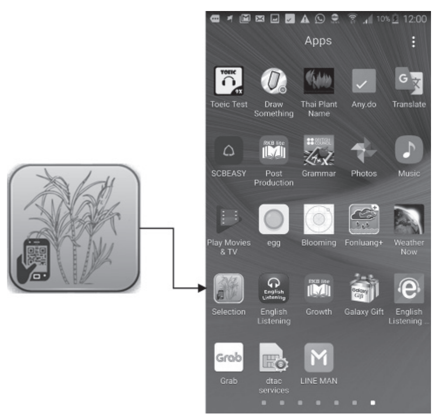
4.2 Development of the TSBC-1st Selection application

4.2.1 System Architecture and Data Flow Diagram

TSBC-1st Selection application is an app on Android OS smartphone version 4.4 KitKat upwards, developed by Visual Studio code, Google Chrome and Android Studio code. The system consisted of 4 components; QR code, Android smartphone or tablet, internet and database server (**Fig. 1a**). Smartphone served as an input device for collecting and transmitting data. Its minimum specification was as follows: Android 5.1 (Lollipop) operating system, Octa-core CPU (4 × 2.1 GHz Cortex-A57 & 4 × 1.5 GHz Cortex-A53), 32 GB internal memory, 4 GB RAM, IEEE 802.11 a/b/g/n/ac wireless communication and built in GPS and camera. It should be capable of working in the field of relatively high temperature and strong sunlight. The TSBC database server had 64-bit operating system, Intel(R) Corei7-6700HQ CPU (2.60 GHz 6 MB L3 Cache to 3.5 GHz), 8.00 GB (7.87 GB usable) DDR4 SDRAM and Hard Disk Drive (HDD) 1 TB 5400 RPM internal Hard Disk Drive (HDD) and 128 GB Solid State Drive (SDD). Software was programmed and processed by using Apache 2.2.4, PHP 5.2.3, MySQL 5.0.45, and phpMyAdmin 2.10.2.

Selection process is explained with the data flow diagram as presented in Fig. 1b. Information flow starts from 1) the stored data from five data storages (D1-D5) which include the information of breeder, expert, staff, check variety and clone number flow to data retrieval function; 2) the measured and evaluated data which is gathered by experts, flow to data retrieval; 3) From the first function; all collected informa-

Fig. 4 Display icon of the app



tion flow to the second function for evaluation processing. The results include the final score to be used for selection; 4) The information and scoring are displayed on the screen of the app; and 5) All processed data are stored in TSBC server.

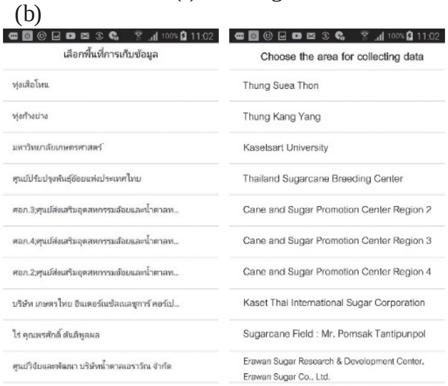
4.2.2 Operation Procedure

The app is communicated in local language (Thai) and login with username and password is required. Only Thai sugarcane breeders, experts, and staffs in the network are authorized by TSBC with access to the app. The operation procedure of the app is summarized in **Fig. 3**.

The app icon is shown on the main screen (**Fig. 4**). After login, a user needs to indicate the location of the experimental field and activities in the application (**Figs. 5-6**). A QR code is scanned to specify the identification (check variety or hybrid clone, family and clone running number) of the plant to be evaluated (**Fig. 7**) before entering any plant data. The plant data consisting of 18 characteristics are recorded (input data 1st selection) starting from the first plant in the row which is the check variety 1 followed by the hybrid clone no. 1, no. 2 in the row and so on until the last hybrid clone of the family and the check variety 2 at the end. Degree Brix of each individual was measured randomly from stalks in the clump, in three replications, using a refractometer (**Fig. 8**) followed by measurements of plant height, stalk number/clone, stalk diameter and internode length and examining for white flies, aphids, mealy bugs, tip borers and stem borers. Other features such as plant shape, characteristics of hairs at leaf sheath, flowering, cane cracking, leaf sheath adherence and characteristics of internal flesh were also examined.

Once data entry was completed, breeders and selection team examined the data together via the app and the data were also verified for correctness (**Fig. 9**). Then the data were processed and total score of the 18 characteristics using as selection criteria is shown. The clones with the total score above the predetermined threshold are selected and advanced to the second selection. In a special case where a hybrid clone had a total score less than the threshold but shows some outstanding characteristics and the breeders decide to select such clone, the system would select that clone

Fig. 5 Display: Choose field experimental location in Thai (a) and English translatation (b)



(a) (b)

Fig. 6 Display: Choose selection activities in Thai (a) and English translatation (b)

(a) (b)

Fig. 7 Generated QR code show detail of all cane seedling planted in the field (English translation)

Fig. 8 Average °Brix from 3 sampling measument (English translation)

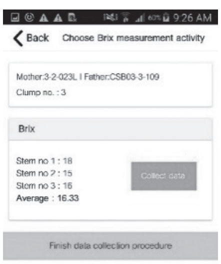


Fig. 9 Total score and evaluation results of each characteristic of a clones in selected row (English translation)

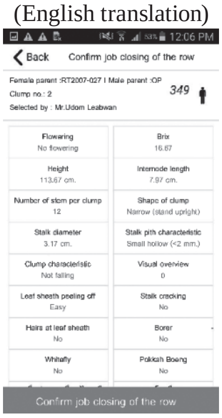


Fig. 10 A photograph of a clone was taken and recorded (English translated)

Fig. 11 All data are summarized and it is ready to end the selection activity in the row (English translation)

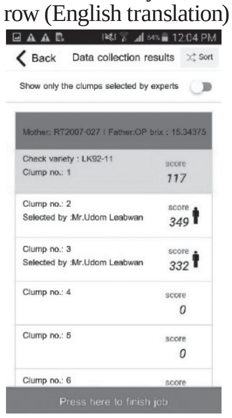


Fig. 12 “Warning” before “Closed Job” is commanded (English translated)

with attached remarks. A staff takes photographs of the selected clones and records them via the app (**Fig. 10**) and the selected clones were marked with a red stick and a rope for further propagation and field planting for the second selection. The ID number and QR code of a newly selected clone are then generated, printed and marked to the corresponding clone right away. This identification is used until the final stage when the clone is released as a new variety.

Concerning the use of the application, once all data are summarized (**Fig. 11**) and it is ready to end the selection activity in that row, the app will alert 'Warning' (**Fig. 12**) to make sure that all data are correct because users cannot change the data after being transferred to the database. There can be more than one family in a row depending on the size of experimental plot. To end the selection activity for each row, the experts select 'close job' in the app and the data are sent in real time to the TSBC database server. All steps will be repeated for the next row and so on until all hybrid clones in the series are evaluated.

4.3 Field Test

4.3.1 Testing of the App in the Field Conditions

This selection system was designed to evaluate all hybrid clones (100% of planted seedlings) and check varieties in the field on a row by row basis. The selection results are summarized in **Table 3**. From the 3,703 hybrid clones evaluated, 132 hybrid clones (3.57%) with the total score above 300 were selected to advance to the next stage of selection. These plants were further propagated into the field for the second selection. The rest of the clones with the total score less than 300 were rejected where 1,099 clones had total score between 1-299 and 2,472 clones had no score as they almost died or had very poor growth. KK3 was the only check variety where 7 clumps (8.33%) out of 72 clumps had the total score greater than 300 (**Table 3**).

4.3.2 Capacity of the Sugarcane Selection Team with the App

In this trial, 3,703 hybrid clones and 144 clumps of check varieties were evaluated by a 12 members team. The team composed of 1 breeder, 2 persons for QR code operation, 1 person for operating open job and taking photograph, 3 persons for degree Brix measurement, 2 persons for examining of cane texture, 1 person for observing of diseases and insect pests, phenotypes and physical characteristics and 2 persons for measuring of plant height, stalk diameter, internode length and number of stalk/clone. The capacity of the sugarcane selection team with the app was calculated as 92.2 clones/h.

4.4 User's Satisfaction of the App

Users were well satisfied with the overall performance of the app. The weighting method and the new scoring system applied for first generation selection of sugarcane clones were well accepted by breeders and selection team to obtain comparable selection results to those performed by experienced sugarcane breeders using the traditional selection procedure. Young breeders and inexperienced staff were motivated and more comfortable to work in the app platform. Most of users agreed that problems on collecting of wrong names, wrong clone numbers and other mistaken data were solved by using the app. Fast data processing and reporting of the selection results were highly satisfied. Data and information obtained during the selection activity were correct and accurate and can be further utilized for sugarcane varietal improvement programs. Knowledge on sugarcane breeding and the first selection was passed along from the older and experienced breeders to the younger generation without losses of data and information. All respondents also agreed that the main icons in the app were suitable and easy to be familiar with. Graphical User Interface (GUI), front size and alphabet colors are clear and understandable. From the open-ended questions, some concerning points were suggested. Using the app in the hot condition with strong sunlight faced poor visibility of the screen which caused errors on data entering. A hang or freeze occurred due to overheating of a mobile device. In addition, low internet signal in the field decreased the accessibility of the app.

Table 3 Section result of the first generation selection of sugarcane clones using TSBC-1st selection app

	Selected variety		Check variety			
	Number	%	KK3		LK92-11	
			Number	%	Number	%
≥ 400	41.00	1.11	1.00	1.39	-	-
300-399	91.00	2.46	6.00	8.33	-	-
200-299	3.00	0.08	-	-	2.00	2.78
100-199	16.00	0.43	1.00	1.39	2.00	2.78
1-99	1,080.00	29.17	13.00	18.06	20.00	27.78
no.score	2,472.00	66.76	51.00	70.83	48.00	66.67
Total	3,703.00	100.00	72.00	100.00	72.00	100.00

*All of clones almost die or had very poor growth

Discussion and Recommendations

The selection system proposed in this study performed well and mostly conquered with the traditional method of selection by experienced sugarcane breeders. It significantly reduced selection bias and translated both science and art of the traditional sugarcane selection into numeric scale ? and thus offered an unambiguous decision. Data obtained from the system are beneficial for young sugarcane breeders to gain more knowledge in sugarcane breeding and can be further studied in other fields related.

In most cases, the weighting percentage assigned for 18 characteristics in the current selection system was found appropriate for the prominent clones which generally had high total score. However, it was found that clones with high total score but also had certain undesirable characteristics such as large hallow stalk, stem borer damage and having serious diseases including white leaf disease, smut and red rot were also selected by using the app. In practice, such clones were rejected by breeders without recording the causes of rejection. The remark slot has therefore been added to the app to record reasons for rejection of such clones before 'close job'. The information is useful for determining of parents and crosses to be made in the future. To reduce work load, the internode length (characteristic No.18) which correlates well with stalk height and contributes for only 1% weighting could be excluded from the selection criteria.

In addition, data entry errors during manual keying in digits could be minimized in the next version of the app by entering data into a specific slot of 1-digit number or using a drop-down list of numbers for entering the data. Low internet signal in some spots of experimental field limits the performance of the app. Expansion of the Wi-Fi internet signal and increasing of access points are recommended to get better performance on data collection and processing. Hanging of smartphone during the field operation due to overheat is unavoidable. It is recommended that the user should have a spare smartphone. The app allows the user to login with the same username and password to be online again and continue the work from where it stops without disturbing other teams as collected data in each step are synchronized all the time once they have been entered into the system. That is, it is not necessary for the user to go to the beginning and enter the data in that step once again.

Conclusion

The developed system of first sugarcane selection could increase the quality of decision by breeders and experts. The results of decision procedure were more explicit, reasonable, efficient and reduced bias by breeder information that is based on visual appraisal which needs breeder's knowledge and experiences in advance as well as it is difficult by young breeders to decide for selection in the experimental field. In this way, the explicit knowledge from senior breeders was extracted which could be transferred to next generation breeders via the whole system of first sugarcane selection. Converting data from descriptive to scale is necessary to avoid the results of selection from bias of breeders by using MCDM-technique and technology; SAW in MCDM technique, protocol creation, QR code and android OS smartphone technology to develop TSBC 1st sugarcane app. The system reduced steps of work redundant, more accurate and faster data processing when compared with previous decision system that needs to transfer the data from paper to excel file by hand. After the first selection stage had finished by real-time analysis, the selected clones immediately planted for second selection lead to the process of selection is faster. Simultaneously, more profitably, breeders could utilize such information for planning of parental matching in the following years which would increase planning efficiency for varietal sugarcane improvement in the future. And all data may probably be used for another objective such as in genetic study. According to the results, it is concluded that the persons who are related in Thailand sugarcane breeding program at the first stage of selection were satisfied with the results of this research in overall. It can be concluded that this application can solve the problem of mistaken data collection. Therefore, data and information obtained during the activity were more correct and accurate. The participants were highly satisfied with fast data processing and reporting of the selection results. However, there are some points to be further investigated in terms of the characteristics of the application, low signal of internet or Wi-Fi that need to be considered and addressed in the improved version.

Acknowledgement

This research was funded by Thailand Sugarcane Breeding Center (TSBC) project under the approval of the Office of Cane and Sugar Board (OCSB), Ministry of Industry, Thailand. The authors would like to thank sugarcane breeders, selection team and staffs of both OCSB and Kasetsart University for their support in this project.

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Development and Performance Evaluation of an Eco-friendly Turmeric Polisher

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Abstract

This research work was undertaken to fabricate an eco-friendly turmeric polisher for pollution free polishing. The existing polishers produce excessive dusty atmosphere during polishing. Also, there exists no mechanism to convey and discharge the polished rhizomes from the polisher. To overcome these problems, development of an alternate polisher is the need of the hour. Based on the results of the preliminary studies, different components of eco-friendly turmeric polisher required for polishing, conveying and controlling pollution were identified and then detailed studies were carried out in order to develop an eco-friendly turmeric polisher. Components of the eco-friendly turmeric polisher namely, octagonal shaped polishing drum, main frame with toe bar assembly, power transmission cum polishing drum driving unit, outer dust cover, aspirator with bag filter arrangement and conveyor for polished rhizomes were fabricated and assembled to perform the polishing without polluting the surroundings.

Keywords: Polishing, turmeric rhizomes, eco-friendly turmeric polisher

Introduction

Turmeric, *Curcuma longa* L. (Zingiberaceae), an important medicinal cum commercial crop, produces economic plant parts in the form of underground rhizomes. Washing, boiling, drying and polishing are some of the unit operations performed on turmeric rhizomes before it is powdered. Dried turmeric rhizomes have a dull appearance due to the rough outer surface with scales and root bits. The appearance is improved by smoothening and polishing the outer surface by mechanical rubbing.

Singh and Shukla (1995) developed and evaluated a power operated batch type potato peeler with a capacity of 100 kg h^{-1}. The peeling drum with protrusions on the inner surface rotated and detached the peel from potatoes by abrasion. Arora et al. (2007) developed a rotary drum type turmeric washer cum polisher. Polishing was done in a single pass by keeping the abrasive surface on the outer as well as on the inner side of the drum. When the abrasive surface was kept on the inner side of the drum, the time of polishing was reduced to half when compared to the arrangement of

Fig. 1 Conventional turmeric polisher

Conventional turmeric polisher

In operation

Manual unloading

keeping the abrasive surface on the outer side of the rotary drum. The optimum capacity of the machine for turmeric polishing was found to be 100 kg h^{-1} when operated at 40 rpm for 20 min. Jain et al. (2007) developed a hand operated batch type abrasion peeling cum polishing machine for ginger. It consisted of a perforated drum with a handle. The inner surface of the drum was lined with waterproof emery strips. The upper half of the drum was covered with a semi-circular folding lid. A trough was provided below the drum for the collection of material. The polishing experiments indicated that 20 minutes were sufficient to obtain a good finish of turmeric rhizomes for a 20 kg batch. The capacity of the polisher was worked out as 50-60 kg h^{-1}.

The existing turmeric polisher (**Fig. 1**) consists of a rotary drum, which is octagonal in shape and the polishing surface is made up of expanded wire mesh. Polishing is achieved by the rubbing and abrasive actions of turmeric rhizomes when rotated together over the metal surface. The expanded wire mesh has lengthy abrasive lines, so during rotation, they scratch away the loose skin and hairy roots and these are automatically pushed out by centrifugal force due to the continuous rotation of the drum. This discharge of the waste matter causes air pollution when carried over to longer distances by the wind due to the blower effect produced by the rotating drum. In the existing polishers, the rhizomes can mix only along the vertical plane and not along the horizontal plane. So uniform polishing of rhizomes becomes impossible; moreover there is no provision to convey the polished rhizomes from the drum. The dust pollution caused by these types of turmeric polishers may draw the attention of the State Pollution Control Board and the turmeric pollution activity may be put an end to as the board had already closed the Sago and textile industries that caused environment pollution.

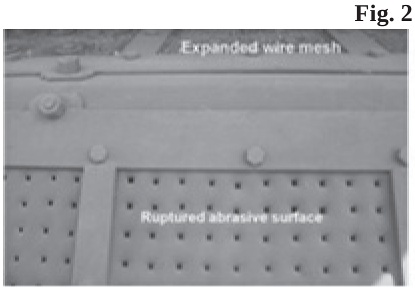
Hence, this research was undertaken with an objective to study the promising and limiting features present in the existing polishers, and develop a new dust-proof turmeric polisher incorporating all essential features of the existing polisher.

Preliminary Studies on Polishing of Turmeric Rhizomes

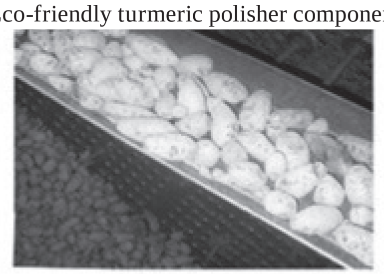
2.1. Movement of Turmeric Rhizomes During Polishing and Improvement on the Side Walls

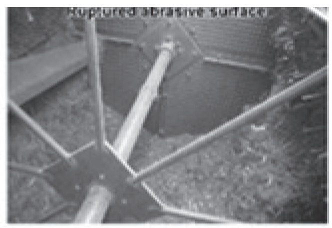
To achieve a uniform mixing of rhizomes in the vertical and horizontal plane, a channel shaped section (**Fig. 2**) made out of 110 × 35 × 35 mm size mild steel channel section having a length of 1080 mm was provided on both ends from the side walls to centre and opposite to each other to shift the rhizomes during operation from end to centre and then centre to end. This resulted in the complete mixing of rhizomes (both in the horizontal and vertical plane) and thus uniform polishing of turmeric rhizomes was achieved. There was no polishing surface on the side walls in the existing polisher. So, a ruptured abrasive surface was introduced by punching the mild steel sheet surface with a special rupturing tool (**Fig. 2**). This improved the polishing in a relatively lesser time when compared to the existing one.

Fig. 2 Eco-friendly turmeric polisher components



Abrasive surfaces


Channel shaped section

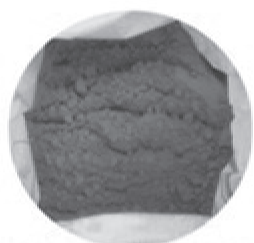


Ruptured abrasive surface on side walls

Inverted V Shaped barrier


Conveyor


Coarse dust at conveyor outlet end


Light dust collected in the bag filter

2.2. Conveying Mechanism

The polished rhizomes were gradually discharged to the conveyor by the provision of an inverted 'V' shaped 'barrier' having 120 mm side width for the entire length of the polishing drum, just above the conveyor with 120 mm clearance on both sloping sides so that rhizomes can slide along the slopes of the dust proof cover and reach the conveyor freely but slowly (**Fig. 2**). A slow tilting mechanism (with gear arrangement) was introduced to control the rotation of the polishing drum during unloading and thereby control the quantum of rhizomes discharged at a time.

A long chain conveyor measuring 4200 mm was mounted on two sprockets (8 teeth and 200 mm diameter) with 3 mm thick endless belt on it was fabricated and mounted at the bottom of the dust proof turmeric polisher (**Fig. 2**). Drive was given to the conveyor through a speed reduction gearbox. During preliminary tests, the above said mechanism gave encouraging results. Hence, fixed a chain conveyor with a belt on its top for conveying turmeric rhizomes and coarse dusts and a slow tilting mechanism through gears for easy and load free tilting of the polishing drum.

2.3. Studies on Dust Collection During Polishing

An aspirator was fixed by taking inlet at the top centre of the dust proof turmeric polisher cover using 30 mm diameter, 8 kg cm^{-2} PVC pipe to draw the air borne dust particles produced during polishing and trapping the same through a bag filter arrangement. The dust collected during polishing operations was analysed for its size and the volume of air drawn by the aspirator was calculated by operating the aspirator at different speeds with the help of a dimmer starter and the aspirator was operated at the required air flow rate to draw all air borne dusts produced during polishing.

Fabrication of Dust Proof Turmeric Polisher

Based on the functional requirements, the following components were fabricated and assembled to perform the polishing operation of turmeric without polluting the surroundings (**Figs. 3** & **4**).

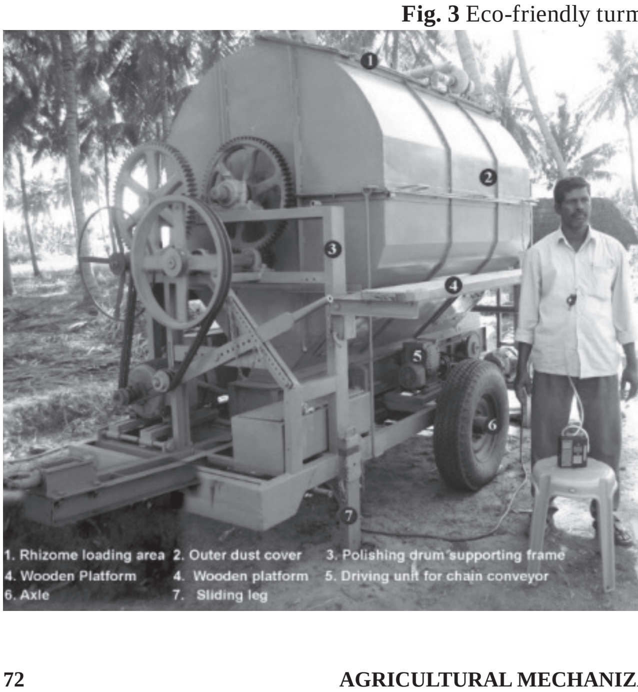
a. Octagonal Shaped Polishing Drum

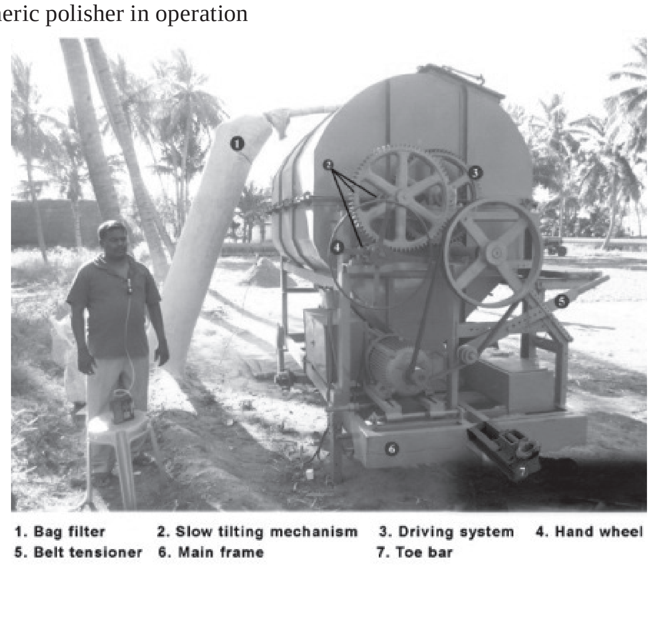
This drum was fabricated to mix, slide and agitate the rhizomes during rotation and thereby achieve polishing by rubbing, abrasion and sliding action. The polishing drum was octagonal in shape (**Fig. 5**). The width of one side was 510 mm and the length of the drum was 1900 mm. The edges of the sides were made out of mild steel sheet having a thickness of 4 mm. This drum was mounted on a mild steel solid shaft of 60 mm diameter having a length of 2750 mm. The shaft was mounted on a frame using two suitable roller bearings (No. S515) using bearing blocks. The eight sides of the polishing drum were fitted with ruptured abrasive surface sheets made by punching the sheet with a special tool and or expanded wire mesh sheets in different combinations.

Thirty five mm size standard diamond shaped mesh and wire mesh having 4 holes per

25 mm length made using No.16 GI wire was used to fabricate an expanded wire mesh. The sides of the wire meshes were mounted on a rectangular frame of 1900 mm length and 510 mm width and fitted with 30 numbers of 50 × 10 mm size GI bolts and nuts and then mounted on an octagonal frame using 8 numbers of 50 × 10 mm size GI bolts and nuts. Each side was made into six compartments of equal width by

Fig. 3 Eco-friendly turmeric polisher in operation



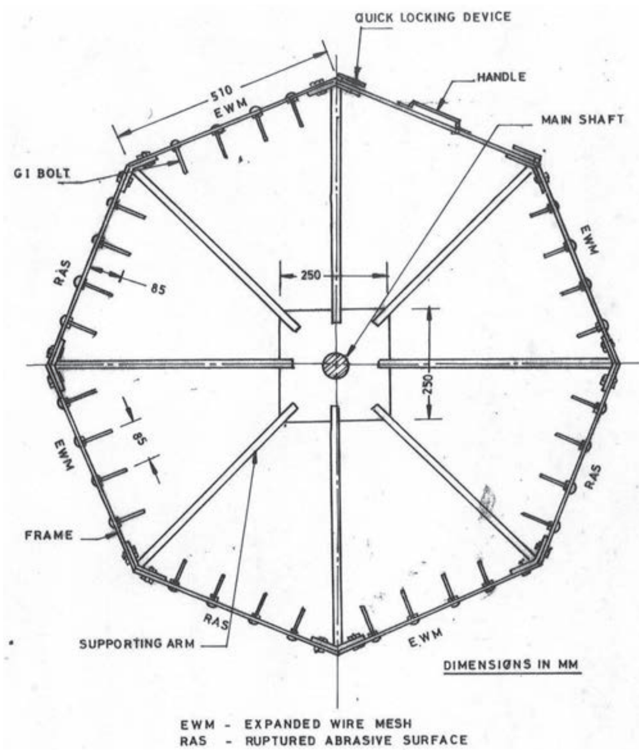


using 50 × 3 mm thick mild steel flat. Seven numbers of 100 × 10 mm size GI bolts were fitted uniformly over each compartment not only to fix the diamond shaped mesh and wire mesh firmly but also to act as an abrasive surface for polishing the turmeric rhizomes.

Eight numbers of ruptured abrasive surface sheets of 1900 × 510 mm size made using 16 gauge mild steel sheets were also fabricated to mount on 1900 mm length,

510 mm width frame. Ruptured

Fig. 5 Octagonal shaped polishing drum – cut section

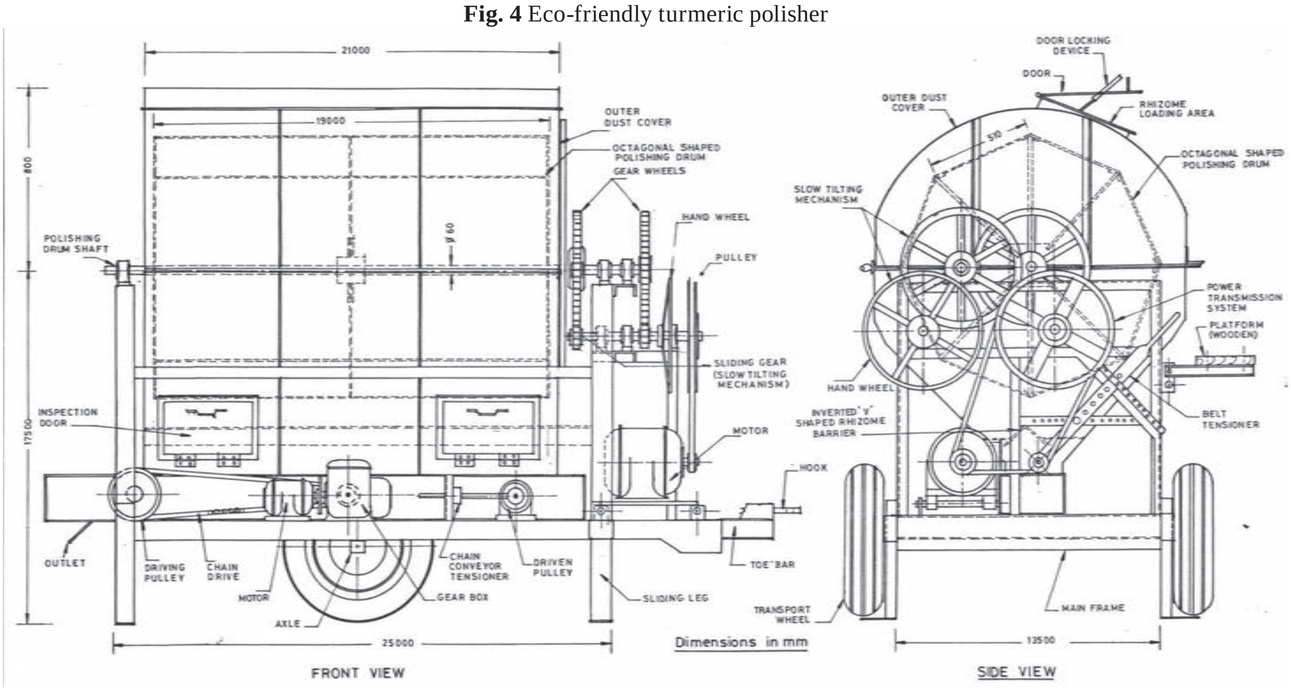


abrasive surface was made by punching 16 gauge mild steel sheets using special 6 mm size punching tool at 25 mm spacing after forming

25 mm square grids and punching at all corners of the grids. The sides of ruptured abrasive surface were mounted on a rectangular frame of 1900 mm length and 510 mm width and fitted with 30 numbers of 50 × 10 mm size GI bolts and nuts and then mounted on the octagonal frame using 8 numbers of 50 × 10 mm size GI bolts and nuts. The ruptured abrasive surface mounted on 1900 × 510 mm size frame was further made into six compartments by using 30 × 6 mm size flats. Three numbers of 100 × 10 mm size GI bolts were fitted diagonally over each compartment of ruptured abrasive sheets resulting in 18 numbers of 100 × 10 mm size bolts and nuts in one ruptured abrasive sheet. These bolts and nuts also act as an abrasive surface and help polishing of fingers and removal of fibrous roots from the mother rhizomes.

For easy loading and unloading of rhizomes in and out of polishing drum, one side of the polishing drum (one face of octagonal shaped

Fig. 4 Eco-friendly turmeric polisher



drum) for the entire length (1900 × 510 mm) was made like a door (two parts), which can be opened and closed using two clip type quick opening and closing locks. Both ends of the octagonal shaped drum was closed using 4 mm thick plate and reinforced with 4 numbers of 38 × 4 mm thick flat. Both end plates were also punched at 25 mm spacing which formed a ruptured abrasive surface so that the rhizomes in contact with the end plate also got polished. A wooden platform of 2670 × 310 × 45 mm size made out of country wood was mounted on a frame made using 'L' angle of 80 × 4 mm size and 2670 mm length and hinged to the frame supported by the polishing drum. The platform was of foldable type used during the loading of rhizomes.

b. Main Frame with Toe Bar Assembly

Two transport wheels fitted with disc, suitable rubber tyres and tubes of 230 × 75 mm size were mounted on both sides of an axle made out of 60 × 60 mm square solid rod using bearings (No: S515) on suitable hubs. The main shaft of the octagonal polishing drum fitted with roller bearings (No: S515) was mounted on a frame made out of 100 × 50 × 50 mm size mild steel channel section. The top width and height of the frame were 1320 and 1260 mm, respectively. On the rear side of the unit, on the right hand side, a ladder of (1500 × 310 mm) size made using 'L' angle section has been fixed for easy approach to the top of the foldable wooden platform provided for loading of rhizomes.

For toeing purpose, a toe bar frame of 800 × 190 mm size using 100 × 50 × 50 mm mild steel channel section was made and fixed to the main frame by welding. For easy toeing by tractor or other vehicle, a round hook of 150 mm outer diameter and 70 mm inner diameter having a length of 420 mm using 38 mm diameter mild steel rod was made and fixed over the toe bar frame by suitable means (thread and nut).

To avoid vibrations during polishing operations, four legs of 620 mm length (each) made out of 100 × 50 × 50 mm size mild steel channel section were attached at four corners of the main frame such that in the work site, the legs could be slided vertically down and during transport it could be lifted and locked using bush and pin arrangements.

c. Power Transmission Cum Drive Unit

A cast iron spur gear wheel of 50 mm width having 71 teeth and 610 mm diameter was mounted on the main shaft to rotate the polishing drum along with rhizomes. Another mild steel spur gear wheel of 60 mm width having 12 teeth and 120 mm diameter was fixed on another counter shaft of 60 mm diameter solid shaft having 660 mm length and mounted on two suitable pillow block bearings (No. P211) and fitted just below the large size cast iron gear wheel mounted on drum shaft for power transmission. On this second shaft (opposite to the small gear wheel end), one 600 mm diameter and 70 mm width cast iron pulley having two 'C' grooves was mounted and locked in position using a key.

One, 10 hp ISI certified closed type electric motor provided with copper wire having 'A' class insulation fitted with 90 mm diameter cast iron pulley having two 'C' grooves was mounted on a suitable slotted frame, for easy horizontal movement of the motor. An ISI certified star delta type starter (25 A) along with double throw 32 A triple pole iron clad main switch was provided for operating the motor along with 3/20, (2.5 mm^2) 4 core ISI certified wire, 50 m length. Two numbers of ISI certified 'C' 112 (suitable for 'C' groove) V belts were provided for transmission of power from motor to polishing drum through gear train.

A belt tensioner made out of 10 mm thick, 75 mm width and 1500 mm length mild steel flat fitted with 90 mm diameter pulley having two 'C' grooves mounted on suitable bearings and attached to a flat was fixed using a pivot arrangement to move the belt tensioner up and down and to hold it at any desired position by inserting a pin. This arrangement is provided to overcome the initial load of approximately one tonne of rhizomes in the polishing drum and help to rotate the drum slowly by tensioning the belt slowly (similar to clutch). When the drum picks up speed and rotates at its full speed, the tensioner is positioned and locked.

A slow tilting mechanism suitable for tilting loaded octagonal drum with rhizomes slowly was fabricated using three gears of 71, 12 and 12 teeth having 50, 60 and 60 mm width, respectively and mounted on the left side of the larger size gear fitted on the drum shaft on suitable shafts and bearings for easy operation. The positioning of the gears on slow tilting mechanism were such that as and when required, the 3rd small gear mounted on a shaft over a lengthy key could be slided over the shaft and both the large size gear on the octagonal drum and smaller gear and large gear in the slow tilting mechanism could be engaged for easy rotation and thereby unloading of polished rhizomes from the polishing drum by rotating a handle attached to the slow tilting mechanism.

d. Outer Dust Cover

An outer dust cover with an annular space of 150 mm all around the octagonal shaped polishing drum having a definite shape, convenient for loading, unloading and other operations was fabricated and mounted over the polishing drum as two halves. Three quick opening and closing doors of 340 × 540 mm size were provided on the sloping sides of the polishing drum for inspection and cleaning purposes. On the top of dust proof cover, an opening of 600 mm width and 2150 mm length with suitable quick opening and closing door was provided for easy loading of rhizomes into the polishing drum. The door for this opening is hinged at four places in such a way that the door can be opened, lifted and kept at any desired angle with the help of suitable fixtures provided at both ends. To avoid the possibility of leaking of air borne dusts through the door joint, rubber gasket was provided over the entire length of the door joint.

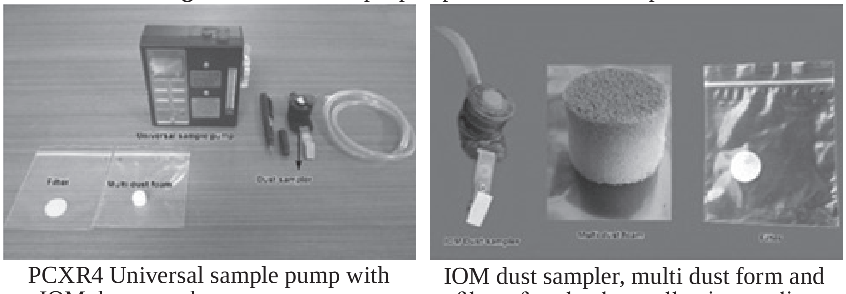
e. Aspirator with Bag Filter Arrangement

An aspirator arrangement was provided by taking an inlet at the top centre of the dust cover using 30 mm, 8 kg cm^{-2} PVC pipe with suitable fixtures and connected to a bag filter made out of cotton cloth of 380 mm diameter and 2900 mm length to collect the fine air borne dusts and release air alone through the pores of bag filter, thereby reduced the air pollution.

f. Rhizome Cum Coarse Dust Conveyor

A chain conveyor of 4200 mm length, mounted on two sprockets (8 teeth, 200 mm diameter and 78.5 mm pitch) was fabricated and mounted at the bottom of the dust proof turmeric polisher just below the sloping sides of the outer dust cover. Two shafts of 60 mm diameter were used to mount the sprockets. The sprocket present on the front side was made as driven sprockets and mounted with sliding provision. This helps for easy tensioning of belt to the required level. The sprocket present on the rear side was used as driven one and fixed at constant position. To avoid falling of dusts through the gaps between the chain links, an endless expandable rubber belt of 230 mm width and 4200 mm length was made and inserted tightly over the chain. The positioning of the chain conveyor with belt on its top was such that both the sprockets of chain conveyor were placed outside the dust cover so that without any difficulties, the unloaded rhizomes/coarse dust could be conveyed and discharged away from the main frame of the polisher for easy collection and bagging. To avoid slagging of chain conveyor, two idle rollers of 90 mm diameter and 230 mm length were mounted each on two bearings and fitted over a frame with a provision for up and down movement. To avoid the movement of rhizomes and dusts along the sides of the conveyor, a flap like closely sliding arrangement was provided along the entire length of the conveyor on both the sides made up of rubber belt. To avoid direct loading of rhizomes on conveyor during discharge of rhizomes from the polishing drum, an inverted ‘V’ shaped load barrier has been fixed just above the belt conveyor having side width of 120 mm and internal angle of 90 degree for the entire length of the drum with 120 mm clearance from the sloping sides (both) of dust cover for easy sliding of rhizomes towards the conveyor. At the end of the conveyor, an outlet chute has been provided very close to the conveyor to collect both the rhizomes and coarse dusts conveyed by the conveyor and discharge the same to bag or basket for easy collection. The conveyor was powered using one three phase 3 hp electric motor through a speed reduction gear box and sprocket and chain arrangement and made to operate at a forward speed of 0.25 m s^{-1}.

Fig. 6 Universal sample pump with IOM dust sampler



PCXR4 Universal sample pump with IOM dust sampler — IOM dust sampler, multi dust form and filter after the dust collection studies

Field Evaluation of Turmeric Polisher

Field evaluation of the newly developed eco-friendly turmeric polisher was conducted at different places in Namakkal District of Tamil Nadu state, India.

4.1. Studies on Dust Pollution

The dust produced during polishing of turmeric rhizomes in both conventional and eco-friendly turmeric polisher were recorded using an universal sample pump with IOM dust sampler (**Fig. 6**). Inhalable dust concentration of 336.67 mg m^{-3} of air was found during polishing with conventional turmeric polisher whereas dust was not collected during polishing with the eco-friendly turmeric polisher and only while conveying and discharging the dust, little air borne particles were floated at the rhizomes discharge end and the concentration was found to be 3.33 mg m^{-3} of air. In both the cases respirable dust particles were not found. It is vital to provide a pollution free atmosphere for breathing, for good health and well-being of labourers working with the polishers and for the people in the vicinity of the polisher in operation. The existing turmeric polisher has become a source of air pollution and due to this the workers health could be affected by pollutants such as dust, microorganisms etc. (which is also addressed as bioaerosols). From the results, it is clear that the newly developed eco-friendly turmeric polisher provides a good environment to the workers and protects them from health hazards. Saleh et al. (2010) conducted dust experiments in the air of poultry houses. The highest inhalable dust concentrations of 10 mg/m^3 were recorded, which is 2.5-times higher than the threshold level (4 mg m^{-3}) as reported by German Occupational Health Threshold for workers. According to German Occupational Health, the permissible level of dust in the air is 4 mg m^{-3}. The newly developed eco-friendly turmeric polisher recorded only 3.33 mg m^{-3} of air, which is well within the permissible level and hence it can be used for polishing operation without polluting the atmosphere and affecting the health of the workers and people near by the polishing area.

4.2. Performance Evaluation of Eco-friendly Turmeric Polisher

Uniform polishing of rhizomes was achieved due to complete mixing of rhizomes resulted from the channel shaped section provided on both ends, from side wall to centre (opposite to each other) to shift the rhizomes during operation from end to centre and then centre to end. Polishing time of 15 min per batch was reduced as compared to existing polisher with the introduction of ruptured abrasive surface on the side walls of the polishing drum and combination of two different abrasive surfaces namely expanded wire mesh and ruptured abrasive surfaces on the sides of the polishing drum. This in turn saved power and cost. The polished rhizomes and coarse dusts are unloaded mechanically with the chain type conveyor with belt on its top. Controlled discharge of polished rhizomes from the polishing drum to the chain conveyor was achieved with the help of a slow tilting mechanism and an inverted 'V' shaped rhizome barrier provided just above the conveyor. Pollution resulting from polishing of turmeric rhizomes could be controlled up to 95% with the help of a dust cover and an aspirator with bag filter arrangement. The man power required was reduced from six to three for the entire operation. The newly developed eco-friendly turmeric polisher saved 42.86 and 41.67% in time and 36.84 and 39.29% in cost for finger and mother rhizomes, respectively when compared to the existing polisher.

Acknowledgement

The authors express their sincere thanks to the National Medicinal Plants Board, Government of India, New Delhi and Tamil Nadu Agricultural University, Coimbatore - 3 for their financial assistance and permission to conduct the study, respectively. The authors also greatly acknowledge the help rendered by peer scientists and other technical supporting staff.

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Development and Testing of Bhutanese Maize Sheller

by

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Abstract

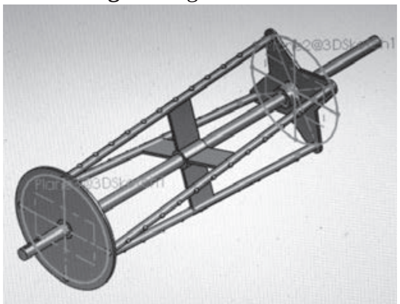
Maximum harvesting and shelling of maize are performed by women in the country. Hence the maize shelling machine designed and fabricated in this study shall be of great help to this section of the society. The tangential shelling is the heart of the shelling process. The peripheral speeds ranged from 3.25 to 5.51 m/s with revolution from 230 to 390 rpm. Hence use of 310-350 rpm and peripheral speed of 4.4 m/s and above are recommended for shelling efficiency. However, higher revolution or peripheral speed may increase the loss through scattering and crack formation.

Keywords: Maize, Tangential shelling, Peripheral speed, Shelling efficiency

Introduction

Maize is widely grown in the eastern and southern parts of Bhutan. The total area under maize cultivation and the total maize production are 70,312 acres and 79,826 MT, respectively in the country for the year 2011 (Bhutan RNR statistics, 2012). In eastern part it is a substitute to rice as a staple food. Since it is cultivated largely on dry land and topography is sloppy, the use of oxen over machine is dominant. The harvesting is also done manually with use of sickles and so is the shelling of the ear from the maize. Maximum harvesting and shelling of maize are performed by women. The shelling process is done at home and hence the women's involvement had become evident. Shelling is also one of most tedious operations in the cultivation of maize as it requires exertion of energy in shelling and continuous shelling results in bruises on the hand. Hence intervention in this operation through the introduction of mechanised shelling would be a boon to the tired farmers, especially the women. Therefore, the objective of the research was to develop a mechanized shelling machine that is cheap, effective and user friendly.

Fig. 1 Tangential Rotor



Materials and Methods

The design of the maize shelling machine consists of the several design parts, which are detailed in the below sub-sections.

Tangential Rotor

The tangential shelling is the heart of the shelling process. The shelling occurs due to the rolling action of the maize between the tangential shelling rotor and the concave sieve. It is fabricated with four numbers of 16 mm mild steel rod welded at an angle of 6.43° between the two rotor plates for easy convey of the ear while shelling. The inclined rod is spotted with spot welding at regular interval for better detachment of the kernel from the ear of the maize. The diameter between the two rods and the length of the shelling rods were taken as 0.27 m and 0.65 m respectively (**Fig. 1**). The peripheral speed of the shelling rod is ascertained to avoid cracks and clogging.

The following equations were used to calculate the recommended revolution of the threshing drum (N), angular velocity of the threshing drum (ω) and the diameter of the threshing drum shaft diameter (Ds)

$$V = (\omega \times Dd) / 2 = (\pi \times N \times Dd) / 60 \quad ...(1)$$

$$P = (2 \times \pi \times N \times T) / 60 \quad ...(2)$$

$$T = (\pi \times \tau \times Ds^3) / 16 \quad ...(3)$$

Where P is the power transmitted (watt) which is 1.0 hp electric motor, T is the twisting moment in N-m, τ is the allowable shear stress in the shaft (MPa) which is assumed as 42 MPa or N/mm²

Concave Sieve

The sieve size of 18.0 mm was punched on 1.6 mm mild steel sheet and shaped concave to have maximum surface area of contact with the maize ear while shelling with the tangential shelling rotor. A clearance of 25.0 mm was maintained between the sieve and the rotor.

Outlet Chutes

There are two outlet chutes mainly the cob outlet chute to collect the cob without the kernel and the maize kernel outlet chute to receive the shelled kernel which is the main product (**Fig. 2**).

Performance Evaluation of the Maize Sheller

Three varieties of maize were collected and their moisture contents calculated using both the oven method and using the moisture tester (Dickey-john) as shown in **Fig. 3**.

The dimension of the maize variety which is length × diameter (l × d) were measured; variety 1 was 208 × 50 mm, variety 2 was 128 × 41.6 mm, and variety 3 was 98.3 × 33.0 Each variety was replicated three times for different revolutions (peripheral speeds) to observe the shelling capacity, shelling efficiency.

A single ear of each variety was shelled with replication with prior weight and maximum diameter recording using digital weighing balance and measuring tape. Time was recorded to complete the shelling and kernel, cob were weighed.

For the evaluation, the following equations were used:

Maize shelling capacity (kg/h) = [Weight of maize shelled (kg)] / [Time taken (h)] ...(4)

Maize shelling efficiency (%) = ([weight of the maize shelled] / [weight of the intial maize]) × 100 ...(5)

Statistical Analysis

The data analysis tool of the Microsoft excel spreadsheet (Microsoft office 2007) was used to perform the Two way ANOVA with replicates between the three varieties and the revolution per minute (rpm) from level 250 to 390 at 20 interval on the shelling efficiency. The peripheral speeds at these rpm, the capacities were also calculated using the average, standard error in excel.

Results and Discussion

The revolution of the tangential shelling shaft which is welded to the rotors was recorded and experiment conducted from 210 till 390 rpm at 20 rpm interval. The experiment was conducted at all these different revolutions with three maize varieties. The peripheral velocity calculated is shown in **Fig. 4**.

The peripheral speeds ranged from 3.25 to 5.51 m/s with revolution from 230 to 390 rpm. For threshing paddy, the peripheral speeds should be higher than 8.0m/s to minimize the breakage of the paddy (Choephyl, 2000). However, the breakage was not examined as some varieties were infested with maize weevils.

The shelling capacities of the machine under test for three different varieties at different revolutions were shown in **Fig. 5**.

It is clearly shown that the capacity of the machine increased with increasing revolutions for these three varieties as shown. However, the capacity for all varieties decreased with revolution beyond 370 rpm as shown. The two way ANOVA with replicates showed that there is significance difference on the shelling capacity with change in rpm at P = 0.05. Also there is significance difference on shelling capacity with three varieties of maize at P = 0.05. However, combination of revolution and the varieties did not have any significance difference on the shelling capacity at P = 0.05. Hence the change in revolution of the tangential rotor and use of these three varieties did not have

Fig. 2 Corn Sheller

Fig. 5 Shelling capacity (kg/h) at different revolutions

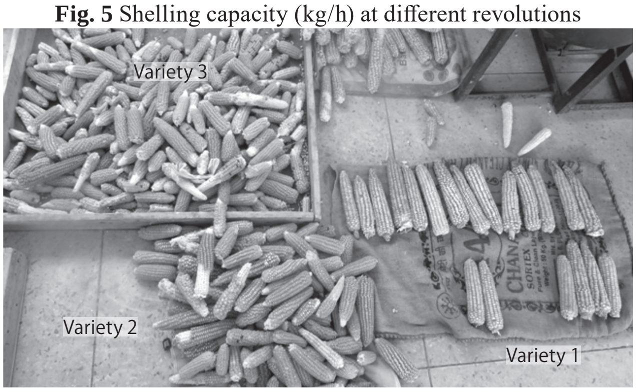
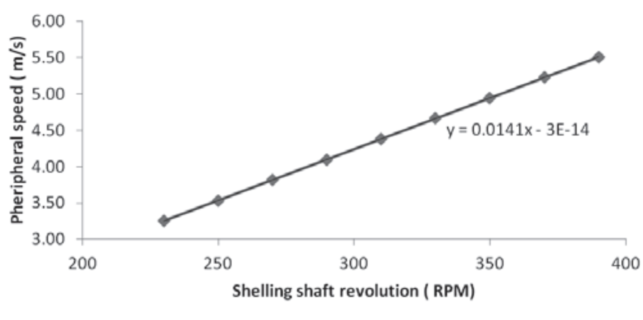


Fig. 6 Peripheral speeds of the threshing shaft drum with different RPM



significance difference on the shelling capacity. Hence use of 310 rpm and above or Peripheral speed of 4.4 m/s and above is recommended for shelling efficiency. However, higher revolution or peripheral speed may increase the loss through scattering and crack formation.

The two way ANOVA with replicates showed that there is no significance difference on the shelling efficiency with change in rpm at P = 0.05 (**Fig. 6**). Also there is no significance difference on shelling efficiency with three varieties of maize at P = 0.05. The combination of revolution and the varieties did not have any significance difference on the shelling efficiency at P = 0.05. In all these conditions the F critical was also higher than the F value calculated.

Hence the change in revolution of the tangential rotor and use of these three varieties did not have significance difference on the shelling capacity. Hence use of 310 rpm and above or Peripheral speed of 4.4 m/s and above is recommended for shelling efficiency. However, higher revolution or peripheral speed may increase the loss through scattering and crack formation.

Conclusion

Based on the evaluation test carried out, the machine is found simple in design and less expensive, and hence can be used by individual farmers. The recommended rpm of 310-350 of the shelling drum can be used for the shelling with this machine.

Acknowledgement

The author would like to thank Mr Watahiki for his guidance as a coordinator during the design of the machine. I would also like to thank Dr Hai Sakurai for his valuable suggestions and advises. The author would also like to thank AMDC incharge for supporting in testing and evaluation of the machine. Lastly I would like to thank the Programme Director AMC for all financial and administrative support during the testing.

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Fig. 5 Shelling capacity (kg/h) at different revolutions

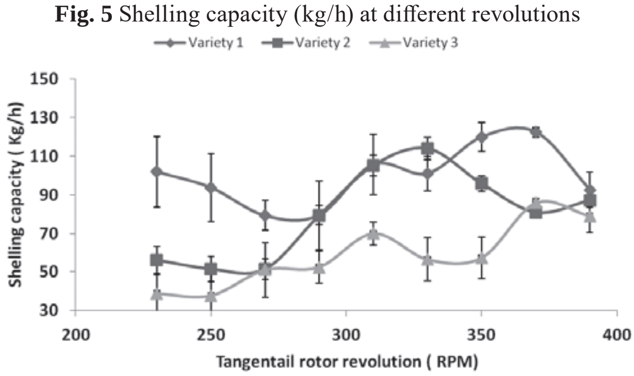
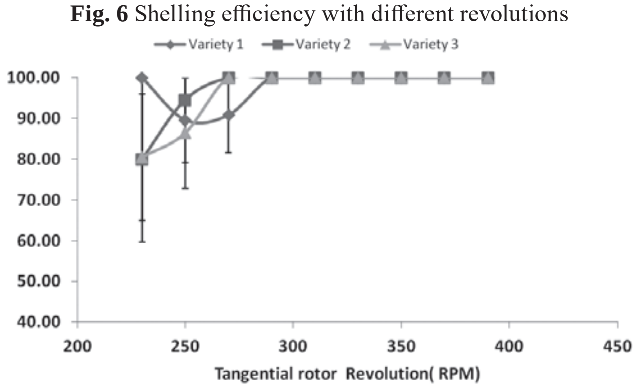


Fig. 6 Shelling efficiency with different revolutions



Current Status and Perspectives of Rice Farming in Sivakovka Village, Primorsky Krai, Russia

by

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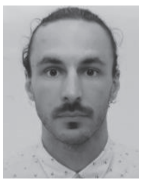

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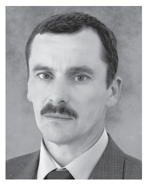

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Abstract

This article briefly describes the current state of rice farming, production and post-production technologies of rice in Sivakovka Village (SV), Primorsky Krai (PK), Russia. We investigated farming capacity, rice mechanization, post-harvesting activities, and the value of a water pumping station (WPS) in a rice farming system. A brief history of the development of rice farming and the current status of PK rice lands are also reviewed. Currently, PK is the only region of the Far Eastern Federal District that produces rice in significant quantity. There have been more than 100 years of rice farming in PK. This article provides scientific data on rice farming in PK, specific prospects and thoughts, which could be valuable for scientists, analytical experts and business entrepreneurs.

Keywords: Rice farming, Water pumping station, Irrigation system, Primorsky Krai, Sivakovka Village, QGIS

Introduction

Sivakovka (Russian: Сивако́вка) Village (SV) is a part of Khorolsky district, one of twenty-two districts in Primorsky Krai (PK), Russian Federation. It is located in the southwest of the region near Lake Khanka (**Fig. 1**).

Lake Khanka is the largest freshwater lake in the Far East and belongs to Russia and China. Lake Khanka shares borders between PK and Northeast China − about 220 km of the lakeshore belongs to Russia and 90 km belongs to China. The maximum length and width of the lake are 90 km and 45 km, respectively. The surface area and the water volume are 4,070 sq. km and 18.3 cu. km, respectively. The lake's average depth is 4.5 m (Xiangcan and Xia, 2007).

Khanka's wetlands are exceedingly important for migratory birds, fish populations and agriculture. Furthermore, several studies have examined the spring migration of waterfowl on Lake Khanka (Bo-

Fig. 1 Location of SV in PK

charnikov et al., 2015), environmental issues of Khanka's wetlands (Xiangcan, 2006; Xiangcan and Xia, 2007), and fish composition in Lake Khanka (Tang et al., 2011). Additionally, there are several studies on the development of rice yield in PK (Pestereva, 2014), improvement of the management of rice production in PK (Nosovskiy et al., 2015), and agricultural production in PK (Park et al., 2015; Zhou, 2018). In addition, a water pumping station (WPS) in SV is the largest such station in PK, which supplies irrigation water for rice farming direct from Lake Khanka, and distributes irrigation water across the region. However, the current status of the WPS and rice farming in SV have not yet been studied.

Due to its geographical location (close to China), suitable climate, landform, and facilities for rice farming in PK, there are many Chinese investors involved in rice production (Zhou, 2018). Additionally, the Ministry of Agriculture, Forestry and Fisheries (MAFF) Japan has a current interest in the agricultural development of the Russian Far East region, under established objectives of Global Food Value Chain Strategy (GFVCS). One of the main GFVCS objectives is to promote the economic growth of developing countries and promote cooperation on food value chain from farmers to consumers by cooperation between state (public) and private sectors, and by official economic cooperation and investments by the Japanese food industry. Moreover, the MAFF has set up a platform by the Japanese government in order to support Japanese companies interested in agriculture, forestry and fisheries, and related businesses in the Russian Far East region (MAFF, 2018).

The purpose of this study is to analyze, describe and promote the current status of rice farming and the WPS in SV, PK, Russian Federation. In this study, we investigated the rice farming in SV with its farming capacity, rice mechanization and post-harvesting activities, and the value of the WPS in rice farming. We also give a brief history of the development of rice farming and irrigation systems in PK, and current state of PK rice cultivated area.

Material and Methods

Study Methods

This study relied upon quantitative methods, including observation, primary research, and secondary research (Chu and Ke, 2017). The study was carried out on-site within PK. The main data was taken from a Russian Federation database, Federal State Statistics Service, annual reports, and scientific articles. Quantum Geographic Information System (QGIS) software was used as a geographic information system (GIS) to capture and analyze geographic data in maps (QGIS, 2018). The QGIS allowed us to analyze the largest rice farming districts by cap-

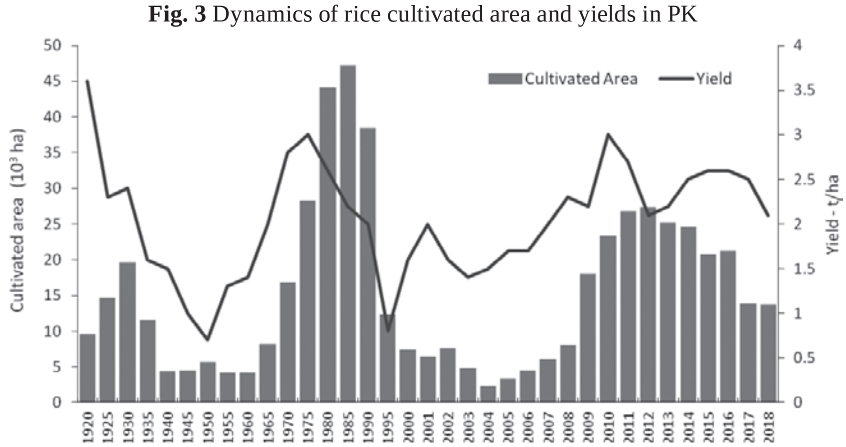
Fig. 2 The first rice sowing in PK

a) manual sowing by a primitive seeder;

b) manual sowing

Source: Trubitsyn and Kuzmenko, 2011

Fig. 3 Dynamics of rice cultivated area and yields in PK



Note: Yield is given in average value
Sources: Trubitsyn and Kuzmenko, 2011; Federal State Statistics Service, 2019

turing a land area and visualize spatial information on graphical maps.

Development of Rice Farming in PK

PK is one of the most suitable regions of the Far East for crop production as regards climate. The average annual temperature in the north and the south of PK is +1 °C, and +5.5 °C, respectively. The average annual precipitation varies 600-850 mm. Agricultural producers can grow soybean, corn, rice and other crops to supply the domestic and export market (Tarasova, 2016).

In the early 1900s, the first rice sowing in PK was performed by primitive cultivation technologies. Due to poor drainage of paddy fields, the sowing was performed manually or by seeders in a spread without furrow openers (**Fig. 2**).

The rice was harvested by a manual technique using scythes and sickles. The rice harvested by sickles was bound up in sheaves with a diameter of 15-20 cm and stored near the field area. The rice harvested by scythes was dried on the field surface for 5-6 days, and then it was bound up in sheaves with a diameter of 20-30 cm and stored around the field. The threshing of rice was carried out in the winter, at -30-40 °C, during the whole winter. However, since sowing and harvesting were done manually, and the threshing was performed in winter, the loss of grain was low, and yields remained high.

Active rice production in PK began in 1918, although only 8 ha were planted at that time. By 1920 9,630 ha were planted, in 1925 − 14,695 ha, and by the end of 1930, the area of paddy fields was about 20,000 ha. At that time, the irrigation systems of paddy fields were primitive and generally consisted of embankments around the fields and one intake irrigation canal. It should be noted that paddy fields were built during a period of decline in water level of Lake Khanka in 1920-1930, which has since risen by 2 meters, leading to the flooding of paddy fields. In 1931 the planted area decreased to 4,000 ha. Since the increase in water level of Lake Khanka, the planted area varied from 4,000 to 10,000 ha until 1960 (Trubitsyn and Kuzmenko, 2011). **Fig. 3** illustrates the dynamics of the cultivated area and rice yields in PK up to the present date.

Fig. 4 Irrigation canal

Source: Trubitsyn and Kuzmenko, 2011

Fig. 5 Sivakovka water pumping station in 1980

Source: Trubitsyn and Kuzmenko, 2011.

After 1960, an organization ‘Primvodostroy’ for the reconstruction and construction of new paddy fields and irrigation systems was established. According to the Resolution of the Soviet Union Government from 1961 (Resolution of the Council of Ministers of the Russian Soviet Federative Socialist Republic (RSFSR) No. 856 of July 3, 1961, and the decision of PK Executive Committee No. 772 of July 12, 1961) the main goals and tasks of the Water Management Department were determined in PK. The goals and tasks were aimed at developing a long-term program which included rice production in PK, development of new paddy fields, development of drainage and irrigation systems, and creation of state rice farms (Nosovskiy et al., 2015). Further, the cultivated area had begun to increase by 1966, and the process of rice sowing and harvesting was completely mechanized. **Fig. 4** shows a developed irrigation canal equipped with drainage locks in 1961.

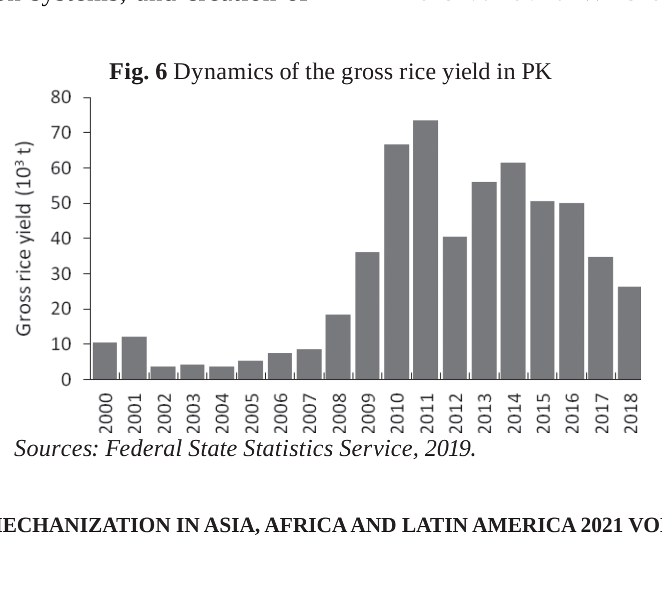
Development of Rice Irrigation Systems in PK

Active construction of irrigation canals and water pumping stations in PK began in the period from 1967 through 1980. During these 13 years, the largest inter-farm main canals began to function (Sivakovsky, Novodevechansky, Astrakhansky, Lugovoy and Platono-Aleksandrovsky), including the canals’ water pumping stations.

Sivakovka WPS was the largest in the Far East, that supplied irrigation water for agricultural purposes with a capacity of 54 m^3/s, (**Fig. 5**). The length of the supply in-take channel from Lake Khanka to WPS is 3 km, and 70 m wide, and the depth at the center of the canal is 8-9 m.

The Sivakovka WPS supplied

Fig. 6 Dynamics of the gross rice yield in PK



Sources: Federal State Statistics Service, 2019.

water for all inter-farm main canals and irrigated more than 20,000 ha of paddy fields. Moreover, it performed the function of a drainage pumping station on an area of more than 28,000 ha. Thus, all drainage systems and inter-farm irrigation canals have embankments to protect against flooding.

Results and Discussion

Current State of PK Rice Cultivated Area

Analysis of the dynamics of rice cultivated area (**Fig. 3**) shows that in 1965-1985 the cultivated area was rapidly increasing due to the agricultural programs on rice production of the Soviet Union government, and the peak cultivated area was approximately 47,200 ha by 1985. Further, there was a steady decreasing of the cultivated area in 1990-2005, as a result of the collapse of the Soviet Union, and a recovering after the post-Soviet period.

Meanwhile, in 2008 (after the collapse of the Soviet Union), Chinese and Korean entrepreneurs began to rent abandoned paddy fields. They began to revive the production bases of former state farms and restarted rice production in PK. Referring to **Fig. 3**, we can see that the cultivated area was significantly increased from 2008, as a result of Chinese and Korean agricultural activities. Currently, the rice cultivated area in PK is approximately 14,000 ha. The cultivated area declined in 2017 by 7,400 ha, in comparison to 2016. This decline of the cultivated area relates to the excess rice storage harvested in 2016 due to fluctuations in the market. The dynamics of the gross rice yield is given in **Fig. 6**.

In general, there are more than five districts of rice farming in PK, and almost all districts are bordered by Lake Khanka, as it is the main irrigation water source. The largest rice farming districts are identified in **Fig. 7**.

Additionally, **Fig. 7** illustrates the total land quantity, which was mostly cultivated in the Soviet Union period. Currently, about 50-60% of the cultivated rice area in PK is operated by foreign entrepreneurs, with full or partial investments.

Unfortunately, due to the specific method of data collection in the Russian Federation and local centers, statistical reports lack some necessary data. The reports do not indicate important specific details, such as the number of rice producers, their cultivated area and post-harvest activities, crop yield by each producer, and many other details. Because, the data published by the Statistics Office are not satisfactory, as they are not systematically collected, the authors went to SV and conducted a survey for the information needed to develop this study. However, the statistical reports did provide general official information about the agricultural production.

Rice Farming in Sivakovka Village

Rice Farming Capacity

By using the QGIS, we were able to measure real distances to determine a potential rice cultivated area in SV. To do this, we made a survey on latitude and longitude coordinates in SV. Further, we inputted the determined coordinates in QGIS and obtained the geographic data in a map.

According to the QGIS measurements, the potential rice cultivated area in SV is approximately 7,559 ha. **Fig. 8** illustrates the map with the collected data.

Secondly, we identified rice farming companies, their type and the size of cultivated area they farmed in SV. Currently, there are five rice production companies in SV. The used cultivated area by those companies is given in **Fig. 9**.

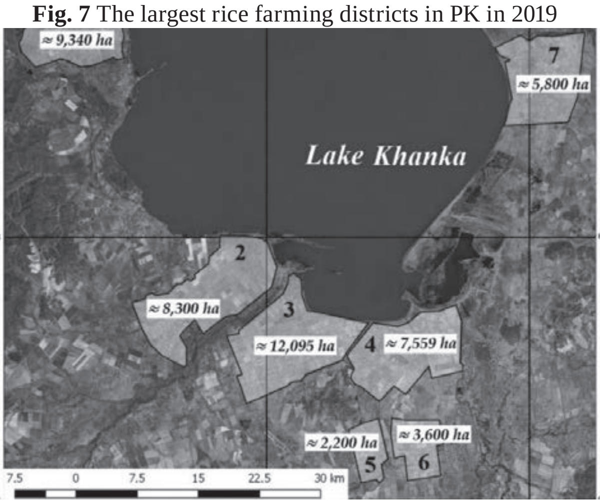


Fig. 7 The largest rice farming districts in PK in 2019

1, 2 – Khankaysky; 3, 4, 5 – Khorolsky; 6 – Chernigovsky; 7 – Spassky

Note: Total land area is 48,974 ha, according to our research measurements

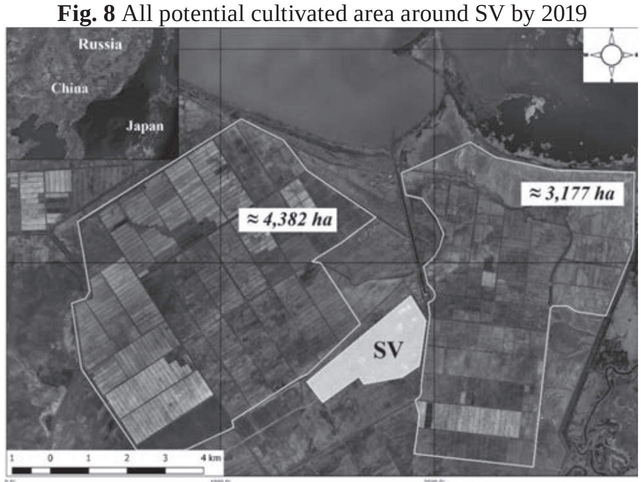
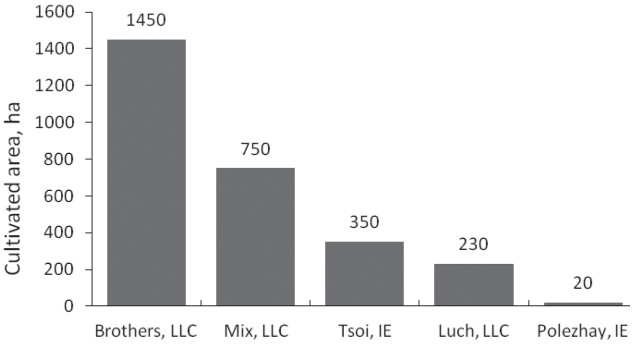


Fig. 8 All potential cultivated area around SV by 2019

Fig. 9 Cultivated area of rice farming companies in SV in 2019



Note: Total – 2,800 ha; Average crop yield – 4.5 t/ha; LLC - Limited Liability Company; IE - Individual Entrepreneur

Fig. 10 Location of used paddy fields around SV

1 – 2,620 ha; 2 – 180 ha

According to data collected, the current rice cultivated area in SV is 2,800 ha; which is approximately 40% of the potential cultivated area in SV (7,559 ha), in addition, it is 20% of the current rice cultivated area in PK. **Fig. 10** shows the geographical location of the currently used paddy fields.

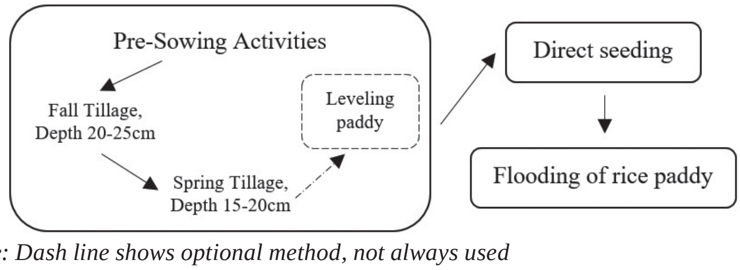
From **Fig. 9**, we can identify two company types. The first type is provided by foreign investments (Brothers, Mix, Tsoi and Luch), and the second type is a local entrepreneur without foreign investments (Polezhay). Brothers, Mix, Tsoi and Luch produce rice in great quantity and offer various rice production, from seeds of Chinese and Russian selection. Due to Chinese investment, all four companies generally have Chinese agricultural technology, rice-processing plants, agricultural machinery, and workers from China. Polezhay is an individual entrepreneur, who produces a small quantity of rice for his own needs (livestock feed and family consumption) with a subsequent small sale.

Rice Mechanization

The companies under Chinese investments use two types of rice cultivation technology, which include different types of paddy fields preparation, sowing seeds, and paddy fields irrigation. **Figs. 11** and **12** show the main principles of rice cultivation technologies used in SV.

Pre-Sowing Activities are typically involved in plowing (fall tillage) to mix and overturn the soil, harrowing (spring tillage) to break the soil clods into a smaller mass, to enhance air exchange in the soil, and for effective weed control, and leveling the paddy field to provide a suitable soil surface for direct seeding. However, the leveling is an optional technique mostly used when there is an uneven field surface after the spring tillage for direct seeding. Moreover, the main difference between the wet direct seeding (**Fig. 11**) and direct seeding (**Fig. 12**) is that wet direct seeding performed by drilling seeds into the wet fields (flooded), which allows a quick growth of rice plants with a better average of yield. Additionally, wet direct seeding is more labor-intensive for its cultivation method and requires more operating time. For instance, the average operating speed of a wet direct seeder is 5 km/h, with the seeder working width of 3 m. In contrast, the average operating speed of a direct seeder is 10 km/h, with the seeder working width of 4 m. However, these two cultivation technologies are actively used in SV and PK. **Fig. 13** shows

Fig. 12 Rice cultivation method used in Direct seeding



Note: Dash line shows optional method, not always used

Fig. 11 Rice cultivation method used in Direct seeding

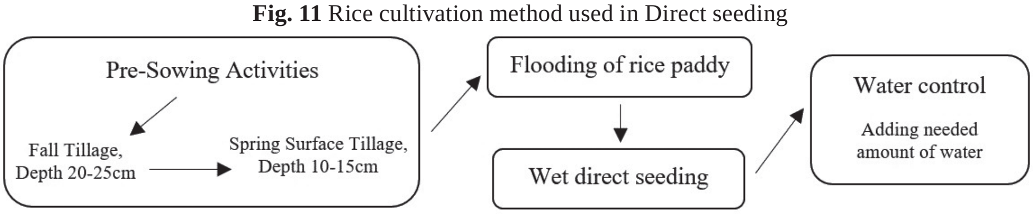


Fig. 13 Rice growth by wet direct seeding in 2019

the result of rice growth by wet direct seeding. **Fig. 14** illustrates a direct seeder of Chinese production used by Tsoi company.

Due to Chinese investments, Chinese agricultural machinery is mostly used in SV. The Chinese tractor's power used for rice sowing and cultivation purposes varies from 36.7-100 kW. However, they also use Russian and American agricultural machinery due to the large size of the paddy fields and availability on the market. **Fig. 15** shows some of the agricultural machinery used for the rice mechanization in SV.

The rice harvesting is performed by a large track-type combine harvester. Due to the peaty soil in SV, the track-type combine harvester is one of the suitable pieces of agricultural machinery with a decreased impact on soil compacting which allows it to operate effectively in flooded rice paddies. **Fig. 16** shows track-type combine harvesters.

Post-harvest Activities

The companies under Chinese investments use a rice drying system and multistage rice milling as crucial steps in the post-production of rice. The rice drying system includes a rice dryer machine (**Fig. 17**), which uses hot air as a thermal medium to dry the grain.

The multistage milling system includes removing the husk and the bran layers, to produce an edible, white rice kernel that is sufficiently milled and free of impurities. **Fig. 18** shows a stockroom with packed rice after processing.

After all post-production operations are finished, the companies supply packed rice to a Russian market, mostly to the Far East market, though part of the production is exported to China as well. The standard packaging size is 10 kg and 25 kg. Moreover, rice husks or hullsare, which is generated during the first stage of rice milling, is used by the companies as a solid fuel for the rice dryers. Rice bran and rice flour, which is generated when brown rice moves through the whiteners and polishers, is used as supply for animal husbandry farmers, as the rice bran and rice flour have high nutritive value. Brewer's rice, which is produced separately when milled rice is sifted, is distributed to poultry and animal husbandry farmers in PK.

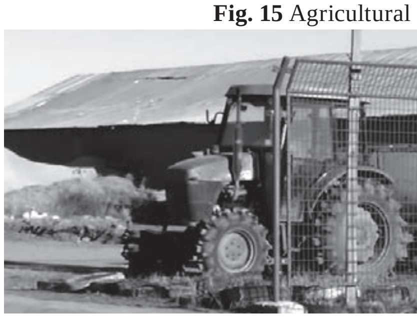
Rice Irrigation System

As introduced above, in the materials part of this study, the Sivakovka WPS was the largest in the Far East, with the capacity of 54 m^3/s. Currently, the Sivakovka WPS performs at only 30% (16.2 m^3/s) of its

Fig. 14 Rice direct seeder of Tsoi company

Operating speed – 10 km/h; width – 4 m; with simultaneous fertilizer application, depth – 8 cm; Chinese producer – no-name seeder

Fig. 15 Agricultural machinery used in SV



a) – Chinese conventional tractor – Foton 804

b) – John Deere 9320 high-power tractor

c) – Disc harrow of high-power tractor, working width – 12 m

d) – Disc harrow of conventional tractor, working width – 6 m

Fig. 16 Large track-type combine harvesters

a) – New combine harvester – Rostselmash VECTOR 450

b) – Old type Russian combine harvester – SKD-6 "Siberian" capacity. It supplies irrigation water for two inter-farm main canals and currently irrigates approximately 5,000 ha of paddy fields and performs the function of drainage on an area of 10,000 ha.

The physical condition of the WPS construction including inter-farm main canals and paddy irrigation system was repaired at the time when the rice farming companies in Khorolsky district began their activities (2008-2010). However, it has been more than 10 years since the WPS and the irrigation system around the district were maintained by a responsible technical service. **Fig. 19** shows the current visual condition of the WPS.

Recently, the MAFF has published its 4th Summary of the Agriculture of the Russian Far East interim report on agriculture commercialization possibility in Russia in keeping with the objectives of GFVCS. In the report, they present one of the water pumping stations, which is located in Khankaysky district of PK, as one of the main irrigation facilities in PK (MAFF, 2019). However, information on the largest WPS in SV, as the most important in the PK rice irrigation system, was not included due to the lack of data.

Conclusions

In Russia, rice has become one of the main crops in agriculture, and PK plays an important role in rice production in the Far East of Russia. Our findings show that there is approximately 48,974 ha of the potential land for rice farming across PK, and rice production has yet to be developed to its full potential. Recently, the rice cultivated area in PK was approximately 14,000 ha in 2018, however, the cultivated rice area could be higher up to 48,974 ha. Moreover, about 50-60% of the current rice cultivated area is rented by Chinese and Korean entrepreneurs.

Fig. 15 Agricultural machinery used in SV

Note: Processing capacity 50 t/day

SV has a great potential for rice production with its irrigation facilities and the potential land area of 7,559 ha. However, the current status shows that approximately 40% of the potential land area is used, and cultivated mostly by Chinese entrepreneurs, and the largest WPS in the Far East performs at only 30% of its capacity.

In addition, the lack of necessary data inhibits development and investment into the region by other foreign institutions to solve important issues.

Acknowledgments

We would like to thank the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan for the opportunity to make this study under providing financial support within a PhD scholarship at Niigata University, Japan. We also thank Mr. Danny Aspell from the Niigata Board of Education for editing a draft of this manuscript.

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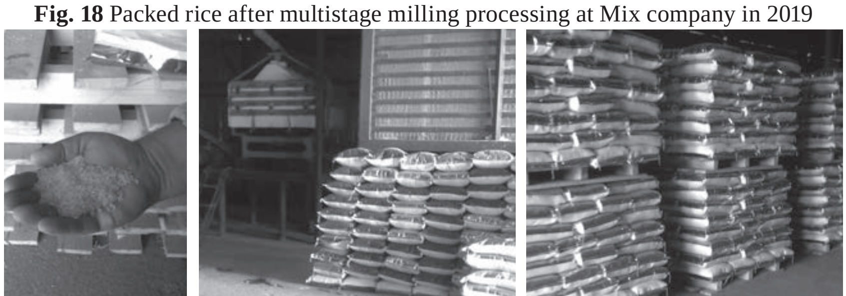
Fig. 18 Packed rice after multistage milling processing at Mix company in 2019



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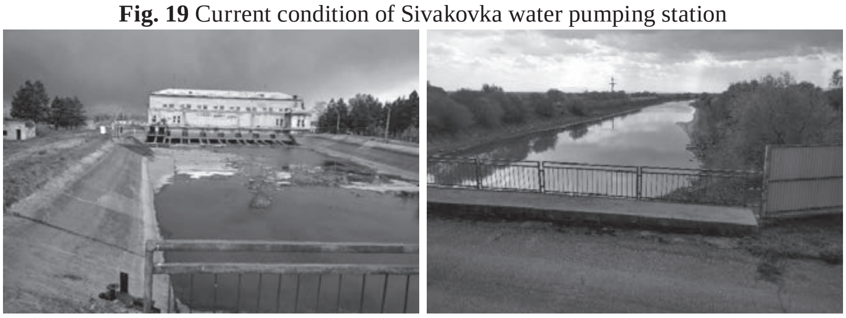
■■

Fig. 19 Current condition of Sivakovka water pumping station



a) – front view - before inter-farm canal   b) – Sivakovka inter-farm main canal

c) – back view - in-take channel   d) – main hall inside

Note: the photos were taken in autumn 2018 when water was drained for the winter season

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.

1854

Anthropometric Studies of Women Agricultural Workers of Chhattisgarh, India: Ajay Kumar Verma, Meera Patel

The Chhattisgarh State of India is rice growing mono-cropped area. Rice is a labour intensive crop. Women agricultural workers are involved in transplanting, weeding, harvesting and threshing operations of rice cultivation. Manual tools and animal-drawn implements are extensively used for different farm operations. These agricultural tools/implements are not designed ergonomically and this leads to an increase in accidents and health hazards to agricultural workers. Proper matching of machine requirements with operator's capabilities is necessary to achieve better performance. Very little data are at present available on anthropometry of women agricultural workers of Chhattisgarh. Therefore, a survey on 22 basic anthropometric data necessary for the design of agricultural equipment was conducted. Total 250 women agricultural workers having five different age groups of 20-25, 25-30, 30-35, 35-40 and 40-45 years from five districts of Chhattisgarh were selected. From each age group, 50 women workers were chosen to collect anthropometric data. The collected data were analyzed statistically. A large variation was observed in the anthropometric data of women agricultural workers of different states of India and other countries. Mean stature and mean weight of the women agricultural workers of Chhattisgarh were 1508 (±53) and 50 (±9) kg respectively. The coefficient of variation was found highest for weight (17.6%) as compared to other body dimensions. The analysis of anthropometric data suggests that the majority of the selected body dimensions were linearly related to stature of the subjects. The result revealed that the mean weight of the agricultural workers is gradually increasing as the age increases.

1859

Physical Characteristics and Nutritional Quality of Chickpea in the Process of Nokhodchi (Roasted Chickpea) Production: Reza Adiban, Hamid Reza Ghassemzadeh, Mohammad Moghdam, Ebrahim Ahmadil

Nokhodchi production process includes: raw chickpea preparation, First Heat Treatment (FHT), Second Heat Treatment (SHT), Moisture Treatment (MT) and Dehulling & Roasting Treatment (DRT). In this study; the time dependent mechanical behavior of chickpea under compressive load, based on rheological theories was perused. Results showed that from raw chickpea phase to FHT; the module and time of the stress relaxation increased but during FHT to SHT decreased. The results indicated the module and time of stress relaxation increase from MT to Nokhodchi phase. Comparing the Nokhodchi characteristics with raw chickpea showed that the final product has 20% volume development and lower resistance.

1903

Topological Analysis and Experiments of Transplanting Robot with Parallel Mechanism in Greenhouse: Xin Zhou, Jing Cai

An integrated machine equipped with conveyor device was designed for advantages of high planting speed, efficiency, accurate control and good flexibility for planting operation. It was used to transplant cucumber seedlings from trays with 128-hole to 72-hole tray. Corresponding equations were established to analyze the topological synthesis of the transplanting robot with parallel mechanisms. Then the simulation workspace of the transplanting robot with parallel mechanisms were achieved through specific set constraints given. The comparative experiments of the prototype transplanting robot in a greenhouse were carried out under different conditions. By setting and increasing the transplanting parameters under different conditions and controlled with PLC, the number of broken and dropped seedlings were measured, and the stable transplanting operation was 30 mm/s^2.

2008

Design, Fabrication and Evaluation a Novel Mechanism to Automatic Weight Transfer Control System on the Tractor: Javad Tarighi, Seyed saied Mohtasebi, Vali Rasooli Sharabiani

Increasing tractor weight during agricultural operations is one of the techniques of optimizing its tires' performance with soil. One method is by adding weight on the front axle of the tractor, which leads to better engagement of front tires with soil. This technique results in better steering wheel in four-wheel drive tractors as well as preventing weight transfer to the rear of the tractor which reduces overturning. In this research, a new approach is proposed which makes automatic weight transfer possible by putting some lightweight instead of main weights on the front axle. To do so, a number of specific weights were added on the front of the tractor which can be moved by means of a mechanical joint and a hydraulic jack considering working and ground conditions. Traction force and slop of land that have the most impact on weight transfer were measured by a dynamometer and an inclinometer. Also, the values of these parameters were controlled by an electronic circuit. Experiments on a sloping surface proved the efficiency of applied system in control of dynamic weight transfer as well as longitudinal balance of the tractor. ■■

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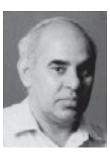
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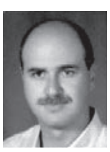
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