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EDITORIAL

Coronavirus infection continues to spread around the world. Development and production of vaccines against coronaviruses has started in some countries and the inoculation of vaccines is going on full swing and most of the people have completed the vaccination.

However, this is not the case in many countries. Even in scientifically and technologically advanced countries such as Japan, vaccine development is still a work-in-progress. As actual war, the war against coronavirus requires concrete strategy and a set of specific and coordinated actions. Therefore, the governments must make a bold budget and carry out the needed action urgently.

However, the reality is that there is a big difference among group of countries where it is done and where it is not. In the world, SDGs are rolled out and many companies are beginning to incorporate this concept into their businesses.

Food, agriculture, forestry and fisheries are the most important things for human beings to live on this earth sustainably.

However, people involved in agriculture, forestry and fishers are aging all over the world. Because of low profits, youngsters don't prefer working in agriculture and continue to go out to the cities for non-agricultural occupations. In Japan and other countries, serious labor shortage, especially during critical agricultural operations has begun due to aging. It's been knowing for more than 20 years, but concrete policy against it has not yet made. It is very unfortunate. The most important concrete strategy is the development and dissemination of technology that increases the labor productivity of agriculture production dramatically.

There is a need for new and appropriate agricultural mechanization that requires urgent formulation and effective implementation of strategies. Globally, the amount of agricultural land per capita is decreasing every year, which means that the land productivity of agriculture must be increased to obtain enough food against all the odds. The most important ingredient to increase the productivity of agriculture is timely and precise agricultural operation. It can only be done by suitable agricultural mechanization.

A strategy to increase agricultural labor and land productivity is needed. It is an urgently-needed agricultural mechanization strategy, which has to be prioritized in each country.

AMA was first published in 1971 with the aim of connecting experts in the world and promoting suitable agricultural mechanization in developing countries; it is now the time for experts in the world to join hands to collectively address this major challenge. I wish that everyone keep safe, healthy and motivated in these difficult and testing times.

Yoshisuke Kishida
Chief Editor
May, 2021

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Multiple Attributed Parametric Review on Mechanical Picking of Cotton (*Gossypium Hirsutum* L.) Crop in Relevance to Developing Countries

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Abstract

Crop characteristics of cotton are very crucial in identifying the important crop features like plant height, canopy width, sympods and monopods distribution, and row spacing that affects the performance of mechanical harvesters. Low temperatures tend to slow the activity and reduce the effectiveness of most harvest aids. Trash content was observed to be lower in cotton harvested by cotton picker than cotton harvested by cotton stripper. In higher yielding cotton, cotton pickers recorded higher picking rate than cotton strippers. The picking or harvesting efficiency of cotton stripper with both finger and brush type mechanisms was higher than the spindle type cotton picker. Picking efficiency of pneumatic picker was higher than the other types of picking mechanisms but with lower rate of picking capacity. Gin turnout of cotton was higher with cotton picker when compared with cotton stripper due to lower trash content observed in cotton picker. The cost of cotton stripper is about two-third of a cotton picker and ranged from 0.25 to 0.5 horsepower. The scheduling and monitoring of various activities involved in cotton picking using a suitable software model can increase the benefits of both growers and harvesting companies. The concept of introducing mechanical harvesting method has been in the process for decades. In Greece, this process took place gradually for over 15 years whereas in Turkey, it took 20 years. Top cotton producing countries like India, Pakistan, China, Uzbekistan and other developing countries like Iran and Paraguay are still not using the mechanical harvesting method. The introduction of mechanical cotton picker or stripper can help improve quality and quantity of cotton harvested thereby increasing its industry value and giving more benefit to growers in developing countries such in a way that it will improve their socio-economic status. One of the controversial issues associated with the introduction of mechanical cotton harvester has been its major role played in the migration of people. Popular opinion has accepted the view that the use of machines eliminated jobs and forced poor families to leave their homes and farms in search for urban jobs. Therefore, government policies towards mechanizing cotton harvesting operation must include alternative jobs, packages for dependent manual cotton pickers and their families.

Keywords: cotton characteristics, mechanical cotton harvester, crop parameters, machine performance parameters

Introduction

Cotton can either be picked by hand or machine. Manual picking is slow but better preserves the fiber characteristics of cotton. Boll opening is the first action on the fiber that pushes fibers from the place where they were embedded for weeks before being exposed to the external conditions. The boll opening action is gentle and thus has no effect on the fiber quality. However, a longer stay of the open bolls in the field can make the fibers shrink and which may also change the color thus affecting the three most important fiber characters namely length, strength and micronaire. One of the characters may be strongly affected more than the other if there is frequent dew. This type of effect cannot be eliminated because all bolls do not open at the same time and some open bolls have to stay in the field for days and sometime for weeks. In the case of hand picking, it is possible to pick open bolls at frequent intervals whereby the weather effects on the fiber after the bolls have opened can be minimized. This effect is minimized in China (Mainland) as land holdings are so small that the majority of the growers who have planted cotton on about one-tenth of a hectare can go many times to the field to pick few open bolls. In slightly bigger plots, fiber quality is preserved through a number of pickings during the season. About 30% of the world's cotton production is harvested by machines. Cotton is mainly picked by machines in countries like Australia, Israel and USA, whereas, in Argentina and Brazil machine picking is increasing and may be adopted in Turkey in the next few years. In countries like USA, Russia, Egypt and Brazil, the picking of cotton is done by mechanical cotton harvesters such as cotton stripper or picker. But in countries like India, the most cotton is manually picking. The operation is not only tedious but also ten times costlier than the cost of irrigation and about twice the cost of weeding operation (Prasad and Majumdar, 1999). The crop characteristics and machine parameters are key elements, which play a major role in the selection, development and field performance of a mechanical cotton harvester. Hence, research publications including crop characteristics and machine parameters were reviewed to find their effect on the performance attributes of mechanical cotton harvester for aiding the development of mechanical cotton harvesters in relevance to developing countries.

Global Cotton Production and Harvesting Trends

Cotton is the most often used natural fiber worldwide thereby making it an important component of the textile industry. The total global production of cotton amounted to 103.17 million bales in 2016 where India, China and the United States were the largest producers responsible for more than half of the world's total cotton production volume. The total global supply of cotton with the inclusion of stocks stood at approximately 238.57 million bales in 2015. The United States was the top exporter of cotton with 10.5 million bales of cotton exported around the world in 2016. US exports majority of its harvests for processing abroad. Other leading exporters of cotton include India, Brazil and Australia. Whereas, Bangladesh, Vietnam and China were also among the leading importers thereby making these countries well-known for their large production of cotton clothing (Anonymous, 2016).

Review of Cotton Crop Characteristics and Parameters Affecting Overall Performance of Cotton Harvesters and Gins

A parametric review study was conducted for selected developing countries where most of the cotton is handpicked so as to encourage the use of mechanical cotton harvesters in their respective regions based on crop variety and characteristics, economic conditions and availability of other facilities like gins and pre cleaners. The study aims to help researchers, manufacturers and government in the formulation of good policies that will encourage the design, adoption and commercialization of mechanical cotton harvesters for their respective regions based on several factors which were reviewed and presented in this paper.

3.1 Cotton Crop Characteristics

Varietal differences do exist within all species. The ideal cotton variety for mechanical cotton harvesters should have short height of plant with a relatively narrow space, growing in more or less upright position, fruits distributed evenly all over the plant, wide opening bolls with fluffy locks and maturity should take place early (Ahmed, 1985). Experience gleaned from the United States, Australia and Xinjiang Production and Construction Corps (XPCC) located in the northwest inland region of China indicates that the height of a cotton plant should be less than 120 cm for spindle-pickers and less than 80 cm for stripper-pickers (Williford et al., 1994) because plants that are excessively tall decreases mechanical harvesting efficiency.

3.2 Role of Chemical Defoliants

Defoliants are not applied in many countries as they cause plants to begin to develop an "abscission layer," or zone of cells that eventually break down and cause leaves to separate from the stem and drop. Abscission is a natural process, but it is been enhanced by defoliant. Defoliants are classified as hormonal, herbicidal or mixtures of both. The indeterminate growth of cotton often leads to boll population at different stages of maturity when the crop is harvested. Boll opening compounds can be used as an aid in mechanical harvesting operation by accelerating the opening of green bolls. The rates of boll opening of all compounds were more influenced by the accumulation of heat units than by the amount of time following the application of boll openers. To predict and model the efficacy of boll opening with these harvest aides, heat unit accumulation may be used (Stewart et al., 2000).

3.2.1 Weather and Other Factors

Paraquat applied in the late afternoon before a bright sunny day boost the effectiveness of desiccation and tend to increase regrowth control. When plant and environmental conditions are not conductive to easy defoliation, TD 1123 (potassium 3, 4-dichloroisothiazole-5-carboxylate) can be an effective harvest-aid chemical on cotton (Cathey, 1985). Two chemical defoliants tank-mixed at half the standard use rate were equal or superior to either single component applied at the standard use rate. The combinations offered additional safeguards against adverse environmental conditions in addition to equal effectiveness (Snipes and Cathey, 1992). Machine harvesting also requires more defoliants and lint cleaners. Depending on the temperature difference between day time and night time, defoliants might be needed to induce leaf drop. Also machine picking will result in more trash. In general, defoliant treatments should not be applied prior to 60% open bolls in order to safeguard against potential losses in yield and undesirable changes in fiber quality (Snipes and Baskin, 1994).

3.3 Effect of Cotton Varieties, Row Spacing and Plant Population on Crop Yield and Field Capacity/ Picking Rate of Cotton Harvester

Cotton harvesting or picking may be accomplished manually or mechanically using cotton picker. A manually operated cotton picker was developed and tested. The test results obtained from the cotton picker was compared with the existing manually operated cotton picker and the traditional method of harvesting cotton on the bases of time input, labour requirement, ground and plant harvest losses. Results indicate that labour requirement for the developed cotton picker; the existing cotton picker and manual cotton picker were 166.17, 173.8 and 93.3 man-h.ha^{-1}, respectively with their corresponding ground harvest losses of 15, 12 and 5% obtained at branch moisture content of 39.5% (w.b.) and cotton moisture content of 2.8% (w.b.) (Adebija and Jackson, 2013). Research papers were reviewed to observe the effect of plant population on yield of seed-cotton. The cotton harvester was evaluated in a cotton field having a plant population of 40,000 plants.acre^{-1}, sown at 96.5 cm row spacing. The crop yield obtained for this practice was 1,164.5 kg.acre^{-1} (Faircloth et al., 2004). In another study, different cotton varieties like Carolina queen, Stoneville and rex smooth leaf were selected having a plant population of 33,000 plants.acre^{-1}. The crop yield for these varieties ranged from 700 to 740 kg.acre^{-1} (Corley, 1966). A cotton stripper was evaluated using rex, stoneville, stripper-31, D.P.L. smoothleaf cotton varieties. The plant population of these varieties was of 45,000-90,000 plants. acre^{-1}. The yield of seed-cotton for this plant population was measured in the range of 101-1,375 kg.acre^{-1} (Mathews and Tupper, 1965).

Cotton harvesters with different mechanisms were evaluated for different cotton varieties planted at different row spacing. The effect of crop characteristics like cotton variety and row spacing on field capacity of the cotton harvester were observed. The field capacity of two narrow row (0.76 m) tractor mounted picker was 0.26 ha.h^{-1} for St 393, St 457 and Carmen cotton varieties (Oz and Karayol, 2007). A tractor operated pneumatic harvester was evaluated to determine its picking rate using Ankur-651 cotton variety. The picking rate of the pneumatic harvester was observed to be 4.58 kg.h^{-1} for selected variety (Sharma, 2008). The effects of spacing between stripping rolls, plant size and plant moisture content were investigated on cotton harvest losses and vegetative foreign material. The total harvest loss increased when spacing between stripping rolls widened and was not affected by plant size. Stick content in harvested cotton increased as the branch moisture decreased. Spacing between stripping rolls did not significantly affect fine foreign material (Wanjura and Brashears, 1983).

Fig. 1 A view of cotton stripper during field operation

Fig. 2 A view of two row cotton stripper

3.4 Effect of Different Mechanical Cotton Harvester Mechanisms on Picking Efficiency

A comparative study between stripper, cotton combine and a conventional picker tested in conventional rows revealed a harvesting efficiency of 92.2, 89.3 and 94.6%, respectively. The quality of the stripped lint was the same as the quality of the combined lint. Both were about one grade lower than that obtained by a conventional spindle picker (Perish and Shelby, 1974). The self-propelled cotton strippers are shown in **Figs. 1** and **2**, respectively.

The overall harvesting efficiencies of brush type stripper was higher when stripping storm proof cotton varieties as compared with open - boll cotton varieties whose average harvesting efficiencies values fell between 96.2 and 90.6%. The spindle type cotton picker average harvesting efficiencies values fell between 86.2 and 90.4% for storm proof and open boll cotton varieties, respectively (Tupper, 1966). A study was conducted on a pneumatic type of knapsack cotton picker. The picking efficiency obtained for the pneumatic knapsack cotton picker was 96.4 and 97.5% for the first and third picking, respectively (Rangaswamy et al., 2006). A self propelled John Deere 9935 cotton picker model was evaluated with different cotton varieties in order to obtain the picking efficiency. The observed mechanical picking efficiency and picker efficiency values obtained were 55.6-83.1 % and 68.3-85.7 %, respectively (Prasad et al., 2007). A cotton stripper also has a higher field and harvesting efficiency than a cotton picker under low yield conditions (Porter et al., 2012). In systems where sufficient support equipment was available, strippers had higher productivity in terms of acres per hour than pickers. The spindle picker header as shown in **Fig. 3** which is used on a spindle type cotton picker as shown in **Fig. 4** is capable of harvesting 95 to 98% of the cotton produced, but some producers experience field harvest losses up to 20%. All pickers manufactured in the United States have two drums usually arranged in tandem or staggered, opposed drum position as shown in **Fig. 5**. The front drum of the row unit harvests about 75% of the cotton. Top-to-bottom spindle contact area of about 30 inches using 18 or 20 spindles per bar is being used in current production pickers. Spindles are spaced 1.625 inch along the bar. Bar cams and cam tracks cause spindles to enter a cotton row pointed slightly toward the rear of the picker and quickly swing to aim slightly forward as they retreat from a row.

3.5 Picking Patterns

Most efficient method practiced in the field is stopping the picker on the row and pulling the boll buggy beside it within a few seconds (**Fig. 6**). The basket is then raised, unloaded and lowered and then the picker resumes harvesting. In order to minimize field compaction from the boll buggy or making ruts when the soil is wet, tractor operators should develop picking patterns based on unloading near row ends - even if baskets are only partially full. Unload the basket into the wind to minimize the scattering of seed cotton during windy days.

3.6 Effect of Cotton Harvesting Methods on Gin/Lint Turnout, Trash Content and Field Losses

Research carried out on field cleaners and on similar stick machines used in ginning have shown that excessive processing rates decrease cleaning efficiency and increase loss of good seed cotton (Baker et al., 1982; Kirk et al., 1970). Previous research indicates that the optimum feed rate of these machines fall within the range of 2-2.5 bales per hour per foot of width (Wanjura et al., 2009). A significant amount of stick breakage occurs in the conveying system of both strippers and this breakage was a contributing factor influencing the removal of bark slivers from sticks, which then became entangled in the seed cotton and ultimately in the ginned lint (Wanjura et a1., 1979). Cotton picker and stripper were both evaluated with a field cleaner and the seed-cotton yield for the cotton stripper was higher giving a value of 5,506 kg.ha^{-1} when compared with 4,410 kg.ha^{-1} obtained for the cotton picker. The gin turnout for the cotton picker was higher (35.4%) when compared with 30.1% that was obtained for cotton stripper. The reason for getting less gin turnout with cotton stripper was the presence of higher trash content in the harvested cotton (Wanjura et al., 2013). Modern cotton harvesters were evaluated using different cotton varieties in determining their field performance. It was observed that the field losses for cotton picker was higher with a value of 6.8% when compared with the losses of 2.0 and 1.3% observed respectively during harvesting with cotton stripper with and without field cleaner. The percent trash content including burrs, sticks, dry leaves, pin trash was higher for the cotton stripper without field cleaner than cotton stripper with cleaner. The trash content for cotton picker was less when compared with cotton stripper. The average value of gin turnout for cotton picker recorded the highest value of 35.6% when compared to 30.2 and 26.6% obtained in the case of cotton stripper with and without field cleaner (Faulkner et al., 2011).

Efforts have been made by researchers to reduce the trash content

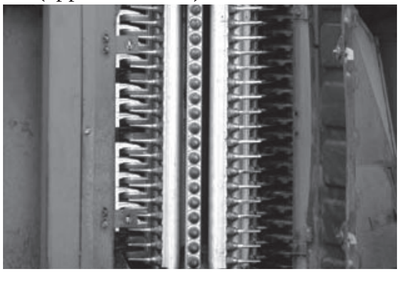
Fig. 3 Spindle type picker header (opposed drums)


Fig. 4 A spindle type cotton picker during field operation

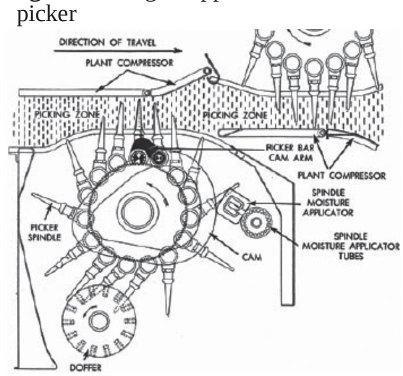

Fig. 5 Working of opposed-drum cotton picker

from seed-cotton during cotton harvesting. It was reported that the initial trash content of the stripped material ranged from 29-38% before cleaning (Smith and Dumas, 1982). An experiment was conducted to reduce the trash content of cotton stripper using pneumatic suction device. Foreign materials (trash content) up to 70 kg.ha^{-1} were removed by the pneumatic system; fine material in the bur cotton was not reduced (Brasher and Ulich, 1986). In previous studies carried out on trash removal it was reported that spindle speeds of 3,000 and 4,000 rpm had more detrimental effects on trash levels in seed cotton, picker stalk loss and cotton fiber quality than a spindle speed of 2,000 rpm. Cotton picked with spindle speeds of 2,200, 2,500 and 2,800 rpm had more trash noticed in the seed than in seed cotton picked with a spindle speed of 2,000 rpm. Trash content differences were eliminated by seed cotton cleaning (same for all treatments). It was reported that the 2,000 rpm spindle speed is optimal because trash in the seed cotton is reduced which reduces ginning costs; however, only minimal differences are present at spindle speeds up to 2,800 rpm (Baker et al., 2015).

Other Aspects of Mechanical Picking

A cotton-picker operation scheduling system (CPOSS) was developed for dispatching machines and labours, and guide the labours to the target field. The CPOSS is a WebGIS based management software. The whole scheduling process mainly includes three modules. The overall scheduling module aims to help the general manager to create fleet groups according to total operation demands of customers and the supply capacity of its own company. The local scheduling module was to dispatch the machines and labours to the fleet. The Google Maps based APP software was developed for center navigating, which receives the guidance commands from the CPOSS by SMS (GSM short message) and initiates the app to create the optimal path for the driver with the handhold mobile phone. Preliminary application shows that the model and system can improve the management efficiency of cotton picking operation (Wu et al., 2015). For scale cotton-picker operation, a Cotton-picker Operation Scheduling and Monitoring System (CPOSMS) was developed for Xinjian Agri. CPOSMS is a WebGIS and BeiDou based management software, which includes four main function modules. It was revealed that the CPOSMS is the appropriate tool for the company and the evaluation model and BeiDou based system can improve management efficiency (Wu et al., 2016). Similarly the collected cotton in boll buggy is unloaded in module builder as shown in **Fig. 7**. The module builder creates a compact brick of seed cotton, weighing approximately 21,000 lb (16 un-ginned bales), which can be stored in field or in the "gin yard" until it is ginned.

Potential Social Impact of Cotton Harvesters on Cotton Pickers and Farmers

Almost all cotton production fields in Australia, Brazil, Greece, Israel, South Africa, Spain, and the United States engage the use of machines for harvesting cotton. In Argentina, Bulgaria, Colombia, Kazakhstan, Mexico and Turkey, between 60 and 90% of cotton production fields were machine harvested. In China, 9% of total production in 2013-2014 was harvested by machine (up from 5% in 1998-1999). Iran and Paraguay also reported small percentages of machine harvesting as in year 2013. Machine harvesting is not used in India even though production has expanded there by 4.5 million tons over the past 15 years. Every country that has adopted mechanical harvesting techniques did so primarily because of labour scarcity. When labour costs rise, mechanized harvesting becomes more economical. In Argentina, machine harvesting is about one-fourth less expensive than handpicking. Other reasons for mechanizing cotton harvesting include (i) reduce contamination, particularly in Turkey and (ii) shorten harvesting time. The mechanization of cotton harvesting operations are also much faster. Cotton pickers in all sites suggested that a positive effect of mechanization will be to eradicate the need for government employees (teachers, doctors) and students to pick cotton (especially in remote areas, where local people do not want to pick cotton). Consequently,

Fig. 6 Conventional basket picker stops on the row and unloads

Fig. 7 A view of module builder in field during operation

schools and local hospitals will operate on a normal schedule during the cotton season. Farmers in all the four regions who participated in the study claimed that mechanization will offer important advantages in terms of the overall logistics of the harvesting process and completing the harvest on time (Swinkles et al., 2016).

In the three countries, most rural workers displaced by the introduction of mechanical harvesting either found jobs in cities or returned to other available agricultural jobs. Men tried to find alternative seasonal agricultural employment, while women often returned to traditional household responsibilities. In Turkey, displaced workers shifted to other agricultural sectors and continued to migrate seasonally in search of employment. While mechanizing cotton harvesting government should make policies, create employment for rural youth/pickers so that their socio economic needs are also fulfilled.

Conclusions

The average seed-cotton yield for high density planting system was higher. Higher picking rate was obtained for cotton pickers than cotton strippers in higher yielding cotton. Under low yield conditions, higher field and picking efficiency were obtained for cotton stripper than cotton picker. Higher productivity rate was obtained for cotton pickers than cotton strippers in higher yielding cotton. The picker harvest had higher harvest losses but also resulted in lower levels of foreign matter while higher turnout Open boll varieties showing storm resistance had high picker and stripper efficiency. In general, defoliant treatments should not be applied prior to 60% pen bolls in order to safeguard against potential losses in yield and undesirable changes in fiber quality. Field losses were observed more in case of picker as compared to cotton stripper. Suitable system with software modelling technique is very beneficial in reducing various losses and increasing benefits to growers/commercial harvesting farmers/industries/companies. In adopting the use of mechanical harvesters in developing countries, their Governments should make policies and create alternative employment opportunities keeping in view the socio economic needs of these dependent manual pickers. Varieties must be developed with bolls that form at least 15 cm above the ground to enable easy access of machinery. Likewise these varieties must be developed to exhibit uniform plant maturity so that at least 80% of the potential bolls are open and ready to be picked at the same time. Plants' hairiness (which impedes spindle picking) must be reduced. Plant breeders indicate that at least eight years are needed to optimize local varieties for machine harvesting. The crop characteristics and machine parameters are key elements which plays a major role in the development and adoption of cotton harvester in cotton areas. The purpose of this study was to collect useful information regarding crop characteristics and machine performance parameters of mechanical cotton harvesters as well as their social impacts on manual cotton pickers, farmers and policies required for their adoption in developing countries. Different research works conducted by several researchers were reviewed to observe the effect of crop and performance parameters on cotton harvesters. In the development of a mechanical cotton harvester, machine performance parameters such as picking mechanism, picking efficiency, trash content, gin turn out, crop spacing and planting system are the important attributes which may be considered by the designer/engineers.

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Design and Development of a Motorized Manioc Slicer for the Small and Medium Scale Processing Industry in Sri Lanka

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Abstract

A motorized manioc slicer was designed, developed and fabricated to have minimum quality inconsistencies in comparison to the manual method of manioc slicing. Special focus was made on the small and medium scale processing industry. It is primarily designed with a disc cutter rotating on a vertical axis, powered by a motor. The machine has two feeders, attached to the top lid with a handle, an electric motor with a belt drive, a collecting hopper with a chute, a stand and a power switch. The slicer is capable of cutting manioc to desirable shapes and sizes in a short time. The motorized manioc slicer was experimentally evaluated and its optimum slicing performance was 85% efficient when making full slices. The average acceptable slicing capacity was 50 kg/h, which reduced the production cost and minimized losses with a daily net profit of LKR 2500 from an output from 100 kg of raw manioc. This justifies the profitability of this value addition to agricultural produce such as manioc. Such a venture in general provides opportunities for over 1.8 million low-income farmers of an entire population to uplift their living standards. Since the motorized manioc slicer is a simple device, it can be easily fabricated even in a workshop with limited resources and with a fair experience in similar engineering applications. Manioc chip production as well as the fabrication of the device has been identified as a self-employment generation project, which could be established with limited investment.

Keywords: motorized manioc slicer, manioc, processing industry, slicing, fabrication

Introduction

Manioc (*Manihotesculantacrantz*), also known as "Cassava", is one of the most important wildly growing root crops under the wide agro-ecological range, even in less fertile lands (Wijesinghe and Sarananda, 2010; Awulu et al., 2015; Adetunji and Quadri, 2011). Even though manioc is being considered as the second staple food, the market value of manioc is considerably low when compared to other similar foods (FAO, 2013). Since manioc is grown in almost any climatic conditions as a non-seasonal crop (Aji et al., 2013), it has been identified as a potential resource for empowering the low income people (FAO, 2013).

Fried manioc chips as a value added agricultural product, have now become a popular snack food among Sri Lankans and also Asians (Adejumo et al., 2011). It has been widely produced as a cottage food industry since and has a high demand at the market place. A majority of manioc chip producers use a sharp knife to make slices out of manioc yam by employing manual labour. This is a slow and time-consuming operation (Adejumo et al., 2011; Aji et al., 2013). The thickness of each slice should be uniform in order to fry evenly within a shortest duration to save energy and fuel as well as to maintain the golden brownish colour throughout the slice. Manioc is highly perishable and has free and bound cyanogenic glucosides which converts into cyanide in the presence of linamarase, a naturally occurring enzyme in cassava, when exposed to the environment(Adetunji and Quadri, 2011; Aji et al., 2013; Oladeji, 2014; Adejumo et al., Ashaye et al. 2005). Hence, it has to be processed within a day the crop is removed from the ground and therefore, slicing of manioc is a high labour intensive task. Processing of manioc is very important and is clearly shown in the business value chain related to manioc (**Fig. 1**). The dotted line, box (A) in **Fig. 1**, shows where value is added in the manioc business and this dotted box with value addition is the focus of the successful return of the manioc business. In this value addition, the quality and standards of processes named "slicing", "frying/drying" and "packaging & labeling" must be given equal prominence. However, the total quality of the final product has a significant impact by the process of "Slicing" which can be considered as critical. Furthermore, the quality of the raw manioc is also, no doubt, important.

The quality of this value added produce depends heavily upon the quality of raw manioc and the uniformity in slice thickness. Quality and consistency of frying or drying needs uniform slice thickness. Frying or drying rates with heat energy consumption, could be uniform if the slice thickness could be fixed. Therefore, the prime factors of manufacturing quality and consistency are the slice thickness and a complete profile. Also, undamaged slices have to be assured. The cutting front sharpness and its profile, optimum cutting speed are to be somehow evaluated, and mostly would be on a trial basis. The need of a simple slicing mechanism with operational safety and higher productivity has been identified as an important issue in developing the Motorized Manioc Slicer.

Since there is a high demand for a machine to make chips from manioc, this device has been aimed at empowering low income people to medium and large-scale manioc chip producers. Therefore, the major objective of this research was to design and develop a motorized manioc slicer which lowers the quality inconsistencies of the manual method of manioc slicing. The machine should include operational safety and a higher productivity and have a special focus on the small and medium scale processing industry. The motorized manioc slicer could be introduced as a versatile mechanism to be used not only for slicing manioc but also for other similar vegetables such as ginger, lotus root, carrot, bitter gourd etc. This paper presents a detailed description of the design, development and fabrication of a motorized manioc slicer, including its performance evaluation.

Materials and Method

The machine (**Figs. 2** and **5**) is basically designed with a disc cutter (**Figs. 4** and **5.1**) rotating about a vertical axis powered by a motor. The machine consists of a hinged lid with two inclined feeders on its top, an electric motor with a belt drive, a collecting hopper with a chute, a stand and a power switch (**Fig. 2**). Manioc yams are fed into the feeder mounted on top of the cutter disc and the yam then is subjected to the slicing process when the yam touches the rotating disc (**Figs. 2** and **5**). The disc cutter is specially designed with a blade having a curved cutting front mounted on the disc which initiates slicing of the yam at a point closest to the center of the disc and to complete the slicing process using the entire face of the blade profile (**Fig. 5.1**). The vertical shaft has a circular disc at the top end and a pulley at the lower end mounted to the main stand through two ball bearings in between the disc and the pulley (**Fig. 5**). Further, the motor is mounted to the main stand and connected to the driven pulley through a belt (**Fig. 5**). The circular disc consists of an opening slot of 16 mm width at the middle, reducing gradually to 10 mm minimum width at both ends with the same profile as the cutting front. The cutting blade is made of 3 mm thick steel with a parabolic shaped cutting front and a straight back edge with a length equal to the radius of the circular disc. The maximum width of the blade is one fourth of the blade length (**Figs. 5.1** and **5.2**). The cutting blade has been sharpened to an angle of 40 degrees from its top surface and is fixed on the circular disc so that the straight edge of the cutting blade has to be in-line with the tangent drawn to the 40 mm diameter circle at the disc centre. The cutting front coincides with the centre-line of the slot on the disc

Fig. 1 The business process

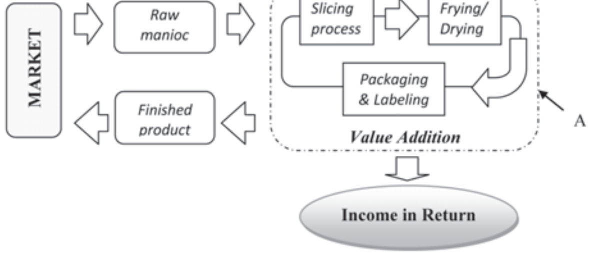
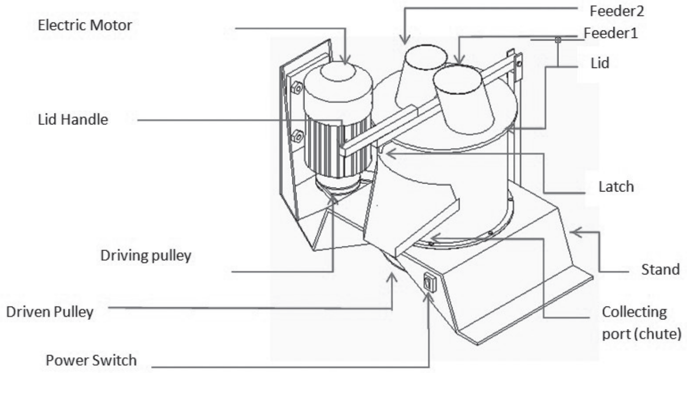


Fig. 2 Details of the manioc slicer



and faces the direction of rotation (**Fig. 5.2**). Two inclined top cylindrical feeders (Feeder 1 and 2) with different diameters are mounted on the lid so as to feed the manioc with an angle of approximately 60 degrees to the cutting disc/blade to get the slices bigger in size (**Fig. 2**). The two feeders are placed to be used according to the size of the yam to be sliced. Manioc yams are fed into the feeder mounted on top of the cutter disc as shown in **Fig. 5** and **Fig. 5.2**. The yam is then moved into the slicing area and sliced when it touches the rotating disc.

Evaluating the Performance of the Motorized Manioc Slicer

At the initial stage, the machine (**Figs. 3** and **4**) was developed with an available motor having a gear reduction speed used for the preliminary work. Therefore, the output speed of the cutter disc which was made of wood (**Fig. 4**), was approximately 40 rpm. This machine was tested on a laboratory scale and the cutting performance and thickness of the slice were found to be acceptable for the requirement. By varying the rpm of the disc and keeping the torque constant, the power requirement which gives the optimum slicing performances with a good production capacity was measured. The slice production rate for the above speed of the disc cutter was 15 kg/h. The required power of the motor was decided based on the experimental results obtained from the above test. In order to determine the optimum cutting speed without affecting the quality of the ultimate product, few tests were carried out using a motor with a Variable Speed Drive (VSD).

Principle of Operation

The machine is connected to a single phase power supply and switched on before feeding the manioc yams into the feeders. **Fig. 5** shows the schematic view of the slicing operation and related components. The cutting disc (C) is mounted on a vertical shaft (S) and rotated by a motor (M) using a belt drive with a speed reduction of 5:1 (**Fig. 5.1**). When the machine is in operation, manioc (B) or the yam is fed into the feeder (F) for the slicing operation. **Fig. 5.2** shows the cutting disc (C) and how the blade (A) is mounted on to the disc with two screws. The cutting disc is made of aluminum alloy casting into a circular shape with a thickness of 8 mm. The disc opening (D - through opening) is made in order to move the sliced chips into the collecting hopper.

The cross sectional view of the blade and the cutting face is clearly displayed in **Fig. 5.2** and shows how the blade (A) is mounted on the disc and how the thickness of the slice could be varied according to the thickness of the blade or the height of mounting the blade. Referring to the blade, it has a circular shaped

Fig. 3 Motorized manioc slicer with a gear reduction developed at the initial stage

Fig. 4 View of the wooden cutting disc and the blade with a curved cutting front at the initial stage

Fig. 5 Schematic view of the slicing operation and related components

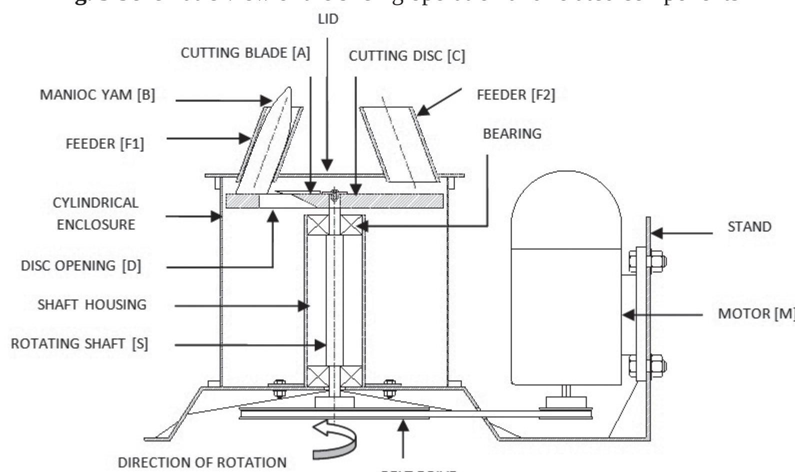


Fig. 5.1 Exploded view of the cutting disc and blade

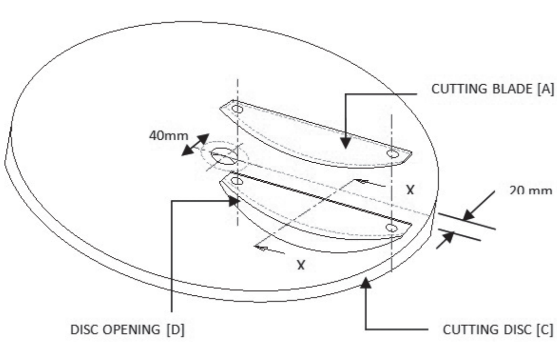


Fig. 5.2 Sectional view of the cutting disc on X-X

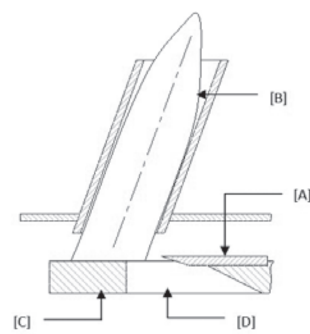


Table 1 Slicing performances with respect to the rotating speed of the cutting disc

No	RPM of the disk	Production rate (kg/h)	Quality of the product
1	260	40	Good and thickness is slightly higher
2	280	60	Very Good and thickness is consistent
3	325	80	Good and thickness is acceptable
4	486	110	Good and thickness is not even
5	585	135	Good and thickness is slightly below acceptable

Table 2 Slicing and overall operating performances of test samples of manioc

Test No.	Quantity with outer skin (kg)	Quantity without outer skin (kg)	Slicing time		Preparation time		Operating time (min)
			(min)	(sec)	(min)	(sec)	
01	10	9.25	9	50	4	55	14.75
02	10	9.30	9	45	4	50	14.58
03	10	9.26	9	53	4	55	14.80
04	10	9.24	9	50	5	0	14.83
05	10	9.28	9	42	5	10	14.86
Total	50	46.33	49 min		24.82 min		73.82

cutting face with the top face flat as shown in **Fig. 5.1**. Manioc yams with the outer skin removed are fed into a feeder according to the size of each yam. Only one feeder is recommended to be used at a time, depending on the size of the yams to be fed. The slicing operation is continued by gently inserting another yam into the hoper with a gentle push. The sliced chips are then collected into a tray through the chute (**Fig. 2**). It is recommended that a tray with water is placed at the bottom so that the sliced manioc falls into the water.

The manioc slicer was tested at the laboratory and several modifications were made to continuously improve the performance of the slicer. After successful slicing of the manioc, the machine was tested several times to evaluate its performance and production capacity so as to decide on the factors affecting the quality of chips/ slices. Five tests were conducted with 10 kg manioc samples and five speeds (260, 280, 325, 486 and 585 rpm) during each test to evaluate the slicing capacity, quality of the slice and the reliability of operating the machine. Thereafter, randomly selected weighed fried samples were analyzed to determine the thickness of the slice, consistency of thickness, and the percentage of broken slices. Further, performance tests were conducted to determine the slicing capacity (Eq. 1), preparation time, overall operating capacity (Eq. 2), efficiency of slicing (Eq. 3) and other factors which affect the same. The operating time of Eq. 2 was calculated by adding preparation time and slicing time. Observations have been recorded with an intention of obtaining the machine performances such as durability, reliability and user friendliness.

Slicing capacity (kg/h) = Weight of manioc without outer skin (kg) / Required time (h) (1)

Overall operating capacity (kg/h) = Quantity with outer skin (kg) / Operating time (h) (2)

Efficiency of slicing = (Weight of well sliced manioc (kg) / Weight of total sliced manioc (kg)) × 100% (3)

Endurance Test

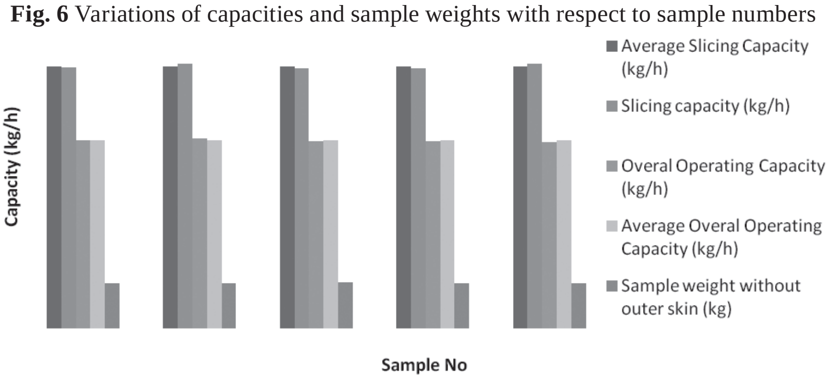
During the slicing operation with more than 200 kg of manioc, the blade was sharpened only once. The steadiness and the rigidity of the stand, height from the table to the feeders, power delivered by the motor to rotate the disc were well accepted since the motor did not show any heat increase while in operation. Aesthetic view of the motorized manioc slicer was well accepted and attractive to the people who were involved in the test.

Results and Discussion

Having constructed the machine as shown in the **Fig. 2**, and in order to achieve the desired rpm of the disc at 280 with a gear reduction (**Table 1**), the power consumption was measured using a power meter as 180 W, while the machine was producing manioc chips. Accordingly, for the power requirement, a single phase motor of 180 W, 230 V, 50 Hz was used for the machine taking frictional losses of moving parts into consideration.

Table 2 and **Fig. 6** show the slicing capacity, preparation time, overall operating capacity and efficiency of slicing. Observations have been recorded with an intension of securing the machine performances like durability, reliability and user

Fig. 6 Variations of capacities and sample weights with respect to sample numbers



friendliness. A sample of fried manioc chips collected was analyzed for chip sizes and the average results are given in **Table 3**.

The presence of full slices and ¾ size slices (slight damage to full slices) in the selected sample were 67.7% and 17.2% respectively by weight. But these slightly damaged chips (those with little breakages also can be considered as whole chips) and then the efficiency of slicing (Eq. 3) of the device was 84.9% (**Table 3**). Half and Quarter size slices were produced while slicing the last portions of the manioc yam. Otherwise, the machine was able to obtain full circular slices. The thickness of slices was in the range of 0.6-1.0 mm (**Table 3**) and was measured after frying. The colour of fried chips was golden brown and indicates that the thickness of chips was acceptable to produce high quality chips. Similarly, other vegetable such as bitter gourd, carrot, and brinjals (eggplant) could also be sliced easily with least effort.

Evaluation of Manufacturability

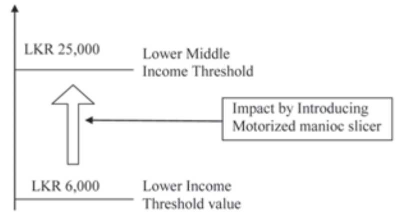
This machine could be fabricated in 5 man-days, using a skilled welder. The basic machines required for fabrication are a welding plant, bench type drill machine, small lathe, facilities for black smiting and hand tools. Machining the cutting disc and making the blade with a curved cutting edge could be done by expert providers of such services. Depending on the quality of materials used and the workmanship, this machine could be priced at about LKR 30,000 (approx. US$ 205).

The Socio Economic Impact

As indicated by the Department of Census and Statistics (2011), there are about 1.8 million, Low-Income people living in Sri Lanka with a threshold value of monthly Income around LKR 6,000, whereas for the Lower Middle Class people the value is LKR 25,000 (**Fig. 7**). It has to be accepted that there is a socio economic impact by introducing the manioc slicer to the low-income people who could move into a Lower Middle Class. This could be evaluated as follows.

Assume, this enterprise produces manioc chips in one day and sells the products the following day. Accordingly, the manioc slicer operates only for about 10 days per month. Therefore, if the producer sells the manioc chips at the retail price, the monthly income would be about LKR 36,000 (**Table 4**).

Fig. 7 Graphical representation of the socio economic impact by motorized manioc slicer



If somebody secures LKR 36,000 as the monthly income for at least six months, his spending pattern will automatically increase and

Table 3 Average Composition of chips in samples and thickness range

Size of slices	Slicing efficiency		
	By count (%)	By weight (%)	Thickness (mm)
Full slices	51.3	67.7	0.8-1.0
Three quarter (¾) slices	17.4	17.2	0.7-0.9
Half (½) slices	14.9	9.8	0.7-1.0
Quarter (¼) slices	16.0	5.3	0.6-0.9

Table 4 Cost & profit analysis (manioc value addition)

Description	Price (LKR)
Wholesale price of 1 kg of raw manioc	30
Cost of slicing & frying 1 kg of raw manioc to produce finished fried chips *- Cost of (Oil + Fire wood + Labour for frying &slicing) = LKR (20 + 20 + 15 + 5) =* ***LKR 60*** *- Electricity cost of slicing of raw manioc = (180 W × LKR25/kWh) / 1000 × 50 kg/h =* ***LKR 4.50***	64.50
Total cost involved in producing finished fried manioc chips out of 1 kg of raw manioc = *LKR (30.00 + 64.50)*	94.50
Effective weight (kg) of produced fried manioc chips out of 1 kg of raw manioc	0.3
Selling price (***Wholesale***) of produced fried 1 kg of manioc chips	400
Return in selling finished product (***Wholesale***) = 400/kg × 0.3 *(1 kg of raw manioc can produce 300 g of finished manioc chips)*	120
Therefore, the profit per kilo = LKR (120.00 – 94.50)	25.50
Profit in processing 100 kg of raw manioc	**2,550**
Considering machine depreciation into account (per day) *(Assumed Machine life time as 2 years) = LKR 30,000.00 / (365 × 2) = LKR 41*	Say; **50**
Therefore, net profit per day for 100 kg of raw manioc	**2,500**
Selling price (***Retail price***) of produced fried manioc chips (1 kg)	500
Return in selling finished product (***Retail price***) = LKR 500 × 0.3 *(1 kg of raw manioc can produce 300 g of finished manioc chips*	150
Market price of 1 kg of raw manioc (***Retail price***)	50
Therefore, the profit per kilo = LKR 150 – (50 + 64.50)	36.50
Profit in processing 100 kg of raw manioc	**3,650**
Considering machine depreciation into account (per day) *(Assumed Machine life time as 2 years)*	50
Therefore, net profit per day for 100 kg of raw manioc	**3,600**

N.B. Present market values were considered there would be significant change in life style. The spending style with the Elevated Life style would be a psychological and sociological thrust to continue this venture by the producer himself to sustain his new life style.

Conclusion

A motorized manioc slicer was successfully designed, developed and fabricated which diminished quality inconsistencies of the manual method of manioc slicing with special focus on the small and medium scale processing industry and including operational safety and higher productivity. The slicing capacity of 50 kg/h with 85% full slice making efficiency encourages producers to deliver quality products with better productivity. The tests have proved that the slicer is a convenient device for cottage; medium or large scale snack producers to save time and labour.

Snack producers would thereby reduce production cost and minimize losses with a daily net profit of LKR 2500 in a wholesale business whereas LKR 3600 in a retail sale business by processing chips out of 100 kg of raw manioc.

Since the motorized manioc slicer is a simple device, it can be easily fabricated even in a workshop with limited resources and a fair experience in similar engineering applications. Therefore, the manioc chip production as well as the fabrication of the device has been identified as a self-employment generation project, which could be established with a limited investment. Furthermore, the developed manioc slicer has a smooth, efficient and safe operation. A homogenous thickness of the sliced chip can be obtained throughout. Bigger size slices could be obtained by adjusting the inclination of the feeder of the manioc slicer. As a user friendly equipment, the thickness of the slice could be adjusted as required by the user.

Note

The technology of the Motorized Manioc Slicer was successfully introduced to SMEs (Small and Medium Enterprises) by the National Engineering Research and Development Centre (NERDC) and created a substantial increase in the levels of income amongst the recipients of the technology. About three NERDC licensees are available to manufacture this motorized manioc slicer to cater to the existing demand for this technology, in addition to the requirements of the NERDC.

Acknowledgement

The technology of the Motorized Manioc Slicer is an R&D outcome of the National Engineering Research & Development Centre (NERDC) of Sri Lanka and Eng. D D Ananda Namal, Director General of NERDC is sincerely acknowledged for facilitating the project of “Development of a Motorized Manioc Slicer. Dr K M W Rajawatta is acknowledged with sincere thanks for her valuable contribution in preparing this technical paper.

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Comparative Field Evaluation of Mechanized and Manual Cassava Production Operations: The Case of Cassava Farmers in Ogun State of Nigeria

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Abstract

In 2015, mechanized technologies for planting and harvesting cassava were introduced to farmers involved in the Cassava Value Chain (CVC) in Ogun State of Nigeria for testing. This study comparatively analysed the profitability of cassava production under mechanized and manual operations. Partial budgeting was used to compare costs and benefits of the new innovations with manual process. The comparison was based on data obtained from farmers involved in an effort to enhance the competitiveness of high quality cassava flour (HQCF). The results revealed that yields from harvested fresh cassava roots on mechanically planted cassava farm plots increased by 38% over the manually planted cassava farm plots. The main gain associated with the mechanized process was the relatively lower costs associated with planting and harvesting operations, which were cheaper over the manual operations by 55% and 59%, respectively. The mechanically and manually planted cassava farm plots have a gross margin of \$491/ha and \$296/ha, respectively. Comparison of these levels of profitability showed that the mechanized operations were relatively more profitable and exceeded the manual farm operations by 83%. Thus, the study concludes that the mechanization of cassava planting and harvesting, combined with high-yielding variety and complementary agronomic practices, can lead to higher competitiveness and economic break-through for cassava farmers in Africa. Therefore, we recommend increased efforts to scale-up mechanized cassava production operations, including building the capacity of cassava farmers with regards to improved production technologies and crop management practices.

Keywords: Cassava, Mechanized, Manual, Profitability, Partial budgeting, Nigeria

Introduction

Cassava (*Manihot esculenta* Crantz) is one of the most important crops in Africa. It is an important source of energy in the tropics, especially in low-income countries, and will continue to be a vital staple to feed the growing African population. The principal economic product is its roots but the leaves, with protein levels of 18-22% on dry weight basis, are widely processed for human consumption and animal feed (Bokanga, 1999). The stems serve as the planting material for its propagation. The crop is cultivated widely in the tropic and sub-tropic parts of Africa, Asia, and Latin America, between latitudes 30° N and 30° S, and from 0 to 2000 m above sea level (Sharkawy et al., 2012). Cassava serves as the main source of nutrition for approximately half of Africa's 500 million population. Furthermore, it is a major source of income for rural communities; smallholder farmers in Africa who produce more than half the world's cassava, an estimated 158 million tons annually (FAO, 2014). Cassava growers are mostly low income farmers primarily because the crop uses its inherent adaptive mechanisms to produce food during droughts and in low nutrient soils more than cereals and grain-legume crops. The current yield of cassava in Africa is about 10 t/ha, while it is more than 21 t/ha in Southeast Asia and above 40 t/ha in India. With yield of 10 t/ha, African farmers are not competitive in the global market. To be competitive, yield of 25 t/ha or more should be the continent's target. However, to get higher yields and greater economic benefits, improved management practices will be required (Howeler, 2010). Mechanization of the production system, use of fertilizers, control of weeds and the use of improved varieties can increase the yield of cassava beyond 25 t/ha.

The planting and harvesting operations of cassava are usually done manually thereby making it labour intensive and time consuming. Generally, it takes 8-10 persons to manually plant one hectare of land in a day against a two -row mechanical planter that can plant 7-10 ha in a day, which is faster and 50% less expensive than manual planting (Abass et al., 2014). Similarly, manual harvesting is slow and associated with drudgery and high root damage in the dry season (Chalachai et al., 2013; Amponsah et. al., 2014). Manual harvesting of cassava requires between 40 and 60 persons, depending on the season, to harvest one hectare of cassava in a day against the mechanized operated equipment which can lift up to 200 plants per hour while the two-row mechanical harvester can harvest up to 3 to 5 ha cassava farm in a day, depending on the terrain (Abass et al., 2014). Amponsah et al. (2014) observed that mechanical harvesters are needed to break the labour bottleneck associated with cassava harvesting but research in Africa on mechanization of cassava production is very low unlike Asia where there have been some meaningful research attempts made on mechanical harvesting of cassava (Chalachai et al., 2013). In Thailand for example, cassava digger suitable for a 50 hp tractor was developed, while others attempted to integrate cassava digger and conveyer unit. In Brazil and Colombia mechanized planting and semi-mechanized harvesting systems have beenevaluated and models for mechanical cassava planters and harvesters have been adapted to the farming systems and practices (Ospina et al., 2012).

Farmers are either not aware of the mechanical methods available for the planting and harvesting of cassava, or access to the mechanized production technologies are constrained by the relatively high initial investment. Although new commercial, medium-scale cassava farmers are beginning to emerge in some cassava growing countries, such as DRC, Ghana and Nigeria, most of them use only some and not all available modern techniques that can increase the yield of cassava. The availability of mechanical planters and harvesters, for example, is still very low and can be found within few localities in few countries like DRC, Ghana, Nigeria, Tanzania and Zambia. Where these machines exist, there are many factors that inhibit their use that could affect the final financial outcome and use-conveniences, depending on the knowledge or competences to use them, which may exist locally. The factors include: loss of cassava root in the field, working width, root breaking losses, greater power requirement, and stringent field cleaning requirements (Chalachai et al., 2013). Thus, full benefits of using improved inputs, such as improved varieties, fertilizers, and herbicides in boosting cassava production, cannot be fully achieved without mechanization of the production operations. Inability to apply modern technologies in a holistic or consolidated manner for the production and processing operations of cassava reduces the prospect to maximize profit (ICS-Nigeria, 2003).

In 2015, "Enhancing the Competitiveness of High Quality Cassava Flour project" introduced mechanical planting of cassava stems and harvesting of fresh cassava roots to farmers in the four innovation platforms in Nigeria. The adoption of these mechanised planting of cassava stems and harvesting of fresh cassava roots were expected to reduce production costs, increase cassava output and the overall relative profitability of cassava production compared to manual process. In addition, they could enhance farmers' willingness to adopt the improved mechanized production technologies, particularly new use of mechanical cassava planters and harvesters, which can expand production of cassava and increase its productivity.

The study was aimed at comparing the costs and benefits of using the new mechanical planting and harvesting innovations against the traditional manual practices in terms of cost-effectiveness, profitability and competiveness of the production operations.

Methodology

2.1 Farmers' Organization in Innovation Platforms

The study was carried out at Joga Orile (N 7.146°; E 3.053°) in Ogun State of Nigeria, comprising farmers in an out-grower arrangement for production of fresh cassava roots for sale to the processing factory (**Fig. 1**). Data were collected on average yields results obtained from 5 cassava farm plots that used mechanical planting and harvesting compared with the average yield results obtained from another 5 cassava farm plots that used manual planting and harvesting methods.

Strong linkage between the out-grower farmers and the HQCF factory was developed through contractual arrangements to increase farm yield through mechanization and other improved production methods.

The aim was to show how to put in-place functional institutional arrangements for out-grower schemes that could present economic success for the farmers. The HQCF plant served as the node to build the model of competitive cassava root production, utilizing best agronomic practices, improved varieties, and farm mechanization.

2.2 Planting and Harvesting Methods

Farmers were grouped in two categories, a group adopting mechanized planting and harvesting and a second group using traditional production system where the use of mechanical planter or harvester were not involved. A total of 34 ha of cassava was planted by the out-growers using two main varieties. These were TMS 419 (well-adaptable to mechanical planting) and TMS 30572. Farmers were trained on fertilizer application and weed management by using boom sprayer for herbicide application.

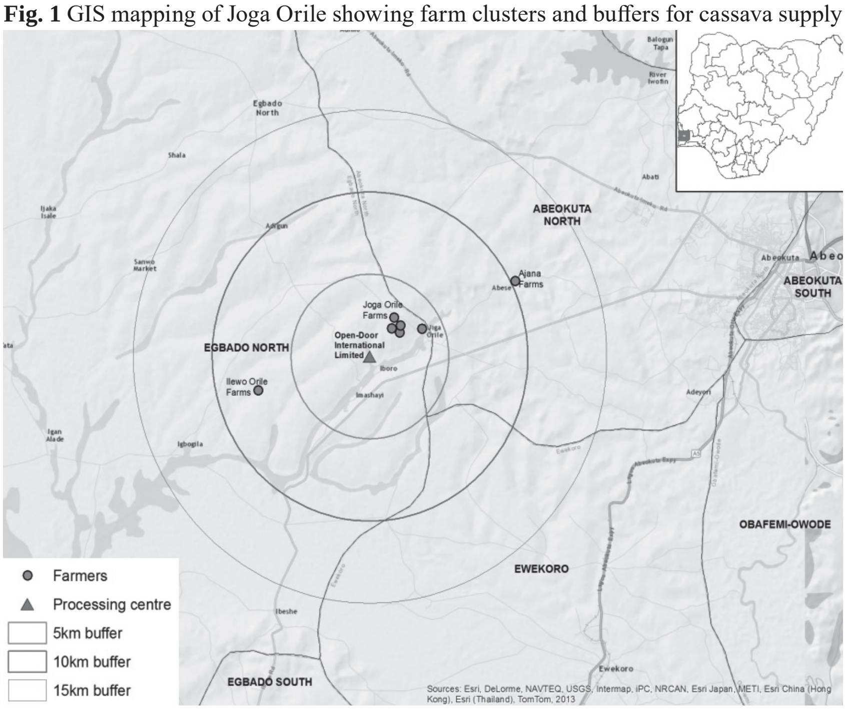
The farmer's group using the traditional planting method planted their cassava during the main rainy season (May-July, 2015). Mechanical land preparation involving field operations such as ploughing, harrowing and pre-emergence herbicide application were done in August, 2015. Planting was done at the beginning of the dry season in October, 2015, a timing that was unusual to the farmers based on the farming practices in the area but scientifically satisfactory since the area has humid climate and the cassava could utilize the small residual soil moisture and the small last rains to initiate root development (Ospina et al., 2012).

Traditional manual planting practices involved 15-20 cm long stakes planted at slanting position on ridges or flat land at a depth of about 10 cm. The direction of bud growth was often not known nor considered when planting by the locally available labour.

The two-row planter used was BAZUGA NCM 8432.31.90 which was designed to plant cassava on flat ground had a planting rate of 0.5-0.8 ha/h at 700 mm row spacing. The two-row cassava planter as shown in **Fig. 2** was drawn by a 60 hp (44.76 kW) tractor. The stalk length for the planted cuttings was 18 cm. Stakes were cut with a power-take-off (PTO) driven circular saws. The planter plants the cuttings at uneven planting distance that ranged from 80 cm to 100 cm which is as a result of the unleveled harrowed land. Planting depth ranging between 60 and 100 mm below soil surface was maintained. No ridges was made for the cassava plot. Planting was done in October 2015 at the end of the rainy season. The farms were managed by the out-grower farmers. Irrespective of the planting method, all the farmers maintained manual weeding in combination with the use of herbicides until the roots were ready for harvesting at 12 months after planting.

Harvesting of the cassava farm plot was done using a Cassava Up-

Fig. 1 GIS mapping of Joga Orile showing farm clusters and buffers for cassava supply



rooter Model P-900 NCM 8432.29.00 harvester, equipped with front disk and depth control wheels. The mechanical harvester as shown in **Fig 3** was driven by an 80 hp (59.68 kW) four-wheel-drive (4WD) tractor at a forward speed which ranged from 2.1 to 6.7 km/h and at a digging depth that ranged from 300 to 400 mm. Manual planting and harvesting were done by hired labour sourced from the area.

2.3 Data Collection

Key Informants Interview (KII) and partial budgeting techniques were used to examine the cost-effectiveness, profitability and competitiveness of cassava production operations. The KII was held with farmers that used mechanical planter and harvester to assess their perceptions. The partial budgeting was used to compare costs and benefits of the new innovation against the manual planting and harvesting. The comparison was based on cassava production operations data from farmers that used mechanized or manual planting and harvesting techniques.

2.4 Partial Budgeting

Partial budgeting is a planning and decision-making tool used to compare the costs and benefits of alternatives available to a farm business. This tool allows comparison of marginal costs and marginal benefits of small, specific changes - without having to financially analyse the entire farm (Rabin, 2012). The simplicity of partial budgeting facilitates decision making by estimating profitability of a given change. It focuses only on the changes in income and expenses that would result from implementing a specific alternative. Thus, all aspects of farm profits that are unchanged by the decision can be safely ignored. Partial budgeting allows better handling on how a decision will affect the profitability of the enterprise, and ultimately the profitability of the farm itself.

Partial budgeting was used to determine and compare profitability in cassava production using mechanized planting and harvesting compared with manual planting techniques. The process provided actual information on farm-input use and costs, output and prices, and farmers' gross margins. The gross margin budget examines the returns to the farmers' resources, which consist mainly of labour used, capital inputs such as fertilizer, chemicals and other production inputs. The procedure involved the estimation of the costs and returns based on 2015/2016 cassava production season.

In developing the gross margin, estimates of production cost and gross revenue from cassava output were collected from the farmers that implemented mechanized techniques and manual planting and harvesting in Joga Orile in Ogun State of Nigeria. In estimating the production cost, family labour cost that were not paid for by the farmers, was estimated as its opportunity cost by using the prevailing market wage rate for labour in the area. The gross margin from cassava production activities is the gross value of cassava output less all the variable costs incurred during the production period.

The gross margin was estimated as:

$$GM = \sum piqi - \sum rjxj$$

where,

GM = Cassava gross margin

pi = Unit price of output i

qi = quantity of output i

rj = unit cost of the variable input j

Xj = quantity of the variable input j

The use of partial budgeting is quite an appropriate technique to assess profitability in crop production as there is often limited or negligible use of fixed inputs by smallholder farmers (Amaza and Olayemi, 2002).

Results and Discussion

3.1 Partial Budgeting Comparison

The results for partial budgeting comparison of mechanized and manual planting and harvesting of cassava are summarized in **Table 1**. The components of variable cost under mechanical planting comprises of land preparation, stem cuttings, mechanical planting, pre-emergence herbicide and its application, post-emergence herbicide and its application, fertilizer and its application, weeding cost, harvesting and transportation of fresh roots and other miscellaneous costs. On the contrary, some of these variable costs were not incurred by farmers who planted cassava manually. The costs that were not incurred are: pre-emergence herbicide and its application, fertilizer or second weeding costs.

The yield from harvested fresh cassava roots on mechanically planted farm had increased by 38% over the manually planted cassava farm (**Table 1**). The cassava stem yields and its corresponding value

Fig. 2 Tractor drawn mechanical planter

Fig. 3 Tractor drawn mechanical harvester

were not measured under both mechanical and manual planted farms. Similarly, as the farmers face the same market prices, revenue obtained from sales of fresh cassava roots had also increased by 38% on the mechanically planted cassava farm over the manually planted cassava farm.

Generally, mechanization of farm operations, including mechanized planting can increase yield through timelier performance of operations and higher quality performance of operations (Bloom, 1979). Because there is an optimum time to perform operations, crop yields tend to be highest where critical operations such as planting and harvesting are carried out closer to the optimum time (Goering, 1992). Mechanized planting unlike manual planting of cassava stems allows for deep tillage whereby the hard pan in the ground are loosened up. This facilitates the development of larger roots with increased number of principle roots, thus greater surface contact between root and soil. Consequently, the improved root system gives the crop better possibility to increase the intake and conservation of soil and mineral, which eventually leads to increase in yield and total production (Bloom, 1979).

The cost associated with land preparation for manual operation is higher by 7% compared with that of mechanical operation. There was 34% increase in the cost of cassava stems; as greater amount of cassava stems were planted under mechanized planting compared to manual planting. Herbicides and its application had increased by 256% on the mechanical operation. The relatively lower costs of purchased inputs for manual operation were possible because the farmer did not fully use some of the inputs purchased, especially fertiliser and herbicides.

The main gains associated with mechanized planting of cassava is its relatively lower costs of planting and harvesting. Planting cost was cheaper under mechanized planting than manual planting by over 55%. The cost for manual planting of cassava was US$29/ha while it was US$13 for mechanized planting. Manual planting accounted for 9% of the total cost as mechanized planting accounted for 4% of the total cost. The cost of production using manual method was $328/ha representing US$20.5/ton of roots, while the cost of production using mechanical method was US$367/ha representing US$16.68 per ton of roots. In a similar study done in Colombia in 2000, Ospina et al. (2012) obtained US$635.1/ha as cost of production for using manual operation. In this same study carried out by Ospina et al. (2012), US$517/ha and US$490.4/ha were the cost of production obtained for mechanical operation using a two-furrow and three-furrow planters, respectively. The planting cost which is a proportion of the total operation cost was found to be 8.8% for manual operation, 5.1% for mechanized operation with two-furrow prototype planter and 4.7% for mechanized operation with three-furrow prototype planter.

According to Ospina et al. (2012), harvesting is the most difficult cassava production operation to mechanize. It is also the most expensive operation under the smallholder production systems in Nigeria due to the rudimentary nature of the harvesting tools used by the farmers combined with the limitations that result from the shape and distribution of roots in the soil, the depth of the roots in the soil, the removal and careful collection of stakes, and the

Table 1 Slicing Performances with respect to the rotating speed of the cutting disc

	Manual Operations	Mechanized Operations	Increase/ Decrease	% Increase/ Decrease
Yields[1]				
Fresh roots ton ha^{-1}	16	22	6	38
Cassava price (US$/ton)	39	39	0	
Revenue from Output (US $)	624	858	234	38
Variable costs (US $) ha-1				
Stem cuttings	85	56	-29	-34
Land Preparation	87	81	-6	-7
Herbicide and application	16	57	41	256
Planting	29	13	-16	-55
Fertilizer and application	0	61	61	
Manual weeding	19	39	20	105
Harvesting	61	25	-36	-59
Miscellaneous and roots transportation	31	35	4	13
Total Variable Costs	328	367	39	12
Total variable cost (US$ per ton of roots)	21	17	-4	-19
Margin (US$ per ha)	296	491	195	66
Margin at farm gate (US$ per ton)	19	22	3	21

Note: The average exchange rate of N310 = 1 USD for September 2016 was used for calculations adherence of sometimes hard soil to roots. The farmer decides when to initiate the harvesting operation depending on the productivity, root size or maturity (months of the cassava after planting) of the plant, the roots' starch content, food needs of the family, culinary properties and other actors such as possibility of disease onset, onset of fibrousness in the roots, or market opportunity that may present itself. This period may coincide with the dry season when the soil is hard.

Results obtained in the study carried out by Ospina et al. (2012) revealed that harvesting cost was lower under mechanized system by 59% compared with manual system. Meanwhile a reduction of 42.8% was obtained in Colombia under the same production operations. Harvesting cost was US$61/ha under manual operation and US$25/ha under mechanized operation. Harvesting cost which is a proportion of the total cost was found to be 18.6% for manual operation and 6.8% for mechanized operation. This is to say that similar to the cost structure found in Colombia, where harvesting cost was reduced by 6% in the relative cost of labor to total production cost per hectare, the reduction obtained in Nigeria was 11.8%.

The difference in the total variable costs between the two categories of cassava farm plots is only US$39, which represents 12% for the manually planted cassava farm compared with the mechanically planted cassava farm. The achieved gross margin in cassava production from the two production systems revealed that both mechanized and manual cassava production systems are profitable. The mechanically and manually planted cassava farm plots have a gross margin of US$491/ha and US$296/ha, respectively. However, comparison of these levels of profitability, showed that the mechanized planted cassava farm plots relatively is extremely very profitable and exceeded the manually planted cassava farm plots by 66%. This finding agrees with Benin (2014), who stated that mechanization can contribute to increasing the production, productivity and profitability of agriculture improving the timeliness, quality, and efficiency of operations. Along with yield and the agronomic benefits, farmers who used mechanization for more services were more technically efficient than farmers who used mechanization for fewer services (Itodo and Dauda, 2013; Shamsudeen et al., 2013).

There are several factors that plausibly influenced the exceedingly higher level of gross margin; however two factors clearly stand out. First, the population density in terms of number of roots and root weight. The average number of roots found on mechanically planted cassava stems was 34 which is more than double that found on manually planted cassava roots which stood at 14. Similarly, the average weight of roots was significantly higher at 58 kg for mechanized planting compared to only 14 kg obtained for manually planted stems. Hence, introducing mechanized planting and harvesting to cassava production operations increased the economic benefits to farmers through the higher weight of harvested roots per unit area as a result of increased yield or due to the mechanical harvester's ability to remove more roots than the traditional harvesting systems involving the use of human labour. Secondly, some variable inputs, especially fertilizer, post-emergence herbicide and second weeding operations were not applied on the manually planted cassava farm. This tend to have negative effect on the quantity of harvest cassava roots in kg/ha. For instance, fertilizers are known to be a major yield enhancing input in the sense that it improves the productivity of existing land by increasing crop yields per hectare as well as well spread difference in gross margin (Amaza et al., 2006).

3.2 Perceived Advantages and Disadvantages of Mechanized Planting and Harvesting

Farmers were asked to give their perceptions on the relative advantages and disadvantages of mechanized planting and harvesting. The results of their perceptions are summarized as follows:

Advantages

a) Increased Plant Population: - The plant population density using mechanized planting is considerably high compared with manual planting. This has effect on the yields of fresh cassava roots, stems and cassava leaves which all have economic value.

b) Increased yield of fresh roots: - The population density was relatively high using mechanized planting which effectively increased the yield per unit area when compared with manual planting.

c) Loose soil: - As a result of the ploughing and harrowing operations carried out which was close to the end of the rainy season, made the soil to be well ventilated and the soil structure was loose for a longer time, thereby creating good conditions for planting and root development.

d) Weed control: - Weeds were more efficiently controlled due to subsequent seizure of rains stifling the growth of weeds that could have competed for nutrients with the germinating cassava. Hence there was a consequential reduction in the cost of weeding for mechanical operation compared with manual operation.

e) Saves time: - Mechanical planting saves time which can be released for other activities.

f) Reduced drudgery:- Mechanical planting and harvesting removes drudgery that characterizes manual planting and harvesting of cassava.

Disadvantages

a) Scale of Operation:- Mechanical planting and harvesting of cassava may not be ideal for the small-scale farmers, where the size of farms are relatively small. Hence, land consolidation may be needed, possible through cooperative system, which is possible under out-grower arrangements in which the farmers are assured for selling their roots collectively to a reliable buyer

b) Limited availability of technologies:- Mechanical planters and harvesters are relatively new technologies that may not be available when needed.

c) Knowledge of the technologies:- The fact that the technologies used for planting and harvesting are relatively new and emerging, most farmers are unware and may need to be educated on their advantages and cost-effectiveness by out-scaling the approach tested in the study.

In addition to all these, the partial budget analysis supports most of the perceptions held by the farmers with respect to the advantages and disadvantages of cassava production mechanization.

Conclusion and Recommendations

The results of the partial budgeting have clearly shown that mechanized method of cassava production is highly profitable and cost effective. The yield obtained from mechanized operation almost doubled the manual operation, while the costs associated with planting and harvesting using mechanized operation is less than 50% of the cost spent by manual operation. Such cost reduction and higher root output from mechanical operation signify increased competitiveness of cassava production system; increased economic benefits and food availability for the farmer.

In order to enhance the competitiveness of the cassava value chain in Nigeria and elsewhere in Africa, we recommend the following:

a) An integrated system of production and processing in which farmers within the same locality are formed into out-growers around a reliable buy or buyers of fresh cassava, forming a platform that allows business deals and agreements to be made in ways that link the growers with the buyer (market) and opportunities for land consolidation and mechanization of the production operations can be practiced.

b) Extension and other scaling institutions should intensify efforts to create awareness among cassava farmers with regards to the adoption of mechanized operation in cassava production.

c) There should be increased efforts to scale-up the promotion and dissemination of mechanical planters and harvester among cassava farmers to improve the competitiveness of cassava operations and build the capacity of cassava farmers with regards to using mechanization implements and improved crop management methods.

d) Extension institutions should identify and create awareness among entrepreneurs that can provide mechanized planting and harvesting services for interested farmers. Such entrepreneurs should be linked to credit institutions and equipment leasing companies.

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Current Status and Perspectives of Agricultural Mechanization in Primorsky Krai, Russian Federation

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Abstract

This article summarizes the results of research on agricultural mechanization in Primorsky Krai (PK), Russian Federation. The investigation focused on the economic sector in context of agricultural production and the current agricultural machinery market. Research and development activities for agricultural machinery also are also briefly analyzed for the study area. Findings revealed that the 21^{st} century business environment in the agricultural sector has become variable, with declining government support; so the development strategies of enterprises have changed to successfully adapt to this environment. Currently, many enterprises are focused on reliability and lowering the cost of agricultural machinery, which plays a key role in the sustainability of agricultural development.

Keywords: Primorsky Krai; Agricultural machinery; Agricultural production; Mechanization; Business environment; Agricultural machinery market

Introduction

Primorsky Krai (PK) is a federal district of the Russian Federation. It is part of the Far Eastern Federal District and located in the far southeastern part of the country (**Fig. 1**).

The PK lies on the western coasts of the Sea of Japan. It shares borders with Khabarovsk Krai in the north, China in the west, and North Korea in the southwest. The PK land area is 165,900 km^2. The capital of PK is Vladivostok.

Currently, PK is becoming a more economically active region owing to the development of foreign agriculture in the Far East. Over the past couple of decades, neighboring countries have been rapidly increasing their investments in PK. The agro-industrial complex (AIC) of PK is one of the most important agricultural producers in Russia. It grows primary agricultural crops, such as rice, soybeans, wheat, corn, and vegetables, and raises livestock and poultry. The PK AIC is in a favorable position for mutually beneficial agriculture agreements between neighboring countries. Moreover, many studies have examined agricultural production, regional investments, and land conditions in the Far East. Several studies have been made on Japanese investment in PK (Ershova, 2014), soybean production (Park et al., 2015), education for the development of the AIC (Komin et al., 2017), and Chinese agriculture in PK (Zhou, 2018). However, the current status of agricultural mechanization has not yet been studied.

The purpose of this study is to review the current status of agricultural mechanization in PK and attempt to estimate future directions. In this study, the PK is evaluated in terms of economic indicators for the region, the current agricultural machinery market, and the structure of the agricultural machinery market. Furthermore, a brief analysis of research and development activities is also performed for agricultural machinery.

Materials and Methods

Research Methods

This research relied upon quantitative methods for market research,

Table 1 Permanent population in PK

Category	No. of people
Total PK population	1,923,116
Working age population	1,043,600
Unemployed population	56,800
Employed population	986,800
Population employed in industries	963,100
Population employed in AIC	23,700
AIC population employed in agriculture	7,900

Source: Primstat (2017)

including (1) observation, (2) primary research, and (3) secondary research (Creswell, 2009). The research was carried out on-site within PK. Basic data for statistical analysis were taken from a Russian Federation database (Federal State Statistics Service, 2017), annual reports, and scientific articles.

Pearson correlation was used in the statistical analysis of variables. The Pearson correlation is a measure of the linear correlation between two variables x and y. It has a value between 1 and -1, where 1 is completely positive linear correlation, 0 is no linear correlation, and -1 is completely negative linear correlation. The Pearson correlation coefficient (PCC) is calculated using the following equation (Zhou et al., 2016):

$$r_{xy} = (\sum x_i - \overline{x} \sum y_i - y) / [\sqrt{\sum (x_i - \overline{x})^2} \sqrt{\sum (y - \overline{y})^2}] \quad (1)$$

where, r is the correlation coefficient of x and y, $\overline{x} = (1/n)\sum_{i=1}^{n} x_i$ denotes the mean of x, and $\overline{y} = (1/n)\sum_{i=1}^{n} y_i$ denotes the mean of y. The coefficient r_{xy} ranges from -1 to 1, and it is invariant to linear transformations of either variable.

Economic Indicators of PK

As economic indicators, we investigated the PK population and agricultural production. These two economic indicators play key roles in the current economic environment and provide insight into agricultural production and mechanization in PK.

PK Population

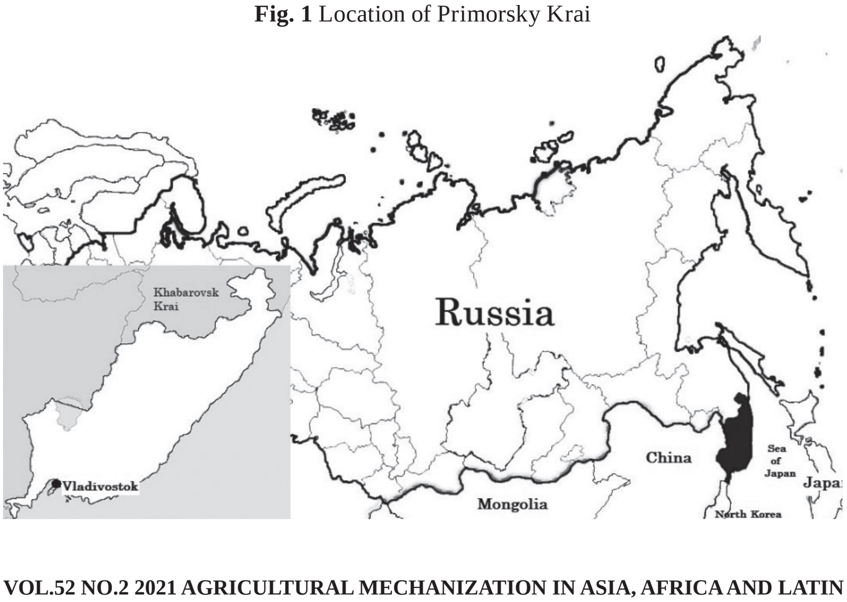
According to official information from the local PK government, the population is 1.92 million (Primstat, 2017). **Table 1** contains data regarding employment. There are 1.04 million persons who are of working age, or from 15 to 72 years old. In this group, the number of employed persons is 0.99 million. The number of people who work within the AIC is 23,700. From the AIC group, we can identify the people who work in the agriculture sector, which is 7,900. The number of unemployed persons in PK is 56,800. The share of agricultural employment with respect to total AIC employment is 2.4%. The total level of unemployment varies between 5 and 6%.

The AIC is the largest inter-sectoral complex, as it unites several branches of the economy, targeted at the production and processing of agricultural raw materials; obtaining retail products from them; supplying these products to consumers; and providing agriculture production machinery, chemicals, and fertilizers. The AIC encompasses four major activities:

a) Agriculture, including growing plants and raising livestock on industrial and personal farms;
b) Agricultural services;
c) Industries that process agricultural products; and
d) Infrastructural entities, which are engaged in supplying agricultural raw materials, transportation, storage, trade in consumer goods, training of workers for agriculture, and construction in the agricultural sector.

This is the set of the region's economic sectors that include agriculture and related industries. The AIC provides PK's strategic security for the production of food and allows PK to be economically independent (Ushachev, 2015).

Fig. 1 Location of Primorsky Krai



Agricultural Production in PK

The PK is a quickly growing region with the most balanced economy in the Russian Far East. The foundation of the region's economy is the richness of its natural land and ocean resources. The industrial complex is the most developed part of PK economy. The main industrial complex comprises agriculture, fishing and fish processing industries, electric power and coal extraction industries, engineering and ship repair industries, and timber and woodworking industries.

Agricultural production is one of the most important sectors in PK, and it has a wide product range. It plays an important place in the Russian Federation due to its large land resources, grain and leguminous crops production, vegetable production, and livestock production. Despite these advantages, it cannot be said that PK has entirely realized its full potential in agriculture or any other industry.

Russia made a commitment to gradually decrease domestic support for the agricultural sector from US $9 billion in 2012 to US $4.4 billion by 2018. In 2015, domestic support did not exceed US $7.2 billion. In 2016, domestic support was expected to be reduced to US $6.3 billion (Baker & McKenzie, 2016). These reductions present some challenges, and scientists and farmers continue their search for ways to improve and enhance production efficiency to counteract economic and environmental constraints (Borowski et al., 2016).

Agricultural production in PK is mainly located in the southern and southwestern districts, although agriculture is present throughout the region. **Fig. 2** shows the locations of agricultural production districts.

Fig. 2 PK districts with large agricultural production

The PK grows grain and leguminous crops, such as soybean, potatoes, spring wheat, oats, corn, beans, and rice, in addition to different types of vegetables. **Table 2** shows the acreage for various agricultural categories (farm and crop type) in PK. **Fig. 3** shows the gross production and crop yields of farms for all agricultural categories.

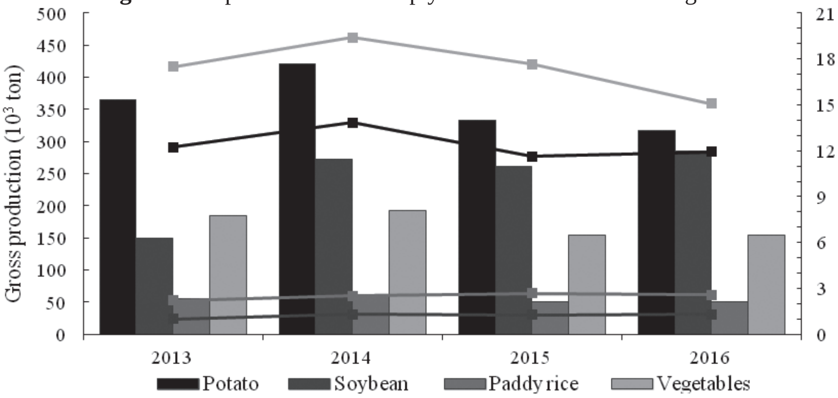
The formation a high-performance agricultural sector in PK requires an appropriate level of development of the material and technical basis of agricultural enterprises. Thus, although mechanization is an important factor in enhancing farm productivity, and the priorities of most organization policies and programs focus on enhancing of agricultural production,

Table 2 Acreage of agricultural farm and crop categories in PK (1,000 ha)

Crop or farm category	2013	2014	2015	2016
Total area*	379.0	423.9	413.7	434.7
Agricultural enterprises	246.8	266.3	243.7	252.1
Peasant farm enterprises and individual entrepreneurs	96.0	121.5	134.7	147.9
Private land for farming by the people	36.2	36.1	35.3	34.7
Grain and leguminous crops	106.8	113.2	101.6	106.9
Agricultural enterprises	80.7	82.1	72.9	76.0
Paddy rice	25.2	24.6	20.8	21.3
Peasant farm enterprises and individual entrepreneurs	24.4	29.5	27.1	28.7
Private land for farming by the people	1.7	1.6	1.6	2.2
Industrial crops (soybeans)	176	218.2	223.1	244.3
Agricultural enterprises	122.3	148.2	140.0	149.6
Peasant farm enterprises and individual entrepreneurs	52.5	68.8	81.9	94.1
Private land for farming by the people	1.2	1.2	1.2	0.6
Potatoes	30.6	30.6	29.9	28.7
Agricultural enterprises	1.7	1.6	1.6	1.7
Peasant farm enterprises and individual entrepreneurs	2.6	2.4	2.6	2.9
Private land for farming by the people	26.3	26.6	25.7	24.1
Vegetables	10.4	9.5	9.4	10.8
Agricultural enterprises	2.5	1.9	2.0	2.0
Peasant farm enterprises and individual entrepreneurs	1.8	1.8	1.5	1.8
Private land for farming by the people	6.1	5.8	5.9	7.0
Fodder crops	54.5	51.8	49.0	43.2
Agricultural enterprises	39.3	32.3	27.0	22.6
Peasant farm enterprises and individual entrepreneurs	14.5	18.8	21.3	19.9
Private land for farming by the people	0.7	0.7	0.7	0.7

*Total area according to the sources is bigger, approximately by 700 ha.
Sources: Primstat, 2016; 2017.

Fig. 3 Gross production and crop yields for all PK farm categories



Sources: Primstat, 2016; 2017; Department of Agriculture and Food of Primorye Territory, 2017.

mechanization has generally not been supported by the programs with respect to smaller production systems, that is, peasant and individual enterprises (Kienzle et al., 2013).

The data published by the Statistics Office, however, may not always truly represent the ground situation - as data collection is not done every year. The authors contacted the office directly for the information needed to enrich this study.

Due to the specific method of data collection in the Russian Federation and local statistics centers, unfortunately, statistical reports lack some needed data. The reports include all the tractors registered on the balance sheets of agricultural enterprises, which includes leased equipment, as well as machinery on the off-balance sheet account. The reports do not indicate important technical details, such as tractor power, manufacturer names, and condition (e.g., under repair or broken but not yet written off). However, the statistical reports provide general official information about agricultural mechanization.

Results and Discussion

Pearson Correlation Analysis of PK Agricultural Data

Pearson correlation analysis was done to determine the relationship between the areas for total acreage area and potato cultivation area, soybean cultivation area, and the total number of tractors, as well as the relationship between the total number of tractors and potato and soybean cultivation areas. These data are agricultural mechanization indicators for PK. The PCC was calculated by Eq. (1). The Pearson correlation data used, an example of one calculation, and the result of the Pearson correlation can be seen in **Tables 4**, **5**, and **6**, respectively.

$$r = -3{,}380.6 \,/\, \sqrt{(1{,}746.07 \cdot 15{,}120)}$$
$$= -0.66$$

From **Table 5**, the PCC was calculated as -0.66. This result indicates a strong negative relation between the total area of the acreage of agricultural crops and the total number of tractors used.

The very strong positive correlation between soybean and total cultivation areas signifies that both variables move in the same direction and have a strong positive relationship. In other words, when the soybean cultivation area increases or decreases, the total cultivation area moves in the same direction with the same magnitude. The very strong negative correlation between soybean cultivation and tractors indicates that both variables move in the opposite direction. If soybean cultivation increases, the number of tractors decreases proportionately.

Analysis of Current Agricultural Machinery Market in PK

The PK farm machinery mar-

Table 3 Primary agricultural machinery and equipment used in PK agricultural enterprises

Designation	2013	2014	2015	2016
Total number of tractors	1,804	1,756	1,648	1,680
Total number of agricultural machinery and equipment	4,587	4,063	4,056	3,802
Plows	670	620	609	613
Seeders	464	438	453	424
Grass-mowing machines	175	173	178	170
Cultivators	566	504	498	492
Harrows	2,093	1,767	1,731	1,558
Tractor-trailers	501	459	482	446
Baling machines	118	102	105	99
Total number of combine harvesters	608	585	562	544
Crop harvesters	540	524	500	486
Forage harvesters	54	48	48	43
Potato harvesters	8	9	11	14
Maize (corn) harvesters	6	4	3	1

Source: Primstat (2017)

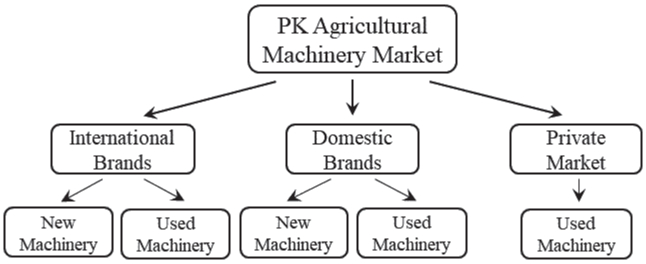


Fig. 4 PK farm machinery market structure

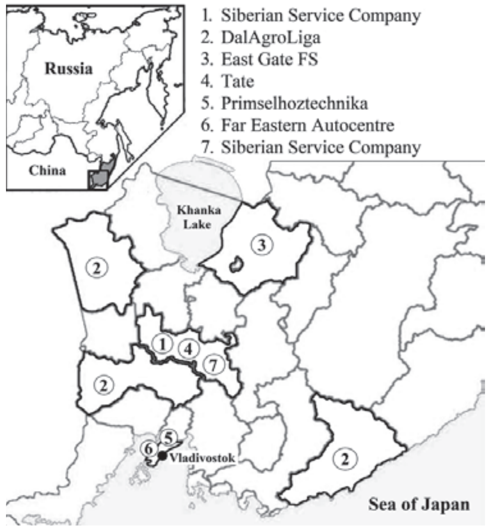


Fig. 5 Locations of official machinery distributors

ket was analyzed to classify it and identify opportunities for expansion. The analysis was based on the distribution of sales offices, data on import and export of agricultural equipment and machinery, details on warranty and post-warranty support, and the PK farm machine service network.

Structure of Agricultural Machinery Market

We divided PK agricultural machinery into three categories. The first category contains machinery from official dealers of well-known international machinery brands, the second category is dealers of domestic brand machinery, and the third category is a private market that consists only of second-hand (machinery that was previously used by farmers) machinery (**Fig. 4**). The first two categories can be further subdivided into markets for new and used machinery.

In PK, a number of companies (limited liability companies) are official dealers of well-known machinery brands, including Russian and imported brands. Common brands (and country of origin) include the Rostselmash group (Russia); Gomselmash (Republic of Belarus); CLAAS, Lemken, and Amazone (Germany); Salford Group (Canada); Maschio Gaspardo and New Holland (Italy); and AGCO Corporation (Challenger, Fendt, Massey Ferguson, and Valtra brands), John Deere, and Case-IH (USA). **Fig. 5** provides the names and locations of machinery dealers.

All companies identified in **Fig. 5** provide new agricultural machinery and equipment, as well as second-hand machinery. Each company offers full lines of tractors, combine harvesters, hay and forage equipment, seeding and tillage implements, grain storage systems, and replacement parts for this equipment. However, few of these companies stock the full line of agricultural machinery and equipment at their location. Generally, only 50-70% of the machines that are in demand are stocked on-site. When distributor does not have an equipment item in stock, it is ordered and delivered through the company's supply network in Russia or abroad.

After-sale Service

Each company in **Fig. 5** has its own after-sale service with different options. With the purchase of any equipment by a client, a company issues a service book that records all the data from previous diagnostic and maintenance services, as well as a dataset for the next scheduled maintenance. Furthermore, the distributor typically tracks maintenance service and contacts the machinery owner to schedule planned maintenance.

Most companies have mobile teams for maintenance and diagnos-

Table 4 Pearson correlation results

Category	2013	2014	2015	2016
Total cultivation area	379	423.9	413.7	434.7
Total number of tractors	1,804	1,756	1,648	1,680
Potato cultivation area	30.6	30.6	29.9	28.7
Soybean cultivation area	176	218.2	223.1	244.3

Table 5 Pearson correlation calculation example for total area versus number of tractors in 2013-2016

	Total area, corrected (x)	Total no. of tractors (y)	$(x-\bar{x})$	$(y-\bar{y})$	$(x-\bar{x})\bullet(y-\bar{y})$	$(x-\bar{x})^2$	$(y-\bar{y})^2$
2013	379	1,804	-33.82	82	-2,773.65	1,144.13	6,724
2014	423.9	1,756	11.07	34	376.55	122.65	1,156
2015	413.7	1,648	0.87	-74	-64.75	0.76	5,476
2016	434.7	1,680	21.88	-42	-918.75	478.51	1,764
Result	$\bar{x}$ = 412.82	$\bar{y}$ = 1,722			$\sum$= -3,380.6	$\sum$ = 1,746.07	$\sum$ = 15,120

$$r = -3{,}380.6 / \sqrt{1{,}746.07 \bullet 15{,}120} = -0.66$$

tic services to address equipment breakdowns. If the maintenance or repair service cannot be provided at the machinery location or the machine cannot be driven to a service facility on public roads, the company provides transportation to a repair facility.

Moreover, several companies have a network in Russia for fast delivery of replacement parts. Parts can reach a customer by plane, train, car, and other means in 1-4 days. This facilitates rapid repair of agricultural machinery and equipment, which is especially important during harvest time.

Used Machinery

Used agricultural machinery and equipment, including international and domestic brands, are divided into two categories. The first category is under support of the selling company (e.g., warranty and warranty maintenance). The second category does not have any official support from the selling company.

An example of the first category is the Tate company, which is an official distributor of John Deere (USA) in PK. The company provides imported new and used agricultural machinery and equipment from the USA. Used machinery and equipment have a warranty period of 6 months, but the warranty is only for the engine and transmission mechanism. New machinery and equipment have a warranty period of 2-5 years, and the warranty covers all machinery malfunctions. The warranty period is determined by machinery model and the sales agreement. Moreover, the company provides the warranty under specific conditions, which generally require the machinery owner to use only the company's diagnostic tools, maintenance, technical fluids, and replacement parts.

Supplementary Services

Companies sometimes provide assistance with machinery selection so the agricultural producer can maximize the machinery's potential. Due to different landscape terrains in PK, field sizes are both small and large (Starogilov, 2009), so companies will calculate machinery power and size for producer-specific fields. Several companies (e.g., Tate and Seberian Service companies) provide document preparation and execution services for purchase via leasing and provide other leasing assistance.

Private Market

The private market allows agricultural producers to sell and buy any equipment that they or other agricultural producers used previously. This kind of market increases the machinery choices available to agricultural producers and lets them sell machinery or equipment that they do not use anymore or upgrade older equipment without incurring the expense of dealer-supplied equipment.

In PK, many types of agricultural machinery and equipment are available from bordering countries. According to information from a Russian vehicle market website (drom.ru, 2018), agricultural machinery and equipment are available from primarily four countries in the private PK market. **Table 7** details the origins and brands of tractors available on the drom.ru private market during April 2018.

From **Table 7**, we can see that most of the private market tractors were made by Japanese manufacturers (327 tractors) and had a power range of 10-25 kW, although other tractor sizes were also available. The number of Japanese tractors available in each power range are shown graphically in **Fig. 6**.

We can interpret the abundance of Japanese tractors in PK as high demand among small agricultural producers due to the high quality and reliability of Japanese equipment. Also, the demand is boosted by a supply of secondhand equipment exported from Japan to local people in PK. Moreover, almost all Japanese tractors are equipped with additional equipment for soil cultivation, such as rotary cultivators and plows.

Tractors provided by Russian and Commonwealth of Independent States (CIS) manufacturers tend to be larger and more powerful, from 40 kW and more, because these tractors are favored by agricultural enterprises, rather than individual farmers and small enterprises. The Chinese tractors are represented by only two brands across a rather broad power range between 10 and 40 kW.

Research Activities and Agricultural Machinery Development in PK

The purpose of this section is to explore future opportunities for international cooperation between institutions on agricultural machinery in PK. International research cooperation is widespread and open, but few efforts in PK have reached the scale and scope of what we would call international research cooperation (Youtie et al., 2017). For this purpose, we investigated agricultural institutions in PK and identified the primary institute in the field of agricultural machinery research, as well as its current areas of research and development.

Table 6 Pearson correlation results for PK

Indicators	PCC	Result
Number of tractors/total area	-0.66	Strong negative
Potato cultivation area/total cultivation area	-0.65	Strong negative
Soybean cultivation area/total cultivation area	0.97	Very strong positive
Potato cultivation area/number of tractors	0.69	Strong positive
Soybean cultivation area/number of tractors	-0.81	Very strong negative

Agricultural Machinery Institutions

The PK has several agricultural institutes, which prepare specialists for agriculture and are engaged in machinery development for agriculture mechanization. These are the Primorskaya State Academy of Agriculture, Ussuriysk Agro-Industrial College, Chernigov Agricultural College, and Chuguev College of Agriculture and Service.

The primary institute for agricultural machinery, which deals with difficult issues of machinery development in agriculture and contributes constantly to the development of agricultural mechanization, is the Engineering and Technology Institute of the Primorskaya State Academy of Agriculture.

The fundamental efforts of scientists at the Engineering and Technology Institute are aimed at the development and improvement of agricultural machinery. Over the last 5 years, development has been aimed at improving and creating new agricultural machinery for soybean production, because soybeans are the leading agricultural crop in PK.

The main areas of research that engage the institutes' students and scientists are agricultural machinery, materials science and technology for metal processing, mechanical engineering and repair, manufacturing automation and creation of automatic systems for animal husbandry, livestock production, and crop production.

Engineering and Technology Institute Research and Development Activities

Agricultural machinery research covers study of the parameters of disk harrows, development of precise grain seeders, improvement of the design of hammer mill combines, and improvement of tools for surface soil tillage (Redkokashin, 2015). Mechanical engineering and repair efforts include improvement of the construction and assembly of high-pressure hoses (Borodin and Borodin, 2014), development of a mechanical gearbox under the control of an Arduino-based software program, and improvement of internal combustion engine systems. Materials science and technology efforts include development of methods for obtaining higher-quality metal parts for mechanical systems. Automation of production and creation of automatic systems for cattle breeding include consideration of questions on loss of soy and other grain crops during cleaning and storage. Animal husbandry and plant growth research includes soybean treatment in an electric field.

All research efforts, such as development of precise grain seeders, contribute to the exchange of experience and development among machine-plant enterprises in Russia and contribute to the development

Fig. 6 Number of Japanese tractors in each power range available in private PK market, April 20, 2018

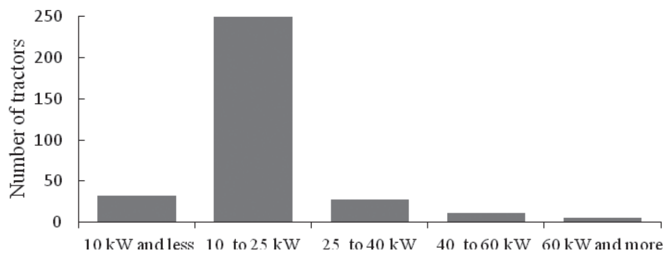


Table 7 Tractors in the private market of PK (data from April 20, 2018)

Origin and manufacturer name	All tractors	≤ 10 kW	10-25 kW	25-40 kW	40-60 kW	≥ 60 kW
Japanese	327	32	249	28	12	6
Yanmar	100	14	69	13	2	2
Iseki	80	2	66	8	3	1
Kubota	51	6	37	4	3	1
Mitsubishi	44	4	34	2	2	2
Hinomoto	26	2	23	-	1	-
Shibaura	19	2	16	1	-	-
Others (Hitachi, Honda, Komatsu and Sato)	7	2	4	-	1	-
Russian and CIS countries (Rep. of Belarus, Ukraine)	46	-	1	9	18	18
LTP (Lipetsk Tractor Plant)	6	-	-	6	-	-
Rostselmash	2	-	-	-	-	2
VTP (Volgograd Tractor Plant)	9	-	1	-	-	8
MTZ (Minsk Tractor Works)	22	-	-	3	11	8
YuMZ (Yuzhmash)	7	-	-	-	7	-
Chinese	10	-	8	2	-	-
Changchun	4	-	4	-	-	-
Jinma	6	-	4	2	-	-
Total	383	32	258	39	30	24

of agricultural mechanization of the AIC in PK. This provides an opportunity for cooperation between the Engineering and Technology Institute and local PK agricultural enterprises in the field of agricultural mechanization, as well as cooperation with international institutions.

Conclusions

Our findings show that agricultural mechanization in PK is yet to be avail its full potential. The current situation of agricultural mechanization in PK was described based on the information gathered from the Statistics Office of the Russian Federation, scientific articles published in Russia, and our observations. However, the perspectives of agricultural mechanization that we obtained, showed us various directions for improving agricultural mechanization and productivity. The material and technical basis of production is most important and provides multiple avenues for improving agricultural production. In particular, modern agriculture requires the acquisition and adaptation of advanced technologies and machinery.

Pearson correlation analysis indicated a very strong negative correlation (-0.81) between the number of tractors and the area under soybean cultivation. Thus, we can conclude that as the soybean cultivation area increases, the number of agricultural machines decreases. This shows that soybean production is associated with a systematic increase in efficiency. In addition, there is a very strong positive correlation (+0.98) between the total and soybean cultivation areas; as soybean production rises and falls, the total area under cultivation rises and falls accordingly. Thus, soybean production is the primary area of agricultural production.

These results can be evaluated as accurate indicators for managing agricultural mechanization; however, it would benefit from controls for producing more reliable statistics. In particular, it is important to determine whether the agricultural mechanization level is in accord with average field area and equipment size.

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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.

17117

Mechanized Agriculture a Necessary Key for Reducing Agricultural Wastes and Loss: Mohammad Emami, Morteza Almassi ,Hossein Bakhoda, Issa kalantari

Today, the global issue of food waste has attracted the public's attention more than ever before. As demographic predictions suggest an increase in the world population over the years to come, and this increase in population will increase the need for food on a daily basis, the large amount of food waste is of great importance. Apart from the need to produce more food, one of the approaches to sustainable food security is to reduce waste, which is also referred to as hidden cultivation. In this research, the effect of agricultural mechanization on the amount of crop waste was investigated. The mechanization indicators, during the years studied, were calculated and defined and then correlation of these indicators with the amount of waste of the specific products was investigated. Based on the findings, agricultural mechanization, despite its growing trend in Iran, has not been able to contribute to the waste reduction. The country needs to review its agricultural policies to further improve mechanization in order to reduce waste and enhance its role in achieving food security.

1806

Development of Cashew Nut Shell Liquid Expeller: Elijah Oladimeji Aina, Alex Folami Adisa, Tajudeen Mukaila Adeniyi Olayanju, Salami Olasunkanmi Ismaila

The shell of the cashew nut in its natural state is leathery and contains thick vesicant oil called Cashew Nut Shell Liquid (CNSL) which is known for its innumerable applications and its ability to undergo all the conventional reactions of phenols. A machine for expelling CNSL using locally available materials was developed which consists of a frame, compression chamber, perforated cylinder, hopper and funnels. The cashew nut shells were sampled, cleaned, and prepared for tests. The mass of liquid extracted was 4.1 kg with extraction efficiency of 82%, machine capacity was 0.41 kg/min with percentage liquid recovery of 20.5% at optimum pressing duration of ten minutes and moisture content 14.00-16.99% wet basis. The pressing duration of 2 minutes and moisture content of 14.00-16.99% were optimum for the machine capacity.

Development of an Electronically-Operated Automatic Transplanting Mechanism for Sustainable Sugarcane Initiative (SSI) System

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Abstract

Sustainable Sugarcane Initiative (SSI) is the latest technique of sugarcane planting, wherein the seedlings raised in portray/plug type is used for planting that require additional manpower. To overcome this constraint, the present work was carried out to develop an automatic transplanting mechanism suitable for SSI plug type seedlings. The experimental automatic mechanism for plug type SSI seedlings consists of an end-effector/gripper mechanism to grasp the plug type seedlings, Printed Circuit Board (PCB) containing a micro controller (16F877A) - controlling the movements of the end-effector, limit switches to control the position of the gripper that picks and carries the seedlings and Liquid Crystal Display (LCD) system that shows the operation of gripper. Laboratory study was conducted to optimize the speed of operation of components of automatic picking and dropping mechanisms viz., horizontal screw rod, vertical screw rod and gripper. The physical dimensions of the gripper was determined by the protray size and the parameters of sugarcane seedlings. Thirty-days old sugarcane seedlings and growth medium of Coco pith + Farm Yard Manure (FYM) + Sand (1:1:1) offered the maximum picking efficiency of seedlings with minimum plug damage. The optimum speed of operation of horizontal screw rod, vertical screw rod and gripper was found to be 85, 60 and 60 revolution per minute (rpm), respectively, which resulted in maximum picking efficiency of 84 percent with 2 percent of missing. Plug damage was observed as 3.86 percent under laboratory condition.

Keywords: End-effector; Limit switches; Micro-controller; Relay and Picking mechanism.

Introduction

Sugarcane (*Saccharum officinarum*) is the main source of sugar in Asia and Europe. Sugarcane is the raw material for the production of white sugar, jaggery (gur) and khandsari. It is also used for chewing and extraction of juice for beverage purpose. Globally, sugarcane occupies an area of 20.42 M ha with a total production of 1,743.09 M tonne. Brazil has a highest sugarcane area of 8.14 M ha, while Australia has the highest sugarcane productivity of 87.11 t ha^{-1} (Yadav et al., 2011).

India ranked second in the world, after Brazil during 2014, in terms of area (5.12 M ha) and sugarcane production (350 M t). There is a growing demand for sugar in India as it is the largest sugar consuming country in the world (around 27 M t during 2013-14). There are 35 M farmers growing sugarcane and another 50 M depend on employment generated by the 571 sugar factories and other related industries using sugarcane. In India, sugarcane plays a major role in the economy of Uttar Pradesh, Maharashtra and Tamil Nadu states (Anonymous, 2014).

Sustainable Sugarcane Initiative System

As the chances of horizontal expansion in the area under sugarcane in India are bleak, the only solution is to increase the productivity by adopting innovative technologies. As such there are few technologies in sugarcane that can minimize cultivation cost. Bud chip planting, popularly known as Sustainable Sugarcane Initiative (SSI) is a novel conglomeration of many viable technologies put together so as to increase the productivity. Sugarcane bud chip seedling transplanting is the latest technique of sugarcane planting, wherein the bud along with a portion of the nodal region is chipped off and planted in protray with FYM soil and sand. Seed material required under this technique is only 1-1.5 t ha^{-1}. The suitable age for transplanting the young seedlings from nursery to the main field is 25 to 35 days (Gujja Biksham, 2009). The optimized age of seedling (25 -35 days) (Chandrasekaran et al., 2014) and growth medium of Coco pith + FYM + Sand (1:1:1) was used (Sivakumar et al., 2014) to obtain the maximum picking efficiency of seedlings with the minimum plug damage.

Transplanter for SSI System

Although there are several advantages of planting the sugarcane by using SSI system, it has limitations in terms of additional manpower required for planting of seedlings. A tractor mounted semi-automatic transplanter for SSI system was developed by the Central Institute of Agricultural Engineering, Coimbatore, in which the seedlings are fed manually and metered mechanically. Two persons are needed for continuous feeding of seedlings through the holes of the rotating metering device. While falling through the chute, due to the combined effect of soil at the root base and parachuting effect of leaves, the root portion is always at the bottom. During the movement of the tractor in the forward direction, shoe type soil opener, opens up the soil. Sugarcane settlings which are dropped by the person, falls into this opened soil. (Annamalai et al., 2012).

Naik et al., (2013) studied the mechanised planting of sugarcane bud chip settlings raised in protrays. The circular metering mechanism consisted of two circular plates of 600 mm diameter mounted on a 25 mm diameter shaft. It was designed on the basis of physiological characteristics of sugarcane bud chip settling nursery. The discs were kept at a distance of 60 mm with each other. The bottom plate was fixed and had a single hole with a diameter of 70 mm. The top plate was rotating, which had 8 holes of 70 mm diameter, taking factor of design safety as 1.50. As and when, the operator places a plant in each hole on the top plate and as the plate rotates, the seedling will drop due to gravity when holes on the top and bottom plates coincide.

Abdel et al., (2014) studied the mechanization of sugarcane transplanting. The seedling metering mechanism consists of four funnels. Each funnel attached to dual displaced arm system that keeps the funnel perpendicular while rotation. The diameter of seedling metering mechanism was 700 mm. Springs were used to keep the lower end of the funnel always closed. Especially cam arrangement used to open the funnels at the proper position of dropping the seedling to be placed inside the open furrow.

The objective of this study was to develop an efficient pick-up device for automatic transplanting of plug type seedlings of Sustainable Sugarcane Initiative system and to perform its laboratory evaluation to identify the ideal set of linear speeds of picking, metering of plug type seedlings and conveyor system for positioning the plug type seedlings to the gripper.

Materials and Methods

The main functional components required for experimental automatic transplanting mechanisms of plug type seedlings consisted of gripper, horizontal screw rod for the movement of gripper from cell to cell of the portray, and the vertical screw rod for the movement of gripper in the vertical plane for pulling out the seedling from the cell. Laboratory tests were conducted to optimize the speed of operations of screw rods and the gripper.

Protray Specifications

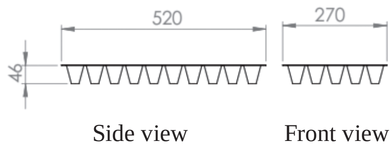
The size of each protray is 530 × 270 × 50 mm, round in shape containing

50 cells (10 × 5) (**Fig. 1** Dimensions in mm). Each cell measurement is 50 mm diameter at top, 30 mm diameter at bottom and 50 mm in depth. The centre to centre distance between each cell in a row is 50 mm. Both cell to cell and row to row distances play important roles in the development of programme for picking mechanism.

Conceptualization of Automatic Picking, Dropping and Protray Conveying Mechanism

In developing an automatic picking and dropping mechanism for sugarcane seedlings raised in protrays, two important mechanisms viz. movement of seedling picking

Fig. 1 Specifications of protray



mechanism from cell to cell in a row, and movement of protray conveyor mechanisms were considered. For picking the seedlings from the protray, an end-effector/gripper, which works like a robotic arm, was selected. The concept of development of automatic picking, dropping and tray conveying mechanisms is shown in the **Fig. 2**.

End-effector/gripper Design and Functionality

A mechanical motorized end-effector/gripper system was developed to successfully grasp, pick and release plug type seedlings during transplanting (Ting, 1990; Simonton, 1991). The end-effector was used to contact the seedlings raised in protrays by means of gripper. **Fig. 3** shows the details of the gripper. The gripper consists of foldable arms that operate like hands. The arms consisted of two rods joined in a 'V' shape. Two Galvanized Iron (GI) plates were provided on both the arms for gripping and lifting the seedlings from the protrays. The end-effector/gripper opening rang was 30-50 mm.

The end-effector mechanism was used to contact the seedlings raised in protrays by means of gripper. A 12 volt (V) Direct Current (DC) motor was used as power source for the gripper. The gripper was connected to the output shaft of the motor. The time of opening and closing of the gripper arms were programmed in the micro controller. Gripper would open and close at regular intervals and it was programmed to open at a spacing of 35 mm. The gripper and DC motor were supported by two flats which are mounted on nut like structure with internal threads. This nut was mounted in such a way to move on the vertical screw rod. Opening and closing of gripper arms influencing the seedlings picking efficiency and plug damage. Hence, the speed of gripper movement at three different speeds viz. 50, 60 and 70 rpm were studied for optimization of speed to achieve the maximum picking efficiency.

Gripper Tower

The vertical screw rod and an end effector mechanism along with DC motor were mounted on a gripper tower (**Fig. 4**). The entire tower can move over the horizontal screw rod in both forward and reverse directions for picking and transplanting the plug sugarcane seedlings. The gripper and gripper tower were designed based on the distance between cells and width of the protray.

Printed Circuit Board (PCB)

Printed circuit boards electrically connected the electronic components using conductive tracks, pads and other features etched from copper sheets laminated onto a non-conductive substrate. In automatic picking and dropping mechanism, a single side printed circuit board (**Fig. 5**) was used to obtain the sequential operation. It consisted of micro controller, relay, (Recommend Standard) RS 232 interfacing cable, ULN 2803 Darlington transistor, bridge rectifier, voltage regulator, male and female connector, insulation Integrated Circuit (IC) and LCD.

Micro Controller

A micro controller is a single integrated circuit containing a processor core, memory, and programmable input/output peripherals. The micro controller gave the step-by-step instruction to the circuit as per the embedded coding programme. A 16F877A PIC micro controller was used for the development of automatic sugarcane seedling picking and placing mechanism. The complete pin diagram and architecture of PIC 16F877A are shown in **Fig. 6**.

Fig. 2 Conceptualization of automatic picking, dropping and protray conveying mechanism

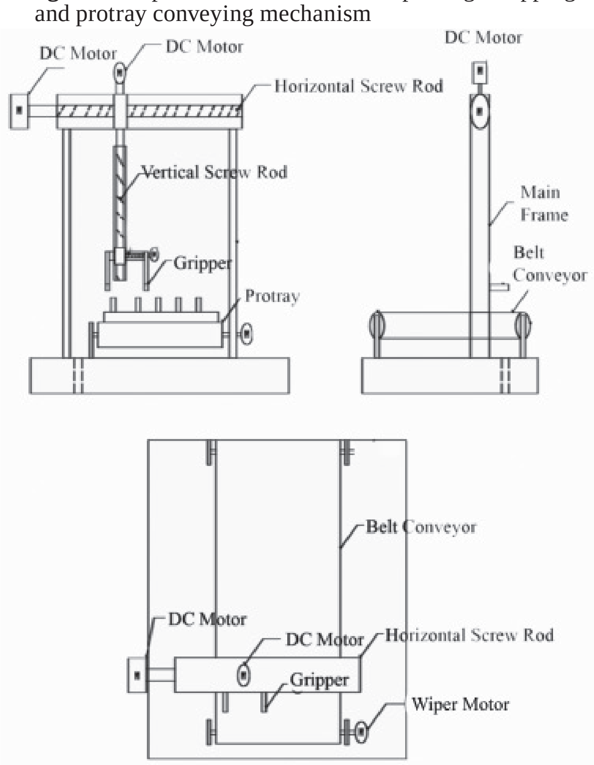


Fig. 3 Gripper/end-effector powered by an electric DC motor

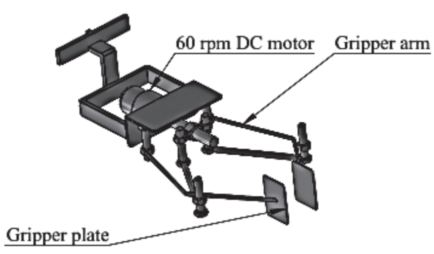
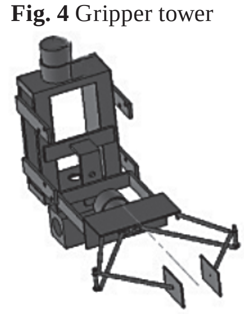


Fig. 4 Gripper tower



Operational Sequence of Automatic Transplanting Mechanism

Initially, the gripper tower is positioned in the front end of the horizontal screw rod. Power is supplied to the PCB by using a 12 V battery connected to the circuit. When the first relay is turned ON and the wiper motor rotates in forward direction, the screw rod rotates in the anti-clockwise direction, which moves the gripper tower to the forward direction and moves to the centre of the first cell in first row of the protray. After first relay is OFF the relay no. 4 is gets ON and connected vertical screw rod will gets contact and rotates the vertical screw rod. Initially the gripper is in upper portion of the vertical screw rod. As the DC motor operates in reverse direction, the vertical screw rod rotates in anticlockwise direction, which enables the movement of nut in downward direction resulting in gripper getting downward direction until it reaches to the downward limit switch. After the 4th relay is OFF the relay no. 6 is ON and triggers the gripper motor. As the gripper motor rotates clockwise, the gripper gets close in such a way the seedling grasped by gripper and the 6th relay gets OFF. Then the relay no. 3 that is connected to the vertical screw rod, will get activate and rotates the vertical screw rod. Due to this, the gripper moves up until it reaches the limit switch provided at the top. Next, as the relay no. 2 is ON, the wiper motor rotates in reverse direction. The horizontal screw rod rotates clockwise, which moves the gripper tower along with picked seedlings in the reverse direction until it reaches the limit switch. After reaching to the limit switch, the relay gets OFF. As the relay no. 5 is ON the gripper motor rotates anticlockwise and gripper gets open and the seedling is dropped.

The same sequence of operation is repeated five times to pick five numbers of seedlings in the first row. After the complete removal of seedlings in the first row, the 7th relay energizes the wiper motor and moves the conveyor one step forward to keep the centre of second row cell just below the gripper. The process will continuously take place to pick the seedlings in the desired position. All above operations are controlled by programmed microcontroller chip. Finally, the transferred seedlings were dropped into decided place. Block diagram and sequential operation of automatic seedling picking, dropping and conveying mechanism are shown in **Fig. 7** and **Fig. 8**.

The data obtained from the experiments were statistically analysed by using AGRES statistical software. Based on the results of the experiment, the speed of grippers, horizontal and vertical screw rods were optimized for maximum successes of picking and dropping of plug type protray seedlings without damaging to the seedling plugs.

Optimum Speed of Machine Parameter on Picking Efficiency and Plug Damage

Opening and closing of gripper arms influencing the seedlings picking efficiency and plug damage. Hence the speed of gripper movement at three different speed viz. 50, 60 and 70 rpm were studied for optimization of speed to achieve the maximum picking efficiency. The other two parameters were fixed as constant. The picking efficiency at different speed of vertical screw rod was observed. The variables and levels selected for the study are given in **Table 1**. The data obtained from the experiments were statistically analysed by using AGRES statistical software. Based on the results of the experiment, the speed of grippers, horizontal and vertical screw rods were optimized for maximum successes of picking and dropping of plug type protray seedlings without causing damage to the seedling plugs.

Performance Test

In the test trails, the seedlings from 50 cell protrays were transplanted. The efficiency of the picking mechanism and damage of the

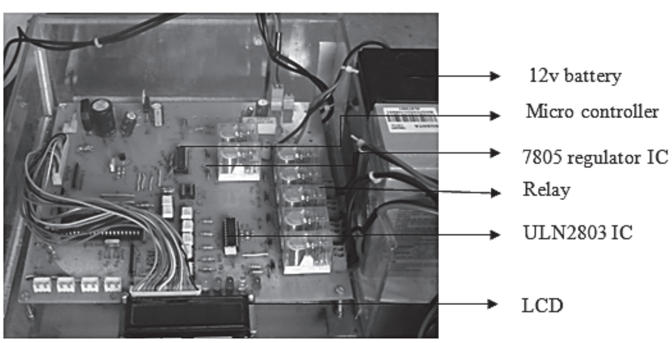


Fig. 5 Printed Circuit Board (PCB)

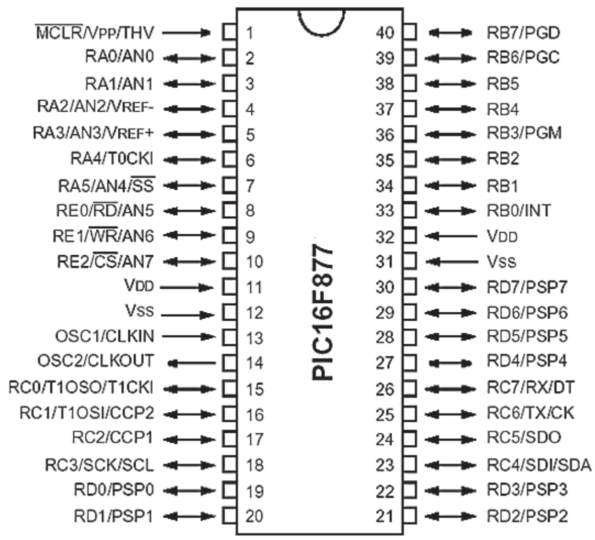


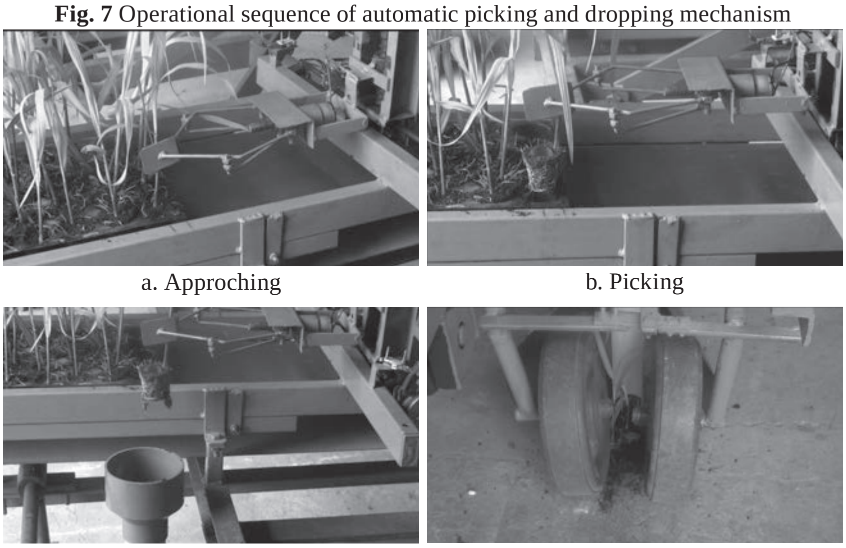
Fig. 6 Pin diagram of PIC 16F877

seedling plugs or media during picking from the protray by the gripper was measured by using the below equations (Equations 1 & 2) (Kavitha, 2005).

Picking efficiency = (Number of seedling picked by the gripper / Number of seedling in a protray) × 100 (1)

Damage percentage = (Number of plugs damaged while picking / Number of seedling in a protray) × 100 (2)

Fig. 7 Operational sequence of automatic picking and dropping mechanism



a. Approching b. Picking

c. Transfering d. Dropping

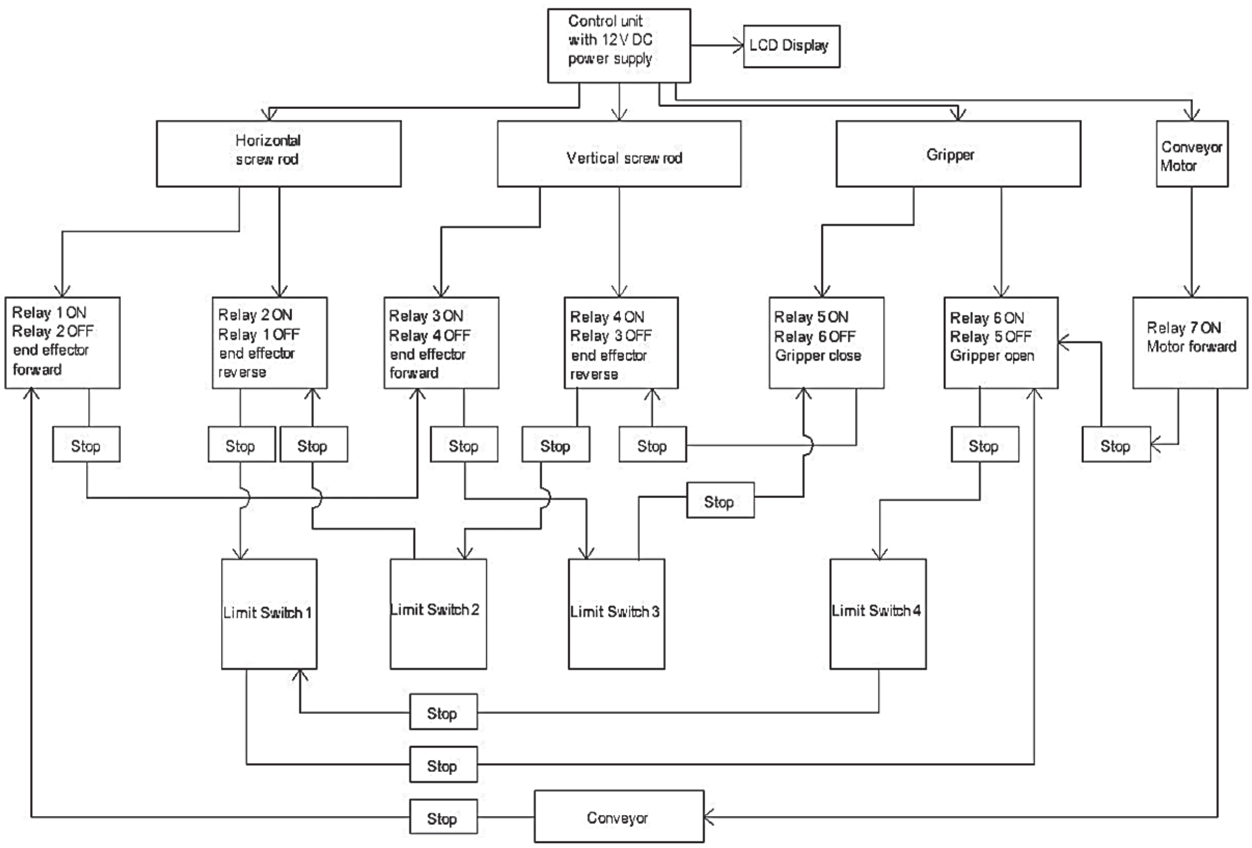
Results and Discussion

The performance of an automatic transplanting mechanism was evaluated with several consecutive tests. Laboratory models of automatic transplanting mechanism were developed followed by optimization of the operating speed of the individual components viz., horizontal screw rod, vertical screw rod and gripper. Speed of horizontal screw rods at three levels viz., 75, 85 and 95 rpm, speed of vertical screw rod and gripper at three levels viz., 50, 60 and 70 rpm were studied, and the variables were optimized based on picking efficiency and plug damage.

Effect of Operational Speed of Horizontal Screw Rod, Vertical Screw Rod and Gripper on Picking Efficiency of Plug Type Seedlings

Picking efficiency of the gripper and the damage of plug at all the levels were observed. **Table 2** shows

Fig. 8 Block diagram of sequential operation of seedling automatic picking, dropping and conveying mechanism mechanism



the Analysis of Variance (ANOVA) on picking efficiency of automatic picking and dropping mechanism for plug type sugarcane seedlings. All the variables and interactions were found to be significant at 1 percent level.

The maximum picking efficiency of 84 percent was observed with operation speed of horizontal, vertical screw rods and gripper was found to be 85, 60 and 60 rpm respectively whereas, the minimum efficiency of 64 percent was observed with operational speed of horizontal, vertical screw rods and gripper was found to be 75, 50 and 50 rpm respectively, the missing percent of seedling was found to be around 2.

Effect of operational speed of horizontal screw rod, vertical screw rod and gripper on plug damage of plug type seedlings

The effect of speed of operation of horizontal, vertical screw rod and gripper, which may cause plug damage during pulling the seedlings from the protray, was studied at three different levels. ANOVA results of plug damage at different levels of speed of operation of horizontal, vertical screw rod and gripper are listed in **Table 3**. The minimum plug damage was recorded 3.86 percent in 85, 60 and 60 rpm of horizontal screw rod, vertical screw rod and gripper speed respectively.

To test the performance of the gripping fingers, 45 seedlings in 50-cell tray were transplanted in laboratory with optimized speed of end-effector mechanism (**Fig. 9**). Test results showed that the operational speed of horizontal, vertical screw rods and gripper as 85, 60 and 60 rpm, respectively, had the best transplanting efficiency of 90 percent with 8 percent moisture content. Other operating speed of end-effector mechanism produced a transplanting success rate of less than 65 percent. Transplants failed because a seedling was stuck to the tray cell, fingers damaged a seedling and it took longer time to pick the seedlings from protray. Based on these results, the operating speeds of the gripper mechanism were finally selected for the automatic transplanting mechanism.

Conclusions

An experimental model of automatic picking and dropping mechanism was developed to optimize the speed of operation of the individual components viz., horizontal screw rod, vertical screw rod and gripper. Speed of horizontal, vertical screw rods and gripper at three levels were studied to optimize the variables based on picking efficiency and plug damage. 30 days old sugarcane seedlings and growth medium of Coco pith + FYM + Sand (1:1:1) was used for the study. The interaction of three variables was statistically analyzed. The maximum picking efficiency of 84 percent was observed at 85, 60 and 60 rpm, whereas, the minimum efficiency 64 percent was observed at 75, 50 and 50 rpm. The missing percent of seedling was found to be 2. The minimum plug damage of 3.86 percent was recorded, hence, the operating speed of horizontal, vertical screw rods and gripper was optimized with maximum sugarcane seedlings picking efficiency of 84 percent.

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Table 1 List of selected variables for picking out the seedling from protray and dropping the seedlings

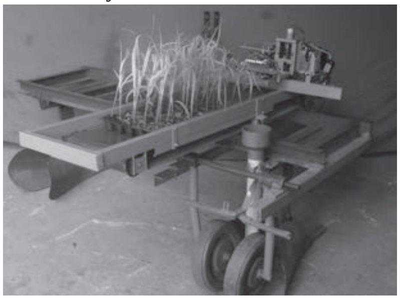
Variables	Levels
Independent	
Speed of horizontal screw rod (H)	75, 85 and 95 rpm
Speed of vertical screw rod (V)	50, 60 and 70 rpm
Speed of gripper	50, 60 and 70 rpm
Dependent or response variable	
	Picking efficiency, percent
	Plug damage, percent
No of replications in each treatment	3 (R1, R2 and R3)

Table 2 Analysis of variance on picking efficiency of plug seedlings

Source	df	SS	MS	F	Probability
Total	80	4,749.26	59.36	18.03	
Treatment	26	4,571.55	175.82	53.41	0.000**
Speed of horizontal screw rod (H)	2	1,284.22	642.11	195.11	0.000**
Speed of vertical screw rod (V)	2	192.88	96.44	29.30	0.000**
Gripper speed (G)	2	26.88	13.44	4.08	0.002**
H × V	4	2,116.44	529.11	160.78	0.000**
V × G	4	217.77	54.44	16.54	0.000**
H × G	4	436.44	109.11	33.15	0.000**
H × V × G	8	296.88	37.11	11.27	0.000**
Error	54	177.70	3.29	1.00	

df- degrees of freedom; SS- sum-of-square; MS- Mean square; F- test

Fig. 9 Performance evaluation of automatic transplanting mechanism in laboratory



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■■

Table 3 Analysis of variance on plug damage

Source	df	SS	MS	F	Probability
Total	80	4,031.76	50.39	285.08	
Treatment	26	4,022.22	154.70	875.12	0.000**
Speed of horizontal screw rod (H)	2	3,254.88	1,627.44	9,206.24	0.000**
Speed of vertical screw rod (V)	2	29.55	14.77	83.59	0.000**
Gripper speed (G)	2	48.22	24.11	136.39	0.000**
H × V	4	205.77	51.44	291.01	0.000**
V × G	4	158.44	39.61	224.07	0.000**
H × G	4	47.11	11.77	66.62	0.000**
H × V × G	8	278.22	34.77	196.73	0.000**
Error	54	9.54	0.17	1.00	

df- degrees of freedom; SS- sum-of-square; MS- Mean square; F- test

Modelling of Tractor Fuel Consumption for Ploughing Operation in a Sandy Loam Soil

by

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Abstract

Tractor fuel consumption is an important factor in farm machinery management. Available tractor fuel consumption models are not applicable in Nigeria due to differences in soil and operating conditions. The modelling of tractor fuel consumption in litres per hectare (L/ha) during ploughing operation in a sandy loam soil was undertaken using available information gathered from the National Centre for Agricultural Mechanization (NCAM) Tractor Test Reports. A multiple linear regression method was used to develop the model. A 10-repeated 10-fold cross-validation method was used to validate the developed model. In this study four different models with p-values < 0.05 were developed for predicting tractor fuel consumption during ploughing operation in a sandy loam soil. The best of the four models had a R^2-value of 0.656 showing ploughing operation parameters such as tractor power rating, depth of cut and effective field capacity as major contributing factors to the model. Also, cross-validation revealed that the best developed model had a test error value of 1.396 L/ha. This test error is equivalent to 23.02% of the observed fuel value. It was concluded that the study had identified contributing factors to tractor fuel consumption during ploughing operation in a sandy loam soil. Therefore, the tractor fuel consumption models developed for ploughing operation in a sandy loam soil are recommended for use in budgeting for diesel consumption.

Keywords: Fuel consumption, diesel, tractor, evaluation, model, ploughing

Introduction

Tillage has been described as the most costly single item in the farm budget (Igbeka, 1986). Soil tilling, according to Oni (1991), is the most intensive of all processes involved in crop production. Tillage of soil is considered to be one of the major farm operations (Finner and Straub, 1985). Agricultural tillage involves soil cutting, turning, and pulverization, and thus demands high energy, not just due to the large amount of soil mass that must be moved, but also due to inefficient methods of energy transfer to the soil. The most widely used energy-transfer method is to pull the tillage tool through the soil (Ashrafi Zadeh, 2006).

Agricultural machinery has become increasingly important in carrying out farm work. The application of machines to agricultural production has been one of the outstanding developments in agriculture. Machinery contributes a major capital input cost in most farm businesses. The primary purpose of agricultural tractors, particularly those in the middle to high power range, according to Zoz and Grisso (2003), is to perform drawbar work. With the increasing use of farm machinery, farm tractors play an important role in enhancing agricultural productivity (Kazmi and Ahmad, 1996). Tractors and farm machinery are important sources of modern technology (Singh, 2000; Xinan et al., 2005). Tractors are one of the fastest farm machines used by farmers for tillage operations instead of human tools and animal-drawn implements (Panam et al., 2010).

Land preparation is one of the most energy consuming operations in the field. Tillage operations require the most energy and power spent on farms (Al-Suhaibani and Ghaly, 2010). As energy becomes more expensive, its efficient utilization in agricultural production has become a major concern of agricultural engineers and tractor owners. Fuel consumption plays a significant role in the selection and management of tractors and equipment.

There are several tillage implements used by farmers to prepare seedbed. However, the selection of tillage implements for seedbed preparation and weed control depends on soil type and condition, type of crop, previous soil treatments, crop residues and weed type (Upadyaya et al., 2009). Two of the common tillage implements widely used by farmers in the southern part of Nigeria are the disc plough and disc harrow. Disc plough plays a prominent role in tillage and under certain conditions they are reported to be advantageous over other implements used for the same purpose, as they roll into the soil instead of sliding (Gulvin and Stone, 1977; Kaul and Egbo, 1985). Disc plough can be used in adverse soil condition and because of its rolling action, their unit draft is low if operated under adverse soil condition. Disc ploughs as primary tillage implements are used for the initial major soil working operations. According to Fathollahzadeh et al. (2009), disc plough is one of the tillage implements used in the fields in Iran where mouldboard ploughs do not have good performance.

Models have played several important roles in many developed countries in the budgeting of tractor fuel consumption in preparation towards next planting season. Models developed for predicting tractor fuel consumption during ploughing operation in developed countries are not applicable in Nigeria due to differences in soil and operating conditions. Most of these developed models are usually recorded in litres per hour (L/h) which may be difficult to use by tractor owners and farmers in Nigeria as it does not account for the farmers' interest who are more familiar with litres per hectare (L/ha) in carrying out their field operations. Hence, this study aims at developing a statistical model for predicting tractor fuel consumption in litres per hectare during ploughing operation in a sandy loam soil.

Materials and Methods

2.1 Experimental Procedure

This study involves the use of information gathered from the National Centre for Agricultural Mechanization (NCAM) Tractor Test Reports on agricultural tractors tested during ploughing operation on a sandy loam soil. Each tractor was tested on an area of 0.25 ha (25 m × 100 m) in a randomized complete block design (RCBD). The implement used for the trials was a tractor mounted disc plough. Parameters measured during ploughing operation included speed of operation, fuel consumption, field capacity, field efficiency, wheel slip, duration of operation, draught force, width of cut, depth of cut, soil cone index, soil moisture content and soil bulk density. The three soil properties, namely, soil cone index, soil moisture content and soil bulk density were measured at depths 0-7 cm, 7-14 cm and 14-21 cm. The resulting average values of these three soil properties form part of the data collated. All parameters of tractor-implement performance were measured and recorded in line with the recommendations of RNAM Test Codes and Procedures for Farm Machinery (1983). A total of 41 tractor test data gathered from NCAM Tractor Test Reports as compiled by Oyelade (2016) were used for this study. Out of the 41 tractor test data, 37 tractor test data - termed as model development dataset, were used to generate multiple regression for use in predicting tractor fuel consumption in litres per hectare during ploughing operation in a sandy loam soil. The remaining four tractor test dataset - termed as model validating dataset, were used to validate the developed model.

2.2 Description of the Study Area

This study was carried out at the National Centre for Agricultural Mechanization (NCAM), Ilorin, Kwara State. It is located at 370 m above sea level in the Southern Guinea Savanna ecological zone of Nigeria by Longitude 4° 30' E and Latitude 8° 26' N. According to Kolo et al. (2012), Ilorin falls under a tropical climate characterized by a bi-modal rainfall pattern with peaks in June and September and a dry spell between mid-July and August. Annual rainfall ranges between 1,000-1,240 mm. The daily temperature range is 20-35 °C.

The various test locations where these tractors were tested fall under the sandy loam soil textural class with the following fractions: sand - 56.79% to 69.92%, silt - 15.33% to 28.64% and clay - 6.44% to 18.33%. The soil in the various test locations were classified as Alfisols (Soil Survey Staff, 1975) under the USDA soil order.

2.3 Particle Size Analysis

Particle size analysis was carried out using the hydrometer method described by Gee and Or (2002). Sodium hexametaphosphate (calgon) was used as dispersant. The textural class of the soil was determined using the USDA Textural Triangle.

2.4 Test Parameters

2.4.1 Speed of Operation

The speed of operation was determined by placing two poles 20 m apart in-between 100 m which serves as the longest distance of the test plot. On the opposite side also two poles were placed in a similar position 20 m apart. The speed of operation for each tractor evaluated during ploughing operation is mathematically expressed as:

$$T_s = 3.6(20 / t_3) \quad (1)$$

where,

T_s = Speed of operation (km/h)

t_3 = Time taken to cover 20 m (sec)

2.4.2 Depth and Width of Cut

The depth and width of cut during field operation were measured using steel ruler and measuring tape, respectively.

2.4.3 Draught of Implement

Draught of implement was measured using the trailing tractor technique. This involves attaching a 20 kN strain-gauge dynamometer to the front of the tractor on which the implement was mounted. Another auxiliary tractor was used to pull the implement-mounted tractor through the dynamometer. The auxiliary tractor pulls the implement-mounted tractor with the latter in neutral gear but with the implement in the operating position. Draught was recorded in the measured distance (20 m) as well as the time taken to traverse the distance. On the same field, the implement was lifted above the ground and the draught recorded under the same (20 m) distance covered placed sideway. The draught of the implement was obtained by finding the difference between the average figures of the two readings. This procedure was repeated for each test-tractor.

2.4.4 Theoretical Field Capacity

The theoretical field capacity measured in ha/h is expressed mathematically as:

$$G = E(3600) / T_a \quad (2)$$

where,

G = Theoretical field capacity (ha/h)

E = Area of field (ha)

T_a = Actual time taken in doing the main tillage work (s)

2.4.5 Effective Field Capacity

The effective field capacity measured in ha/h is expressed mathematically as:

$$X_5 = E(3600) / T_t \quad (3)$$

where,

X_5 = Effective field capacity (ha/h)

E = Area of field (ha)

T_t = Total time taken in completing the whole tillage operation (s)

2.4.6 Field Efficiency

Field efficiency is expressed mathematically as:

$$H = (X_5 / G) \times 100\% \quad (4)$$

where,

H = Field efficiency (%)

X_5 = Effective field capacity (ha/h)

G = Theoretical field capacity (ha/h)

2.4.7 Fuel Consumption

The fuel required for each tillage operation was determined by filling the tank to full capacity before and after the test. The amount of fuel used for refilling the tank to full capacity after each test is the fuel consumption for the test. The filling of fuel tank before operation and then refilling after completing the operation is a common method used in the field for determining tractor fuel consumption in litres per hectare. The same method was used by several researchers (Ajav and Adewoyin, 2011; Ikpo and Ifem, 2005; Kudabo and Gbadamosi, 2012; Meshack-Hart, 1997; Sirelkatim et al., 2001; Udo and Akubuo, 2004) in determining tractor fuel consumption in litres per hectare.

Fuel consumption measured in either L/ha or L/h is expressed mathematically as:

$$I = J / E \quad (5)$$

$$K = X_5 \times I \quad (6)$$

where,

I = Fuel consumption (L/ha)

J = Volume of fuel consumed (L)

E = Area of field (ha)

K = Fuel consumption (L/h)

X_5 = Effective field capacity (ha/h)

2.4.8 Travel Reduction (Wheel Slip)

In determining the wheel slip (travel reduction), a mark was made on the tractor drive wheel with coloured tapes. This was used to measure the distance covered by the tractor drive wheel at every 10 revolutions under no load and the same revolution with load on same surface. The travel reduction (wheel slip) measured in % was expressed mathematically as:

$$L = [(M_2 - M_1) / M_2] \times 100\% \quad (7)$$

where,

L = Travel reduction (wheel slip) (%)

M_2 = Distance covered at every 10 revs of the wheel at no-load condition (m)

M_1 = Distance covered at every 10 revs of the wheel at load condition (m)

2.4.9 Tractive Efficiency

Tractive efficiency measured in % is the ratio of drawbar power to wheel power and is expressed mathematically according to (Macmillan, 2002) as:

$$Q_t = (D_p / Q_w) \times 100\% \quad (8)$$

where,

Q_t = Tractive efficiency (%)

D_p = Drawbar power (kW)

Q_w = Wheel power (kW), power losses in the transmission from engine to the wheels of, say 10% is assumed, it can be written as:

$$Q_t = [D_p / (0.9 \times Q_e)] \times 100\% \quad (9)$$

where,

Q_e = Engine power (kW)

2.4.10 Duration of Operation

The duration of operation measured in h/ha which is the time spent in completing the whole operation is mathematically expressed as:

$$X_9 = 1 / X_5 \quad (10)$$

where,

X_9 = Duration of operation (h/ha)

X_5 = Effective field capacity (ha/h)

2.5 Soil Parameters

2.5.1 Soil Bulk Density

Soil bulk density (ρ_b) is a measure of the mass of soil per unit volume and is usually reported on an oven-dry basis. The soil bulk density was determined by the core method described by Blake and Hartge (1986). The core samples were oven dried at a temperature of 105 °C to a constant weight.

$$\rho_b = M_s / (V_T) \quad (11)$$

where,

ρ_b =Soil bulk density (g/cm^3)

Table 1 Pair-wise correlation results of four models' predicted fuel values with observed fuel values during ploughing operation in a sandy loam soil

Models developed	Observed
Model 2	0.809925*
Model 3	0.668831*
Model 4	0.665886*
Model 5	0.595915*

*significant at 5% level when r-value ≥ 0.338788

M_s = Mass of dry soil (g)
V_T = Total volume of soil (cm^3)

2.5.2 Soil Moisture

Klenin et al. (1985) defined soil moisture content as the amount of liquid, usually water, that is present in the soil. It is expressed as a percentage of the mass of water in the soil to the mass of the dried soil (for dry weight classification). The soil moisture content (in dry basis) measured in %, can be expressed mathematically as:

$$Mc = (W_w / W_s) \times 100\% \quad (12)$$

where,
M_c = Soil moisture content (%)
W_s = Mass of oven dried soil (g)
W_w = Mass of water present in soil (g)

2.5.3 Soil Cone Index

The soil cone index (CI) is the soil resistance to penetration and was measured using a cone penetrometer.

2.6 Statistical Tool

2.6.1 Regression Analysis

The multiple linear regression method was used for establishing the relationship that existed between fuel consumption (the model response variable) and other factors (or predictors of fuel consumption) identified to be factors influencing tractor fuel consumption in litres per hectare during ploughing operation in a sandy loam soil. In this study, tractor fuel consumption in litres per hectare was the dependent variable while other factors identified as factors influencing tractor fuel consumption in litres per hectare stands as the independent variables. The model selection method adopted for developing the model for this study was the backward elimination technique.

2.7 Developing Models without Intercept Term

Models with intercept term remain common to all models built round multiple linear regression models. In this study, the assumption was whether a tractor could consume some amount of fuel before commencement of ploughing operation if such variable as air (ambient) temperature could constitute measurable parameters. The study was therefore governed by building models without intercept term because it is the most appropriate model type that fits this study based on refilling-tank method of measuring fuel consumption.

2.8 Model Validation

The model validation method adopted for this study is the cross validation method. This validation method is an extremely flexible

Table 2 Table of parameter estimates for models developed for predicting tractor fuel consumption in litres per hectare during ploughing operation in a sandy loam soil

Model No.	P-value of model	Model multiple R-square value	Model adjusted R-square value	Coefficients	Estimates	Std. error	T-value	P-value
2	4.01e-12	0.6561	0.460	Tractor power rating	0.0696	0.0824	0.84	0.408
				Width of cut	-0.0770	0.0471	-1.63	0.117
				Depth of cut	0.0946	0.1135	0.83	0.414
				Draught force	-0.6432	0.8620	-0.75	0.464
				Effective field capacity	24.8679	16.3571	1.52	0.143
				Tractive efficiency	0.1032	0.2069	0.50	0.623
				Field efficiency	-0.0819	0.0640	-1.28	0.214
				Wheel slip	0.0300	0.0607	0.49	0.627
				Duration of operation	7.6650	3.2410	2.37	0.028*
				Speed of operation	-1.8970	0.8469	-2.24	0.036*
				Average soil moisture content	-0.0699	0.1139	-0.61	0.546
				Average soil bulk density	2.5118	3.3379	0.75	0.460
				Average soil cone index	-0.0347	0.0157	-2.20	0.039*
3.	< 2e-16	0.447093	0.3708	Tractor power rating	0.04319	0.02203	1.96	0.0596
				Width of cut	0.02804	0.01658	1.69	0.1015
				Depth of cut	0.21540	0.09156	2.35	0.0256*
				Effective field capacity	-7.85486	2.60259	-3.02	0.0053*
				Average cone index	-0.00469	0.01123	-0.42	0.6791
4.	< 2e-16	0.440350	0.3844	Tractor power rating	0.0418	0.0215	1.95	0.0610
				Width of cut	0.0267	0.0160	1.66	0.1064
				Depth of cut	0.2125	0.0900	2.36	0.0250*
				Effective field capacity	-7.8545	2.5665	-3.06	0.0046*
5.	< 2e-16	0.352695	0.3325	Depth of cut	0.3759	0.0544	6.91	7.9e-08*
				Effective field capacity	-4.3582	1.9691	-2.21	0.034*

*significant at 5% level

and powerful technique and widely used approach in validation work for estimating prediction error. The measure of error for cross-validation is the mean square error (MSE) for a quantitative response. The 10-fold cross-validation is commonly used. According to Bouckaert (2003), 10-fold cross-validation remains the most widely used validation procedure.

Results and Discussion

3.1 Model Development and Validation

Four models with p-values < 0.05 were statistically developed for predicting tractor fuel consumption in litres per hectare during ploughing operation in a sandy loam soil. Details of the pair-wise correlation analysis showing the results of the correlation strength of these developed models is presented in **Table 1**. Results obtained for parameter estimates and Analysis of Variance (ANOVA) for the four developed models are presented in **Tables 2** and **3**, respectively. Model 2 developed for predicting tractor fuel consumption in litres per hectare during ploughing operation in a sandy loam soil was chosen as the best fuel predictive model because it has the highest coefficient of multiple determination (R-squared) value of 0.6561. The model explains 66% of the proportion of variance in the mean squared errors of tractor fuel consumption for ploughing operation with duration of operation, speed of operation and average soil cone index contributing statistically significantly to the model. In terms of marginal (individual) significance of the predictor variables, results in **Table 3** reveal that tractor power rating, width of cut, depth of cut, effective field capacity and average soil cone index with corresponding p-values of 2.9e-16, 0.0109, 0.0092, 0.0054 and 0.0388, respectively, are statistically significant in the developed model provided others are included in the model. It also implies that they cannot be removed from the model.

The equation used for expressing Model 2 developed for predicting tractor fuel consumption in litres per hectare during ploughing opera-

Table 3 ANOVA table for models developed for predicting tractor fuel consumption in litres per hectare during ploughing operation in a sandy loam soil

Model No.	Source of variation	Degree of freedom	Sum of squares	Means squares	F-value	P-value
2.	Tractor power rating	1	1,253	1,253	515.42	2.9e-16*
	Width of cut	1	19	19	7.80	0.0109*
	Depth of cut	1	20	20	8.24	0.0092*
	Draught force	1	4	4	1.51	0.2324
	Effective field capacity	1	23	23	9.60	0.0054*
	Tractive efficiency	1	0	0	0.15	0.6990
	Field efficiency	1	2	2	0.90	0.3539
	Wheel slip	1	0	0	0.20	0.6631
	Duration of operation	1	7	7	2.82	0.1081
	Speed of operation	1	8	8	3.30	0.0834
	Average soil moisture content	1	1	1	0.22	0.6424
	Average soil bulk density	1	0	0	0.03	0.8707
	Average soil cone index	1	12	12	4.86	0.0388*
	Residuals	21	51	2		
3.	Tractor power rating	1	1,253	1,253	442.47	2e-16*
	Width of cut	1	19	19	6.70	0.0149*
	Depth of cut	1	20	20	7.07	0.0126*
	Effective field capacity	1	26	26	9.11	0.0053*
	Average cone index	1	0	0	0.17	0.6791
	Residuals	29	82	3		
4.	Tractor power rating	1	1,253	1,253	454.98	2e-16*
	Width of cut	1	19	19	6.89	0.0135*
	Depth of cut	1	20	20	7.27	0.0114*
	Effective field capacity	1	26	26	9.37	0.0046*
	Residuals	30	83	3		
5.	Depth of cut	1	1,289	1,289	428.3	2e-16*
	Effective field capacity	1	15	15	4.9	0.034*
	Residuals	32	96	3		

*significant at 5% level

tion in a sandy loam soil as contained in **Table 2** is given as:

$$\hat{Y} = 0.0696X_1 - 0.0770X_2 + 0.0946X_3 - 0.6432X_4 + 24.8679X_5 + 0.1032X_6 - 0.0819X_7 + 0.0300X_8 + 7.6650X_9 - 1.8970X_{10} - 0.0699X_{11} + 2.5118X_{12} - 0.0347X_{13}$$

where,

$\hat{Y}$ = Tractor fuel consumption (L/ha)

X_1 = Tractor power rating (hp)

X_2 = Width of cut (cm)

X_3 = Depth of cut (cm),

X_4 = Draught force (kN)

X_5 = Effective field capacity (ha/h)

X_6 = Tractive efficiency (%)

X_7 = Field efficiency (%)

X_8 = Wheel slip (%)

X_9 = Duration of operation (h/ha)

X_{10} = Speed of operation (km/h)

X_{11} = Average soil moisture content (%),

X_{12} = Average soil bulk density (g/cm^3)

X_{13} = Average soil cone index (N/cm^2).

The model equations generated for each developed model were used for predicting tractor fuel consumption in litres per hectare using the model development dataset complied by Oyelade (2016). Results of the predicted fuel values obtained for the four different developed models are presented in **Table 4**. The values for

Table 4 Results of predicted tractor fuel consumption values in litres per hectare during ploughing operation in a sandy loam soil using the four developed models

Tractor observations	Observed fuel values (L/ha)	Models developed							
		2		3		4		5	
		Predicted fuel values (L/ha)	Residual (L/ha)	Predicted fuel values (L/ha)	Residual (L/ha)	Predicted fuel values (L/ha)	Residual (L/ha)	Predicted fuel values (L/ha)	Residual (L/ha)
1	4.92	4.504932	0.415068	4.012308	0.907692	4.039407	0.880593	3.983409	0.936591
2	5.9	4.738817	1.161183	4.277951	1.622049	4.333797	1.566203	4.50484	1.39516
3	8.7	6.704515	1.995485	6.049063	2.650937	5.911631	2.788369	7.255713	1.444287
4	2.84	3.404142	-0.56414	3.654674	-0.81467	4.030153	-1.19015	4.351823	-1.51182
5	8	7.441957	0.558043	6.77359	1.22641	6.902695	1.097305	7.064	0.936
7	5.4	7.231962	-1.83196	6.826732	-1.42673	6.781448	-1.38145	7.692533	-2.29253
8	4.5	6.034616	-1.53462	5.99809	-1.49809	6.092008	-1.59201	6.097549	-1.59755
9	6.8	5.619735	1.180265	7.331446	-0.53145	7.198159	-0.39816	6.868998	-0.069
10	5.3	5.427223	-0.12722	5.775078	-0.47508	5.889235	-0.58923	6.875971	-1.57597
11	3.6	6.064586	-2.46459	6.24955	-2.64955	6.137243	-2.53724	5.899346	-2.29935
12	5.9	5.878337	0.021663	5.709825	0.190175	5.592534	0.307466	6.161659	-0.26166
13	6.65	5.614693	1.035307	5.375527	1.274473	5.358725	1.291275	4.870159	1.779841
14	2.32	3.211174	-0.89117	2.596168	-0.27617	2.660781	-0.34078	3.247984	-0.92798
15	2.96	4.969718	-2.00972	6.293663	-3.33366	6.251716	-3.29172	5.376933	-2.41693
16	8	6.004281	1.995719	7.139911	0.860089	7.23522	0.76478	6.663533	1.336467
18	3	5.906286	-2.90629	6.830996	-3.831	6.912452	-3.91245	7.374137	-4.37414
19	9	8.321294	0.678706	6.435052	2.564948	6.551724	2.448276	6.33236	2.66764
21	6.8	6.887992	-0.08799	7.63841	-0.83841	7.599358	-0.79936	8.268947	-1.46895
22	6.3	6.742895	-0.44289	7.278797	-0.9788	7.21952	-0.91952	6.456614	-0.15661
23	6.8	5.705672	1.094328	5.80083	0.99917	5.892009	0.907991	5.958618	0.841382
24	5	5.495992	-0.49599	6.319763	-1.31976	6.37745	-1.37745	6.013724	-1.01372
25	6	4.279325	1.720675	5.061182	0.938818	5.101503	0.898497	5.980515	0.019485
26	7	7.220535	-0.22054	5.788542	1.211458	5.682744	1.317256	5.848152	1.151848
27	6	6.970787	-0.97079	6.316868	-0.31687	6.225816	-0.22582	5.887356	0.112644
28	6.33	5.91589	0.41411	6.707189	-0.37719	6.597298	-0.2673	7.382101	-1.0521
29	6.67	6.065741	0.604259	5.509166	1.160834	5.417425	1.252575	5.047366	1.622634
30	3.6	4.701902	-1.1019	4.254556	-0.65456	4.304744	-0.70474	4.689992	-1.08999
31	5	3.786904	1.213096	4.088668	0.911332	4.230469	0.769531	4.135871	0.864129
32	7.04	7.717204	-0.6772	5.347574	1.692426	5.148201	1.891799	4.603456	2.436544
33	5.16	5.312685	-0.15269	5.528327	-0.36833	5.722003	-0.562	4.644984	0.515016
34	13.33	12.72252	0.607483	10.50451	2.825485	10.60235	2.727653	9.630453	3.699547
35	8	6.894283	1.105717	7.906482	0.093518	7.719946	0.280054	7.729835	0.270165
36	6.8	7.524664	-0.72466	8.208617	-1.40862	8.132635	-1.33263	7.489121	-0.68912
37	6.67	5.448528	1.221472	6.203405	0.466595	6.15697	0.51303	4.855605	1.814395

Note: Tractor observations 6, 17 and 20 meant for POWERTRAC 455, YTO-704 and MAHINDRA 705 DI tractors were not included because they contain potential outliers both observed and predicted tractor fuel consumption as shown in **Table 4** for Model 2 were correlated together, and gave a correlation coefficient of 0.809925 as shown in **Table 1**. According to the rule of thumb as provided in http://www.westgard.com/lesson42.htm for evaluating correlation coefficient, noted that size of r with correlation values between 0.70 and 0.89 are said to show high correlation. This indicates that tractor fuel consumption prediction values of Model 2 in litres per hectare during ploughing operation in a sandy loam soil is highly correlated with the observed tractor fuel consumption values in litres per hectare obtained during ploughing operation in a sandy loam soil. **Fig. 1** shows the plot of observed and predicted tractor fuel consumption values using Model 2 developed for predicting tractor fuel consumption in litres per hectare during ploughing operation in a sandy loam soil.

3.2 Predictors for the Best Developed Model

The results of parameter estimates and Analysis of Variance (ANOVA) for the best model developed for predicting tractor fuel consumption during ploughing operation in a sandy loam soil as shown in **Tables 2** and **3**, respectively, have revealed that the best model developed for predicting tractor fuel consumption during ploughing operation in a sandy loam soil contain some important predictors found to be significant at 5% level. These predictors include tractor power rating, width of cut, depth of cut, effective field capacity, duration of operation, speed of operation and average soil cone index. These seven set of predictors are ploughing operation parameters affecting tractor fuel consumption in litres per hectare during ploughing operation in a sandy loam soil. Among these seven ploughing operation parameters affecting tractor fuel consumption in litres per hectare during ploughing operation in a sandy loam soil, ploughing operation parameters such as tractor power rating, depth of cut and effective field capacity contributed highly to the model developed. Therefore, these three ploughing operation parameters, namely, tractor power rating, depth of cut and effective field capacity strongly determine tractor fuel consumption in litres per hectare during ploughing operation on a sandy loam soil.

3.3 Model Validation for the Developed Models

Results of 10-repeated 10-fold cross-validation method used for validating the four models developed for predicting tractor fuel consumption in litres per hectare during ploughing operation in a sandy loam soil are presented in **Table 5**. It can be deduced from **Table 5**, that Model 2 gave the least root mean square error (RMSE) of 1.396169 L/ha serving as the model's test error value using the four model validating dataset presented in **Table 6**. This test error value of 1.396169 L/ha is equivalent to 23.02% of the observed fuel value.

Fig. 1 Plot of observed and predicted tractor fuel consumption using model 2 developed for predicting tractor fuel consumption during ploughing operation in a sandy loam soil

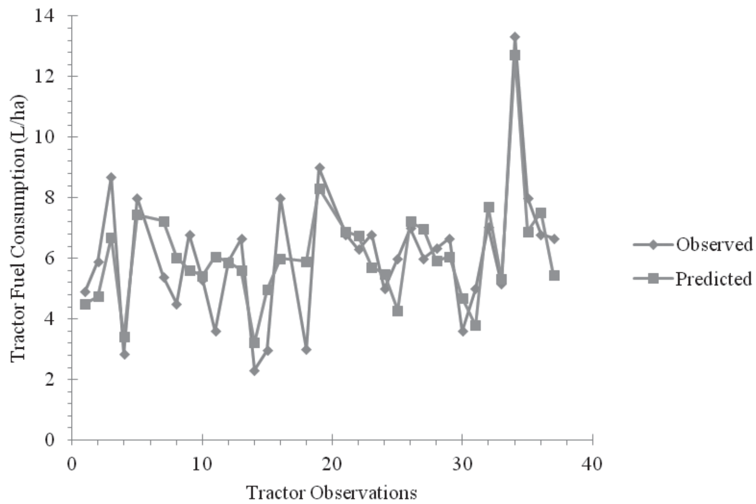

Table 5 Results of 10-repeated 10-fold cross-validation for the four developed Models

Replicate No.	Models developed for ploughing operation			
	2	3	4	5
1.	1.949211	2.792198	2.831958	2.912375
2.	1.94913	2.792403	2.832152	2.912221
3.	1.949481	2.792417	2.832133	2.912761
4.	1.949877	2.793022	2.832733	2.913029
5.	1.949671	2.793667	2.833414	2.912854
6.	1.948958	2.793028	2.832708	2.913275
7.	1.949406	2.792267	2.832067	2.911927
8.	1.948969	2.792082	2.831893	2.91237
9.	1.94896	2.792328	2.832261	2.912773
10.	1.949211	2.792198	2.831958	2.912375
Average MSE (L^2ha^{-2})	1.949287	2.792561	2.832328	2.912596
Average RMSE (Lha^{-1})	1.396169	1.671096	1.682952	1.706633

MSE – Mean square error, RMSE – Root mean square error
Note that each replicate contains the average mean square error value of 10-fold cross-validation

Conclusion

A study was carried out to develop a model for predicting tractor fuel consumption in litres per hectare during ploughing operation in a sandy loam soil using information gathered from NCAM Tractor Test Reports. From the outcome of this study, it is safe to conclude that:

1. Four effective models with p-values < 0.05 were developed for predicting tractor fuel consumption in litres per hectare during ploughing operation in a sandy loam soil. Model 2 among the four models developed with the highest coefficient of multiple determination (R-squared) value of 0.6561 was found to be the best model for predicting tractor fuel consumption in litres per hectare during ploughing operation.
2. Ploughing operation parameters such as depth of cut, duration of operation, effective field capacity, tractor power rating, width of cut, speed of operation and average soil cone index were found to be statistically significant at 5% level in Model 2 with tractor power rating, depth of cut and effective field capacity contributing highly to the model developed.
3. The best model for predicting tractor fuel consumption in litres per hectare during ploughing operation in sandy loam soil based on cross-validation result had a test error of 1.396 L/ha. This test error value is equivalent to 23.02% of the observed fuel value.

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Table 6 Results of Predicted and Residual Fuel values of the developed Models during Model Validation

Tractor observation No.	Observed fuel values (L/ha)	Models developed							
		2		3		4		5	
		Predicted fuel values (L/ha)	Residual (L/ha)	Predicted fuel values (L/ha)	Residual (L/ha)	Predicted fuel values (L/ha)	Residual (L/ha)	Predicted fuel values (L/ha)	Residual (L/ha)
38.	7.12	4.612495	2.507505	4.069519	3.050481	4.209221	2.910779	4.294018	2.825982
39.	3.40	4.816193	-1.416193	4.431772	-1.031772	4.722796	-1.322796	4.339565	-0.939565
40.	5.04	6.496771	-1.456771	7.169993	-2.129993	7.430002	-2.390002	6.736545	-1.696545
41.	8.68	6.599781	2.080219	7.224233	1.455767	7.398638	1.281362	7.606503	1.073497

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Design and Development of a Double Peeling Machine for Watermelon


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Abstract

The skin and rind of watermelon (*Citrullus lanatus*) are considered by-products and are mostly unutilized. An automatic watermelon peeling machine was designed and developed, which is capable of double peeling viz. first the skin and then grating the rind in a single run. The design is based on the concept of lathe-machining, which was applied for the fruit peeling with change in the machining axis. The unit was capable of peeling fruits up to 500 mm in height and 250 mm in diameter, and had capacity of 24 ± 2 fruits per hour. It removed two layers of desired thickness through adjustable spring loaded axial thrust and radial force arrangements in a single motion. The fruit was rotated (0.25 hp, 70 rpm) and at the same time a peeling blade moved parallel to the vertical axis of the fruit and peeled/grated it. The designed peeler had an average skin peeling efficiency of 81.62%, rind peeling efficiency of 81.08% and flesh wastage of 4.98%.

Keywords: watermelon, peeling, trident, rind, pneumatic, peeling efficiency, flesh loss

Introduction

Watermelon (*Citrullus lanatus*) is one of the important horticultural crops belonging to the family Cucurbitaceae. Watermelon is consumed as a dessert, fruit salad or processed as drinks. It is a natural source of carotenoid lycopene, phenolic antioxidants; immune-supportive vitamin C, amino acid, etc. Additionally, water melon is an excellent source of vitamin A, potassium and magnesium. Watermelon can be viewed as a nutritious alternative to energy drinks or supplements prior to exercise (Picha, 1986; Pons, 2003; Perkins and Collins, 2004).

Watermelon is botanically a fruit, a fleshy berry with tissues derived from the pericarp. The flesh is used as extraction for human consumption while peel and rind are considered as by-products (Bawa and Bains 1977; Crandall and Kesterson, 1981; Gowda and Jalali 1995; Chahal and Saini 1999). Watermelon rind constitutes nearly a third of the watermelon weight. More than 90% of the rind is discarded indiscriminately into the environment thereby constituting environmental challenges (Picha, 1986; Pons, 2003). Chemically rind has moderate total phenolic content and high content of the citrulline (3.34 and 2.33 g/kg respectively). The rind can used for extraction of pectin and citrulline, an amino acid that helps to remove nitrogen from the blood for conversion to urine (Muhamad, 2014; Perkins and Collins, 2004; Pons, 2003). Several possibilities exist for the use of watermelon rind to produce value-added products such as pickle, candy and development of dehydrated cubes/flakes/shreds for curry purposes (Huor et al., 1980; Uddin and Nanjundaswamy, 1982; Afoakwa et al., 2006; Hanan and Ahmed, 2013).

Mechanical peeling, over manual peeling, is preferred because of certain advantages such as low damage to the flesh and enhanced freshness of peeled produce, low environmental pollution, and possibility of utilization of by-products of the fruit (Emadi et al., 2008). During mechanical peeling, the products are loaded with unwanted mechanical loads (compression, impact, shearing and vibration) which results in bruising of the fruits (Emadi et al., 2008; Sadrnia et al., 2008; Adekunle et al., 2009; Ajibola and Babarinde, 2016). Peeling loss in mechanical methods occur due to irregular weight, size and shape of produce, variation in the texture of skin/peel, rind and flesh and low flexibility of the machine. Thus, it is difficult to design a peeling machine that is capable of efficient peeling due to wide differences in properties from various sources. An effort has been made to develop a watermelon peeling machine capable of double peeling, so that the rind and skin are removed separately.

Theoretical Considerations

Principle of Operation of the Peeling Machine

Peeling operation can be mechanised by applying fruit to a device operating on the principle of a lathe, with the fruit being mounted between spikes and with one or more fixed or rotary tools being brought to the periphery of the fruit in order to imitate manual peeling, i.e., in order to detach a continuous piece of layer (Khurmi and Gupta, 2008). The concept of machining on lathe was used for fruit peeling with change in the machining axis from horizontal to vertical (**Fig. 1**). Majority of fruits have a uniform peel thickness throughout their surface from the pole, where, the fruit can be attached to the peduncle, to the opposite pole and a continuous peeling of skin and rind of desired peel thickness (between 2-10 mm) can be done.

The cutting forces, resulting from feeding the fruit from top to bottom, removed a surface layer of the fruit in the form of peels and would consist of three components:

1. Main cutting force (F_c): - It acts in the direction of peeling speed and is created by peeling knife.
2. Feed force (F_f): - It acts in feed rate direction due to rotation of the fruit
3. Thrust force (F_r): - It acts normal to the peeling speed. It is created due to translational movement of the fruit

Design Consideration

Following considerations were made in the design the watermelon peeler.

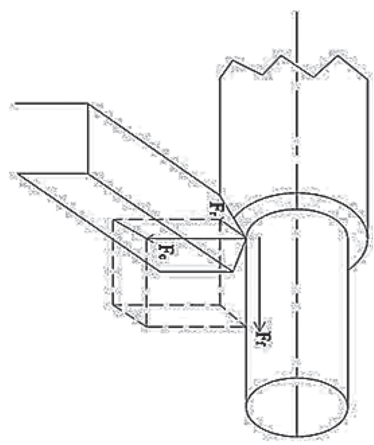
a. The designed capacity of machine was 24 ± 2 fruits per hour considering view point of handling time on machine.
b. The peeling time of 150 seconds per fruit was considered adequate including the time for placing the fruit on trident and release of fruit by cutting the fruit.
c. The peeler can be peeling the watermelon of length 500 mm and 250 mm diameter.
d. The width of peel to be removed per rotation of ball screw is 5 mm i.e. pitch of the ball screw.
e. The axial velocity of the arm of the peeling blade should be minimum so that the peeling operations can be closely observed; hence the motor of 70 rpm were used for revolving trident and to drive the screw ball shaft for transverse movement of peelers.
f. Stainless steel (SS304) was used as fabricating materials for parts which are in contact with the fruit in order to avoid any chemical reaction between the fruit and material of construction.
g. Simple, easy inspection, serviceability, portability and maintenance of the machine.

Description of Machine

The developed machine is a multifunctional apparatus which can peel, grate and cut the fruit. The combination of the three functions (peel, grate and cut) differentiates this apparatus from other available peelers/pulpers in the market. It can act as a useful machine to automatically peel and pulp the fruits without using manual instruments that will contribute in reducing time and effort. The amalgamation between the three functions which are peeling, grating and cutting has contributed to the reduction of operating time. The aim of combining these unit operations into one has resulted in diminished operating cost.

The peeling machine comprised a

Fig. 1 Cutting forces acting on the fruit during peeling operation



clamping mechanism, peeling blade, movable arm and also a pair of end-cutting blades. The fruit was held at its both ends between a revolving support and at the same time a peeling blade started to move parallel to the vertical axis of the fruit which enabled the contact between the peeling blade and the fruit (Olusegun and Adekunle, 2008; Mazlina et al., 2010; Singh et al., 2013; Imonifewo, 2015; Thongsroy and Klajring, 2015). The fruit was peeled using the peeler which had sharp edges on the curve surface. The fruit was peeled progressively by the combination of arm and peeling blade which moved on the fruit profile. After the fruit peeling, both the fruit ends were cut by moving the end-cutting knives by movement of holding arm towards the fruit. The complete unit was automated using electronic circuits and sensors. The structural setup is briefly described as follows:

a. Trident: The trident was set on the machine body to support the fruit to be peeled and cut. It gripped the fruit making it spin along with it.

b. Pushrod: The pushrod was opposite to the trident and on the same axis. It can be moved by adjusting the pressure in the pneumatic cylinder. It held the fruit up to enable the rotation and also to push the fruit against the trident.

c. Peeling blades: The peeling blades (2 Nos.) were situated on the movable arm and their function was to peel the fruit skin and rind. They must be made in contact with fruit to peel the fruit as per the penetration (depth) required.

d. Arm: The arm was situated on a sliding vector and it moved parallel to the fruit rotation axis. It supported the peeling blade, which peeled the fruit twice; an elastic system pressed the arm softly on the fruit and held the peeling blade position against the fruit. The arm enabled the peeling blade to move on the profile of the fruit, so that the fruit can be completely peeled.

e. End-cutting blade: A pair of end-cutting knives was situated on another handle operated by pneumatic action and its function was to cut the fruits ends.

f. Pneumatic cylinders: The actuation of the pressure plate was linked to a pneumatic cylinder piston reciprocatory motion. The fruit holding pressure and end cutting knives pressure were regulated using pneumatic cylinders. The pneumatic cylinder delivered a piston stroke for a set pressure, controlled by the micro-controller.

Design Analyses and Calculations

Power Requirement for Rotating the Trident

The power requirement for peeling on revolving trident can be calculated using the equation adapted from Jones and Kisher (2005) as:

$$Ps = T_s\ \omega_s = = F_s\ r_s(2\pi N_s) / 60 = T_s(2\pi Ns) / 60 \quad (1)$$

Where, P_s = power, watts; T_s = total torque required for peeling, N-m; ω_s = angular velocity of the shaft attached to motor, rad per sec; N_s = motor rpm; F_s = total force required for peeling, N; r_s = radius of watermelon fruit, m

But, $F_s = F_{s1} + F_{s2}$ (2)

Where, F_{s1} = cutting force required for peeling the skin of watermelon, N; F_{s2} = cutting force required for peeling the rind of watermelon, N.

From textural analyser, it was found that F_{s1} = 79.87 N and F_{s2} = 55.27 N, therefore, the total force (F_s) required to perform complete peeling operations was determined from Equ (2) was 135.42 N. Torque (T_s) power required and for peeling was calculated from equation Equ 1 were 20.27 N-m and 148.511 W respectively. Considering 25% motor drive efficiency, the required motor power to drive the system was 0.186 kW or 0.248 hp. A single phase 0.25 hp electric motor with a rated speed of 70 rpm was chosen for the peeling into account the friction and other losses.

Power Requirement for Screw Ball Shaft

Ball screws shafts are used to transform rotary motion from an electric motor into linear motion of a carriage (Oyawale and Adeniyi, 2009; Mazlina et al., 2010; Imonifewo, 2015). The kinematics of screw ball shaft is simple. The product of the rotation θ (radians) of either the screw or the nut (one rotates the other not) and the thread lead (distance/revolution) results in the translation of the other element (Khurmi and Gupta, 2008).

$$x = l\theta / 2\pi \quad (3)$$

Where, x = axial translation, m; θ = angle of rotation, θ; l = thread lead, m. The ball screw used under the study had a diameter 30 mm, pitch = thread lead = 5 mm, length 1200 mm and thread angle of 30°. Thus, from Eqn (3), for one complete rotation of the ball screw the axial distance covered is the thread lead.

Similarly, the product of the angular speed (radians/second) and lead equals the translation speed (v),

$$v = l\omega / 2\pi \quad (4)$$

Where, v = translational speed, m/s; $\omega = 2\pi N/60$ = angular speed, rad/s.

The translational speed of the screw for one rotation from Eqn (4) was calculated as v = 5.88 mm/s

There must be a critical state of friction and thread geometry where an axial force on one member can just cause the other member to rotate. This condition, known as back driveability, means that rotation cannot occur when a force is applied if the lead is smaller than a critical value (Khurmi and Gupta, 2008).

$$l \le \pi\mu D_{pitch} / \cos\alpha \quad (5)$$

Where, α = thread angle (30 degrees for standard bolt); μ = coefficient of friction (0.1 for greased threads, (Stanley and Guthrie, 1998). Putting the values in Equ (5), we get $l \le \pi\mu D_{pitch} / \cos\alpha$ = 1.36 mm which is less than 5 mm.

Power required for driving the screw balls can be calculated using the equation given by Khurmi and

Gupta, 2008.

$$P_p = T\omega = T(2\pi N_1 / 60) = W_r\,(2\pi N_1) / 60 \quad (6)$$

Where, T = torque (Nm); ω = angular speed (rad/sec); N_1 = speed of screw ball shaft, rpm; W = total weight of carriages, peeler arms, peelers, spring loading arrangements and pneumatic cylinders, N; r = distance of centre of gravity (c.g.) of all weights from screw centre, m. Measured weight of carriages (w_1), peeler arms (w_2), peelers (w_3), spring loading arrangements (w_4) and pneumatic cylinders (w_5) are 32.16, 28.14, 4.41, 37.35 and 14.32 N respectively.

Thus, $W = w_1 + w_2 + w_3 + w_4 + w_5 = 116.38$ N

Distance of screw centre from c.g. of each carriage (x_1), peeler arms (x_2), peeler (x_3), spring loading arrangement (x_4) and pneumatic cylinders (x_5) are 133, 98, 48, 283 and 177 mm.

Thus, $r = (w_1x_1 + w_2x_2 + w_3x_3 + w_4x_4 + w_5x_5) / (w_1 + w_2 + w_3 + w_4 + w_5) = 174.87$ mm.

From Eqn (6), T = 20.35 N-m and Pp = 149.11 W.

Considering 25% drive efficiency, power of the prime mover = 186.36 W = 0.189 kW. Power from the motor was transmitted to the shaft of the rotating trident through coupling arrangement.

Revolving Trident

Three cone-shaped structures (dia 16 mm; height 32 mm) forming shape of a conical trident (**Fig. 2a**) was mounted on a circular base. The trident gripped and supported the fruit held on it. A cone-edged pushrod opposite to the trident and on the same axis pushed the fruit against the trident and gripped the fruit firmly during rest and in rotational motion. Thus, this arrangement having two opposing ends firmly secured any spheroid fruit such as watermelon during rotation.

The pushrod was actually the shaft of the pneumatic cylinder (Techno India, New Delhi; model SC50X400) with a pointed cone (SS304) fitted at its end. For the present study, pneumatic cylinder of pressure range 147-785 kPa was selected based on the textural property of the watermelon as pressure above 785 kPa can burst the watermelon longitudinally due to excess load acting on it. The end of the pushrod along with the cone was attached to another movable aluminum casted frame which moved up and down with the reciprocating action of pneumatic cylinder (**Fig. 2b**).

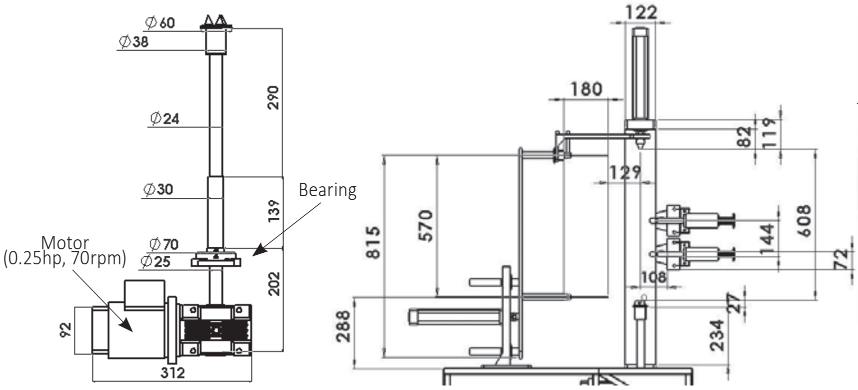
End-cutters

The function of pair of end-cutting knife was to cut the peeled fruits ends so that it may be dislodged from its position and fall on steep ramp (**Fig. 3**). The two knives were positioned near the two ends of the fruit and movement was provided to each knife through separate pneumatic arrangements. The pneumatic cylinder, knife holder, linear motion supports (2 Nos.) and the two shafts were supported on aluminum casted support frame. The knife holder moved towards the fruit by the push imparted from the pneumatic piston reciprocatory motion (Techno India, New Delhi; model SC50X100; stroke length 100 mm 147.1-784.5 kPa).

The upper knife was hung on the movable aluminum casted frame which was pushed towards the fruit by the knife holder attached to the shaft of the pneumatic cylinder. The knife was positioned 10 mm below the tip of the cone-edged pushrod. Thus, this knife would cut the fruit at the top 10 mm below the pushrod independent of the size of the fruit. This knife was also moved towards the fruit by the push imparted by the knife holder through pneumatic action. However, when the pneumatic push was released, the knife came to its initial position through elastic/ spring loaded arrangement.

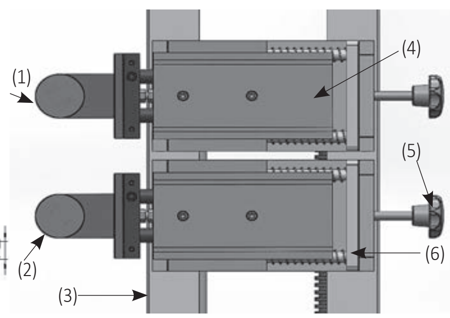
When the pneumatic cylinder is actuated, the knives were forced to move ahead towards the fruit piecing it through its profile. But due to the rotational motion of the fruit on the revolving trident, the fruit was cut starting from outer part to the centre of the fruit. The knives were adjusted by the electronic based automation to stay at its extended position for 15 second to endure the complete cutting of fruit at this end.

Fig. 2 Schematic view of drive mechanism of rotating trident and end cutting knives



(a) (b)

Fig. 3 Pictorial view of peeling assembly



1. Threaded thrust regulator, 2. Peeling arm holder, 3. Slider, 4. Pneumatic cylinder, 5. Thrust adjusting knob, 6. Limiter

Support Frames

The aluminum casted frame at the bottom of the structure had two holes to support ball screw shaft and stainless steel shaft. The ball screw shaft supported the aluminum casted carriage frame through a linear motion nut. The height of the side frames was selected based on the maximum length of watermelon for which the peeling unit was designed. The required height (H_1) of the side frame can be determined by

H_1 = maximum height of the watermelon + limit switch at the top + distance between the two carriage + height of pushrod on which trident was mounted from base = 520 + 53 + 144 + 234 = 951 mm (7)

Spring Loaded Thrust Mechanism

The function of this mechanism was to ensure a varying thrust towards the fruit during the peeling operation. The fruit being biological in nature may have varying hardness throughout its profile. This hardness varies with peeling depth i.e. outer skin, rind or pulp. For skin which have greater magnitude of hardness require higher thrust towards the fruit during peeling while the rind require lesser thrust which further decreases with the depth of peeling. A varying thrust ensures a varying thrust will regulate the depth of peeling irrespective of the hardness of the fruit during peeling. The trust can be pre- adjusted through the spring (spring constant 1.2 N/mm) compression arrangement via tightening screw. The pitch of screw thread was 1.5 mm, hence, one complete rotation of the screw (i.e. pitch) will add 1.8 N force on fruit The limiter was pressed against the spring through the tightening screw which adjusted the required thrust against the fruit being peeled (**Fig. 3**). Higher the thrust required, more will be the tightening of screw knob. The thrust was delivered to the fruit through the peeling arm holder mounted on the shafts of the pneumatic cylinder. Separate adjustment was made for each peeler arm.

Peeling Arm

The arm was mounted on peeler holder and was situated on a sliding vector and it moved parallel to the fruit rotation axis. The peeler blade was mounted at one end of the cuboid shaped part while the cylindrical part acted as piston to the threaded cylindrical controller (**Fig. 4a**). The peeling blades peeled the fruit twice through spring loaded elastic system which pressed the arm softly on the fruit and held the peeling blade position against the fruit. The arm enabled the peeling blade to move on the profile of the fruit, so that the fruit can be completely peeled.

Peeling Arm Holder

It is a cylindrical casing which supports the peeling arm at one end and the threaded cylindrical controlled (**Fig. 4a**, **Fig. 5**) at the other. A spring (spring constant 0.52 N/mm) was placed between the arm and the controller whose elongation/ compression depend upon the number of threads moving inside the holder. The pitch of screw thread was 1.5 mm, hence, one complete rotation of the screw (i.e. pitch) will add 0.75 N force on fruit. The elongation or compression of spring determines the elastic force acted by the spring on the peeler arm as the other end is fixed. The spring compression can be regulated by lateral movement of the controller inside the holder through thread.

Peeling Knife

The peeling blade is shaped like

Fig. 5 Schematic view of the spring loaded force adjustment mechanism

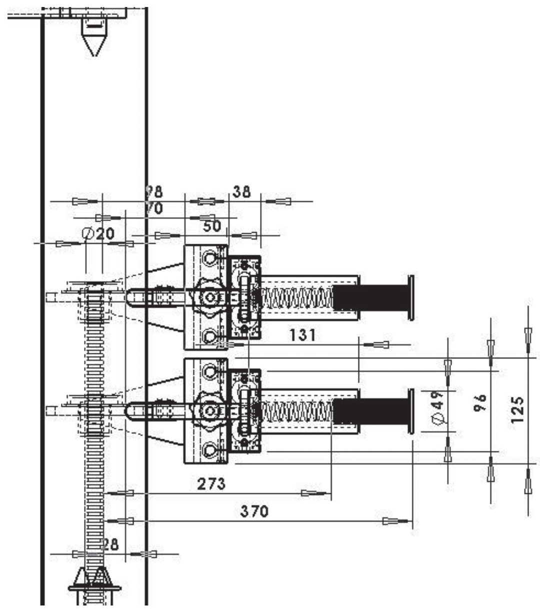
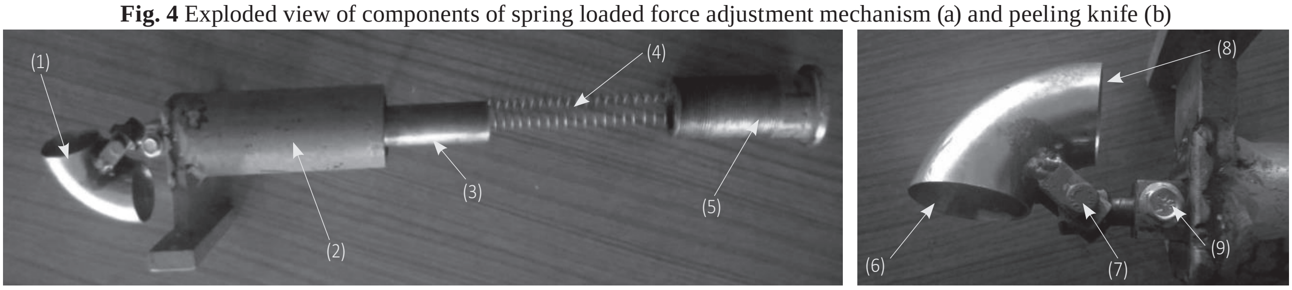


Fig. 4 Exploded view of components of spring loaded force adjustment mechanism (a) and peeling knife (b)



(a) (b)

1. Peeler, 2. Peeling arm holder, 3. Peeling arm, 4. Spring, 5. Thrust controller, 6. Sharpened edges act as peeler, 7. Adjustment for providing angle to peeler, 8. Outlet end, 9. Adjustment for changing lateral movement to peeler

pipe bend (SS 304). One end of the bend (circular face) is sharpened at its edges. This sharpened edges act as peelers. The other open end of the bend act as outlet for the peeled skin/rind. The bend is attached to the peeler arm through nut and bolt arrangement (**Fig. 4b**) Provisions have been made to change the slope of the bend and to change the projection of the peeling face towards the fruit. During peeling, the bend is adjusted is such a manner that it provides a force tangentially to the surface of the fruit thus enabling the spring loaded mechanism to actuate.

Performance Evaluation of Peeling Machine

Performance evaluation of the developed peeling unit (**Fig. 6** and **Fig. 7**) was conducted. The machine made use of two peeling blades which were spring loaded and these peeling blades were fixed to the peeler arms which peeled the fruit body to a pre-set depth. The first peeling blade removed the skin of the watermelon while the second peeling blade removed the rind (**Fig. 8**). Each experiment was replicated for twelve fruits (Oluwole and Adio, 2013; Akintunde et al., 2005).

i) Skin peeling efficiency (%) = (Weight of skin peeled by machine × 100) / Total weight of the skin (8)

ii) Rind peeling efficiency (%) = (Weight of rind removed by machine × 100) / Total weight of the rind (9)

iii) Percentage flesh loss (%) = (Weight of flesh removed by machine × 100) / Total flesh of the fruit (10)

The data recorded was laid out in factorial completely randomized design and was statistically analysed at 5% level of significance.

Results and Discussion

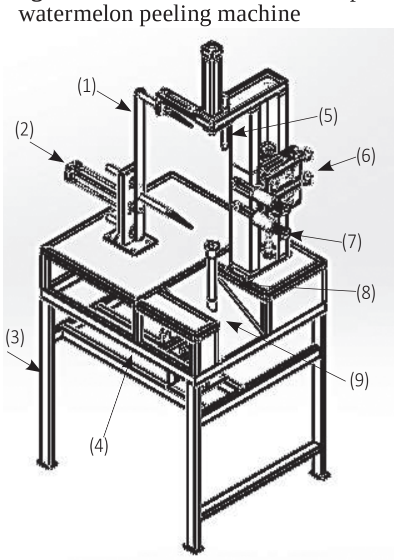
The performance evaluation of watermelon peeling machine was evaluated for different heights of fruits for double peeling operation (**Table 1**). The peeling depth of the fruit or the thickness of peeled skin was adjusted to 2.0 mm while that for rind was adjusted to 4 mm through the separate peeling blades. However, the thickness can be changed as per requirement with the spring loaded force and thrust arrangement provided in the machine. The mass and height of fruit fed into the machine, mass of skin and mass of rind removed, mass of peeled fruit and time taken for peeling were recorded.

It was seen that the machine successfully peeled the skin and grated the rind. The average time to peel and grate the fruit depend on the size and shape of the fruit tested. Smaller fruits were peeled faster than the larger ones. The peeling rate from Eqn (4) was 5.88 mm/s and hence a fruit having a height ranging from 150 to 300 mm took peeling time between 50 to 75 second. The average skin peeling efficient, rind peeling efficiency and flesh loss percentage for twelve fruits were found to be 81.62, 81.08 and 4.98%, respectively (Adetan et al., 2005; Emadi et al., 2008).

From **Table 1**, it was seen that the effect of height on skin peeling efficiency was significant at 5% level of significance while the effect was non- significant for rind peeling efficiency and percent flesh loss. This shows that the rind peeling efficiency and percent flesh loss are unaffected by the change in height of watermelon and the peeling machine was equally efficient for these two parameters for different sized watermelon. The low coefficient of variation supports the marginal variation in machine performance parameters with height.

From **Fig. 9**, it can be seen that watermelon with larger height had greater skin peeling efficiency, lower flesh loss percentage, but least rind peeling efficiency. Skin peeling and rind peeling efficiency was least for low mass fruit. This may be due to losses incurred at the two ends of the fruit which were used to grip the fruit and hence remained unpeeled.

Fig. 6 Isometric view of the developed watermelon peeling machine



1. End cutters, 2. Pneumatic cylinder, 3. Frame, 4. Electric motors, 5. Adjustable fruit holding arm, 6. Actuator and pneumatic system for peeling, 7. Peelers, 8. Rotating trident, 9. Ramp for end-cut peeled watermelon

Fig. 7 Complete setup of watermelon peeling machine

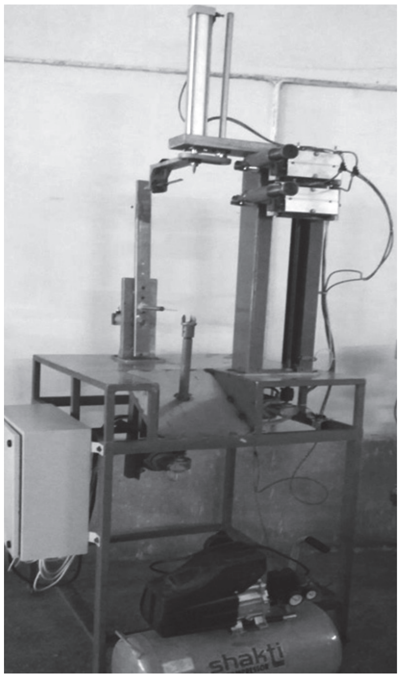


Table 1 Statistical analysis to determine the effect of height on performance parameters of the developed watermelon peeling machine

Source of variation	Fcal	Ftab	Test of significance	Mean	Standard deviation	Critical difference	Coefficient of variation
Skin peeling efficiency	6.194	5.153	*	81.62	1.20	1.91	1.44
Rind peeling efficiency	2.791	5.153	NS	81.08	0.611	0.97	0.37
Percent Flesh loss	1.457	5.153	NS	4.98	0.674	1.07	0.46

*5% level of significance; NS non-significant

Hence, it can be concluded that the developed peeling unit is best suited for watermelon of height ranging between 250 to 300 mm with their respective mass between 3 to 3.75 kg.

Conclusions

An automatic watermelon double peeling machine was developed and tested. The new apparatus made fruits peeling and grating process more efficient i.e. rind will be grated after the skin peeling process and it is done within the same apparatus. The developed peeling machine was capable of peeling variable sizes of watermelons and was low cost, fast, efficient, simple and required less processing time. The unit has a peeling capacity of 24 ± 2 fruits (i.e. 75 ± 5 kg) per hour with an average skin peeling efficiency of 81.62%, rind peeling efficiency of 81.08% and flesh wastage of 4.98%. However, maximum skin peeling efficiency (84.92 %) and rind peeling efficiency (82.95 %) can be obtained for watermelon of larger height (250-300 mm).

Fig. 8 Line diagrams of the developed watermelon peeling machine

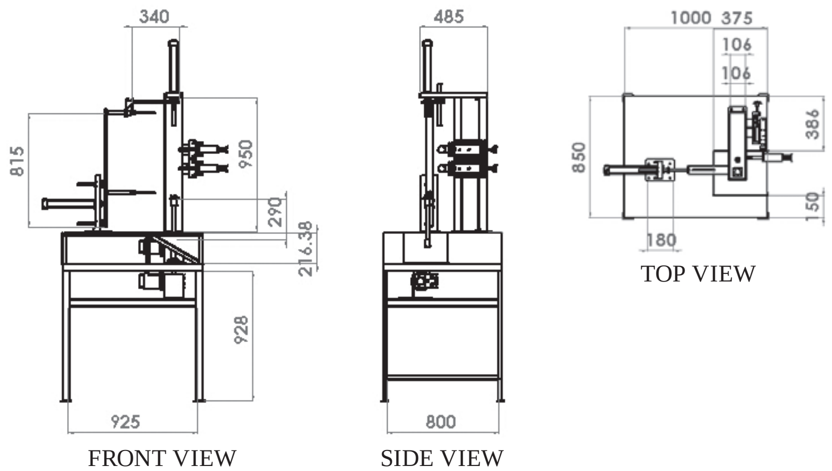
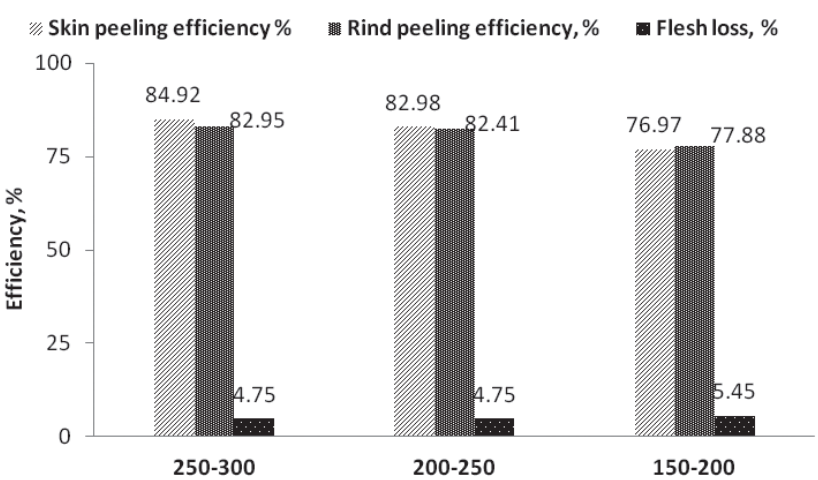


Fig. 9 Performance evaluation of peeling machine w.r.t. size of the watermelon



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Shelflife Extension of Jew's Mallow by Means of a Modified Evaporative Cooler

by

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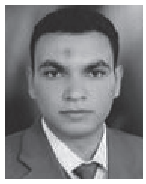

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Abstract

An evaporative cooling system was manufactured and constructed at Rice Mechanization Center (RMC) at Meet Eldeebah village, Kafr Elsheikh Governorate, Egypt to extend the storage life of fresh Jew's mallow (variety of Alaskndrany). The main aim of the current investigation was to assess the locally developed evaporative cooler. Measurements of air temperature and relative humidity for both the ambient conditions and evaporative cooler were monitored by digital humidity-temperature meter. The developed evaporative cooler was evaluated in terms of Jew's mallow weight loss, drops in temperature, evaporative effectiveness and raises in the relative humidity. The evaporative cooler performance was investigated by studying three different levels of superficial air velocities The evaporative cooler had cooling potential of 9.1 °C of 0.13, 0.17 and 0.21 m/s, three different water flow rates of 1, 2 and 3 L/h and two different thicknesses of jute fiber pad of 7 and 10 cm. The results obtained from the experiments indicate that the optimum performance of the developed evaporative cooler was at superficial air velocity of 0.21 m/s, water flow rate of 4 L/h, and pad thickness of 10 cm which increases the shelf life period under achieved relative humidity of 98.7%, and weight loss rate of 0.85% at 20.2 °C evaporative cooler air temperature. The evaporative cooler had cooling potential of 9.1 °C at ambient air temperature of 29.3 °C and relative humidity of 68.8%.

Keywords: shelf life extension, mallow, evaporative cooler, superficial air velocity, cooling potential

Nomenclature

ΔT: Cooling potential (Temperature reduction), °C
T_{db}: Dry- bulb temperature of the ambient air, °C
T_c: Dry- bulb temperature of the cooled air inside the evaporative cooler, °C
SE: Saturation efficiency, %
$T_{wb:}$ Wet-bulb temperature of the ambient air, °C
AV: Superficial air velocity, m/s
WR: Water flow rate, L/h
T: Air temperature of evaporative cooler, °C
AT: Ambient air temperature, °C
Q: The airflow rate at suction fan outlet, m^3/s
A_f: The fan outlet cross sectional area, m^2
V_f: The exhausted air velocity at fan outlet, m/s
A_p: The pad surface area, m2
V_p: The superficial air velocity at fan outlet, m/s
AV1: Superficial air velocity of 0.21 m/s
AV2: Superficial air velocity of 0.17 m/s
AV3: Superficial air velocity of 0.13 m/s
WR1: Watering rate of 4 L/h
WR2: Watering rate of 2 L/h
WR3: Watering rate of 1 L/h
ARH1: Ambient relative humidity of first processing day at Watering rate of 4 L/h
ARH2: Ambient relative humidity of first processing day at Watering rate of 2 L/h
ARH3: Ambient relative humidity of first processing day at Watering rate of 1 L/h
AT1: Ambient air temperature of first processing day at superficial

air velocity of 0.21 m/s

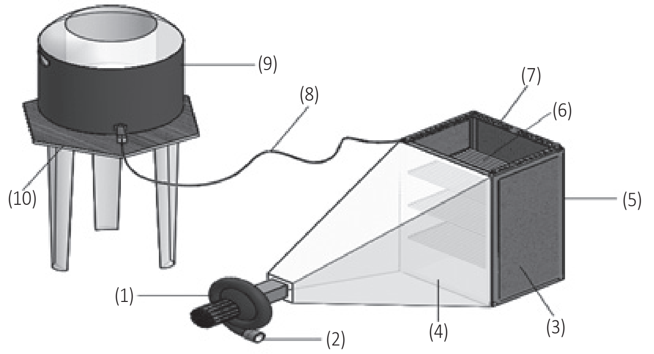
AT2: Ambient air temperature of first processing day at superficial air velocity of 0.17 m/s

AT3: Ambient air temperature of first processing day at superficial air velocity of 0.13 m/s

Introduction

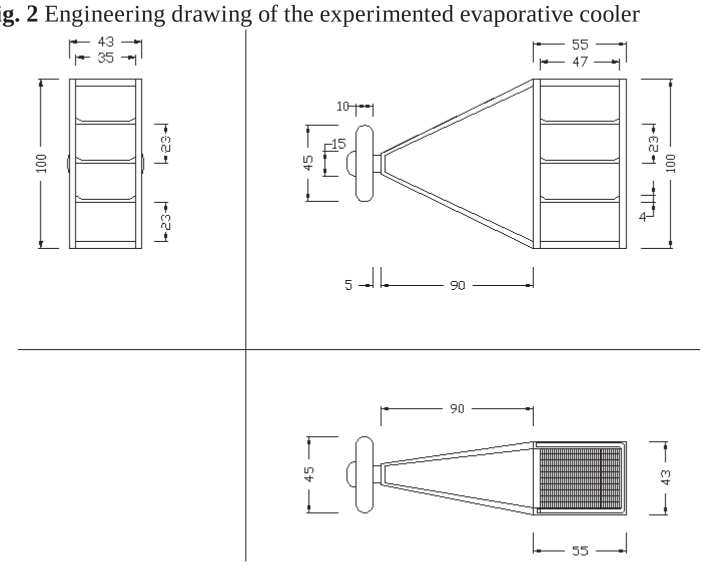
Jew's mallow is the major horticultural crop in Egypt. Its cultivated area is about 18,053 feddan (1 feddan = 0.42 hectare) in Egypt and production is about 8.710 ton/feddan and total production of 157,241 ton/year (ASEAS, 2012). Jew's mallow has an important place in terms of human health. It is loaded by minerals such as calcium, iron and phosphor and vitamins such as "A" and "B" is the pioneer ingredient of mineral "A", is essential for epithelia tissues casing our organs and bodies, eye-health, bone and teeth growth and working of endocrine glades. In general, leafy vegetables are important source of vitamins, minerals, amino acids, fiber and health- promoting phytochemicals with antibiotic, antioxidant and anticancer and other nutraceutical properties (Yang and Keding, 2009). Jaw's mallow is considered as a leafy vegetable that is highly perishable commodities and presents a lot of difficulties in storage due to their perishable nature. Temperature and humidity play a major role in storage of fruits and vegetables. Temperature is the most important factor affecting the deterioration rate of freshly harvested produces; also proper relative humidity is required to be maintained during storage (Kadar, 1992). Rapid cooling of the agricultural products to safe storage or transportation temperature is quality imperative and increases the shelf life by holding the deteriorative changes produced by pathological and physiological agencies. The harvested product contains substantial amount of heat is known as field heat, a significant part of cooling load. Precooling is the rapid removal of heat from the product after harvesting. Depending on the temperature, the product will drop its quality in no time except punctually and appropriately cooled (Rashwan, 2016). Cooling temperature is important to extend the period of fresh appearance of the Jew's mallow. It supports in keeping quality by reducing the rate of metabolic activities as respiration, transpiration. Also increasing superficial air velocity does not affect the quality and ostensibly properties probable due to hard skin of the mallow and the cooling temperature was not very low. Although many researchers reported that, tropical and subtropical plants, and some tissues of temperate origin plants are injured by exposure to temperature below 12 °C (Saltveit and Morris, 1990). However, (Alexander et al., 2012), indicated that, chilling temperatures (1-10 °C) cause to numerous physiological troubles in the cell which result in chilling injury and death. The storage life can be prolonged by removing the field heat as soon as possible after harvesting. Most of fruits and vegetables prefer storage temperature above their freezing point (FAO, 1995). Temperature can be controlled by using energy consuming methods such as evaporative cooling system (Thomson et al., 1998). Proper storage is important for marketing and distribution of horticultural commodities. Storage also balances the daily fluctuations

Fig. 1 Solid view of the experimented evaporative cooler



1. Fan, 2. Outlet air, 3. Jute fiber, 4. Plastic sheet, 5. Metal frame, 6. Shelves, 7. Watering network, 8. Water hose, 9. Water tank, 10. Table of 50 cm height

Fig. 2 Engineering drawing of the experimented evaporative cooler



of supply and demand (Chakraverty et al., 2003). Losses can be minimized by using the best postharvest handling techniques during storage, transportation and distribution to market. There are various technologies available to create and maintain optimal temperature, relative humidity and atmospheric composition for harvested fruits and vegetables during storage (Chakraverty et al., 2003). Evaporative cooling is a well-known system to cool the environment. This is adiabatic process, in which ambient air is cooled as a result of transferring its sensible heat to the evaporated water carried with the air. In the evaporative cooled structure, the maximum advantage of the natural environment is taken for lowering down the temperature of outside ambient air to a considerable low level. Since ages, the human race has been practicing different methods to increase the shelflife of these commodities. The lack of sufficient cool storage space at farm level and refrigerated storage at market level further enhances loss of fruits and vegetables (FAO, 2006). Reducing the losses in postharvest fruit and vegetable operations is a worldwide goal (Clement et al., 2009).

The main objective of the current research is to reduce heat stress on the stored Jew's mallow by manufacturing an evaporative cooler to extend its shelf life to a specific period that determined by its weight loss rates. The specific objectives are as follows:

1. To study the thermal performance of the manufactured evaporative cooler under different levels of pad wetting rates and pad thicknesses,
2. To investigate the influence of superficial air velocities (0.13, 0.17 and 0.21 m/s) on the evolution of evaporative cooling process, and
3. To develop an empirical equation for the evaporative cooling rate during Jew's mallow storage.

Materials and Methods

In the present investigation, an evaporative cooling system was developed and tested for Jew's mallow storage after harvesting at Rice Mechanization Center (RMC) at Meet Eldeebah village, Kafr Elsheikh Governorate, Egypt, during the summer season of 2017. The evaporative cooler consists of frame, suction fan, water tank, plastic sheet and jute fiber as shown in **Figs. 1** and **2**. Ripe fresh Jew's mallow (variety of Alaskndrany) was used in this study. The crops were collected from a private farm in Kafr Elsheikh Governorate. The leaves were cleaned to remove all foreign materials such as dust, dirt, immature and damaged parts.

Table 1 Calculated superficial air velocity

Measured exhausted air velocity, m/s	Airflow rate at suction fan outlet, m^3/s	Superficial air velocity at pad section, m/s
1.5	0.1884	0.13
2.0	0.2512	0.17
2.5	0.3140	0.21

Table 2 Boundary conditions of the developed model application

No.	Item	Boundary values
1	Weather conditions	
	• Air temperature	29-37 °C
	• Relative humidity	40-74%
2	Superficial air velocity	0.13-0.21 m/s
3	Wetting rate	1-4 L/min
4	Pad thickness of Jute fibre	7-10 cm

3.1 Experimental Setup

The evaporative cooler unit was mainly developed to simulate pad fan evaporative cooling system. Four steel angles of 1m length were used to connect the suction fan (has an operating voltage of 220 V, 0.85 kW, 50 Hz and 4 cm in diameter) with the evaporative cooler's storage room (Test section of 0.55 m long, 0.35 m wide and 1 m height) which constructed from welded steel angles (30 × 30 mm) to form the connection between suction fan and storage room. This connection creates a quadrilateral pyramid shape; where one wall side of the storage room geometrically showed as pyramidal base and the fan as pyramidal top. The constructed pyramidal tunnel was covered with plastic sheet to keep the airflow. Evaporative cooler was covered with jute fiber (7 and 10 cm as thicknesses of pad material). Evaporative cooler pad (ECP) was assembled under a manifold tube for pad wetting which is connected with a water tank.

3.2 Experimental Procedures and Measurements

3.2.1 Instruments and Data Acquisition Method

Air temperature and relative humidity inside and outside evaporative cooler were measured by a digital temperature and humidity meter model chino HNK. They were measured and recorded during the period started from 9 am to 5 pm. A digital balance was used for weighing yield (maximum weight is 20 kg) and an anemometer (with temperature measurement) was used for measuring the exhausted air velocity at suction fan outlet, m/s (Japan, with a range from zero - 50 m/s).The performance of evaporative cooler was experimented under the effect of superficial air velocity, watering rate and jute fiber pad thickness. Three different levels were selected of superficial air velocity of 0.13, 0.17 and 0.21 m/s and watering rate of 1, 2 and 4 L/h and two different levels pad thicknesses of 7 and 10 cm. Variables were tested to show their effect on air relative humidity and temperature and instantaneous weight of Jew's mallow with homogeny distribution on shelves of 7 cm depth.

3.2.2 Evaporative Cooler Performance Evaluation

Superficial Air Velocity Calculations and Regulations

Superficial air velocity facing pad surface has a potential effect on the thermal of evaporative cooler performance. To achieve the highest thermal performance of the evaporative cooler, superficial air velocity facing and passing through the whole surface of wetted pad must have been determined. The following formulas were used firstly to calculate and regulate the superficial air velocity levels during the experimental runs, **Table 1**;

a. Airflow rate at suction fan outlet, m^3/s:

$$Q = A_f.V_f \quad \text{Eq. 1}$$

b. Superficial air velocity at pad section, m/s:

$$V_p = Q / A_p \quad \text{Eq. 2}$$

The cooling potential of the evaporative cooler can be expressed as temperature reduction and can be estimated using the following equation:

$$\Delta T = T_{db} - T_c \quad \text{Eq. 3}$$

The averaged cooling potential was calculated for each experimental treatment.

Saturation efficiency can be determined by calculating the saturation potential at the same time of process (Hellickson and Walker, 1983). It was calculated from the following formula:

$$SE = (T_{db} - T_c) / (T_{db} - T_{wb}) \times 100 \quad \text{Eq. 4}$$

The averaged saturation efficiency of each treatment was estimated. Multiple non-linear regression equations were developed to predict the influence of pad thickness and superficial air velocity together

Fig. 3 Air relative humidity of the evaporative cooler under: different watering rates of WR1, WR2 and WR3; superficial air velocities of AV1, AV2 and AV3; ambient air relative humidity of ARH1, ARH2 and ARH3 of experimental runs of charts of A, B and C, respectively, at pad thickness of 7 cm

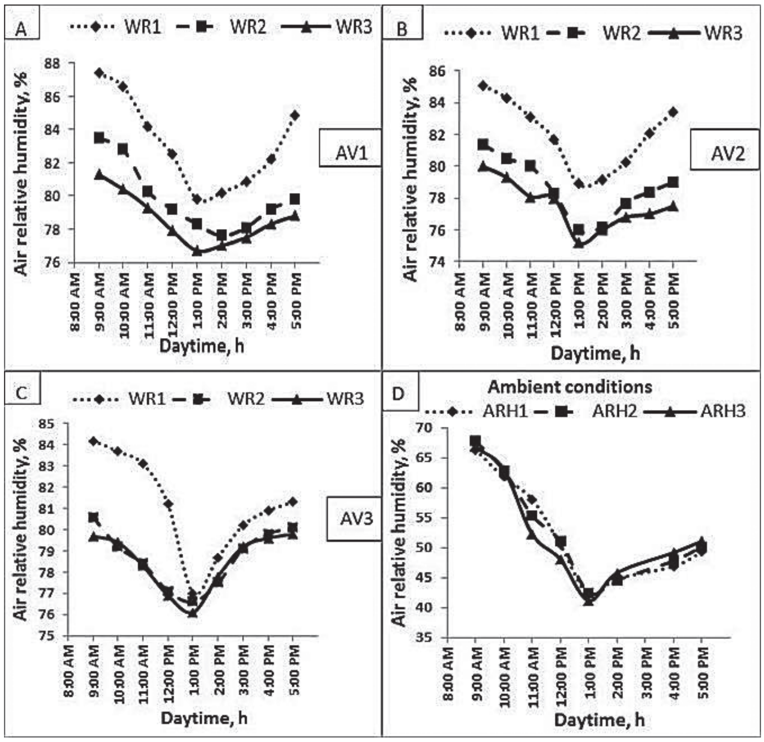


Fig. 4 Air relative humidity of the evaporative cooler under: different watering rates of WR1, WR2 and WR3; superficial air velocities of AV1, AV2 and AV3; ambient air relative humidity of ARH1, ARH2 and ARH3 of experimental runs of charts of A, B and C, respectively, at pad thickness of 10 cm

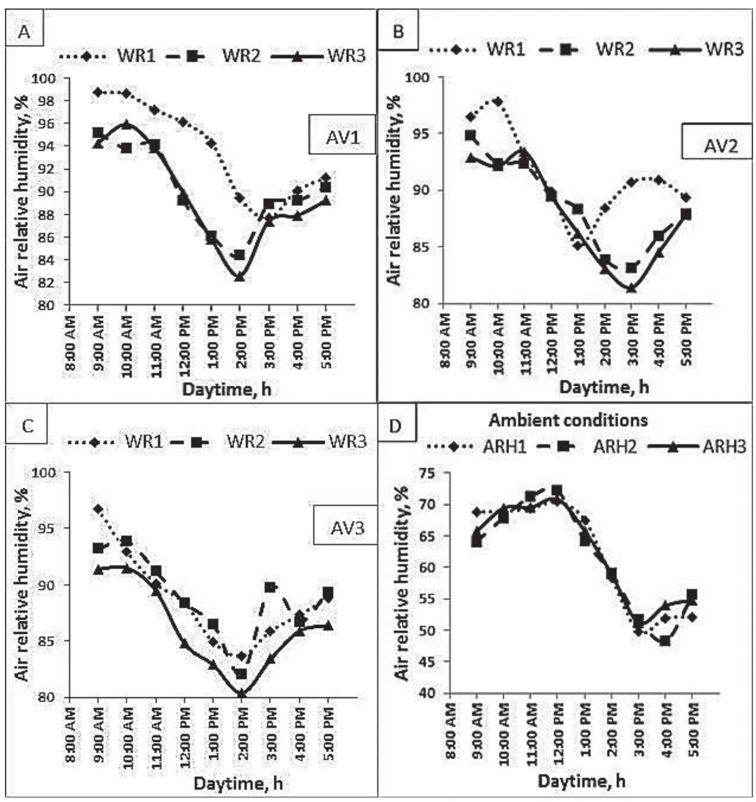


Fig. 5 Air temperature of the evaporative cooler under: different watering rates of WR1, WR2 and WR3; superficial air velocities of AV1, AV2 and AV3; ambient air temperature of AT1, AT2 and AT3 of experimental runs of charts of A, B and C, respectively, at pad thickness of 7 cm

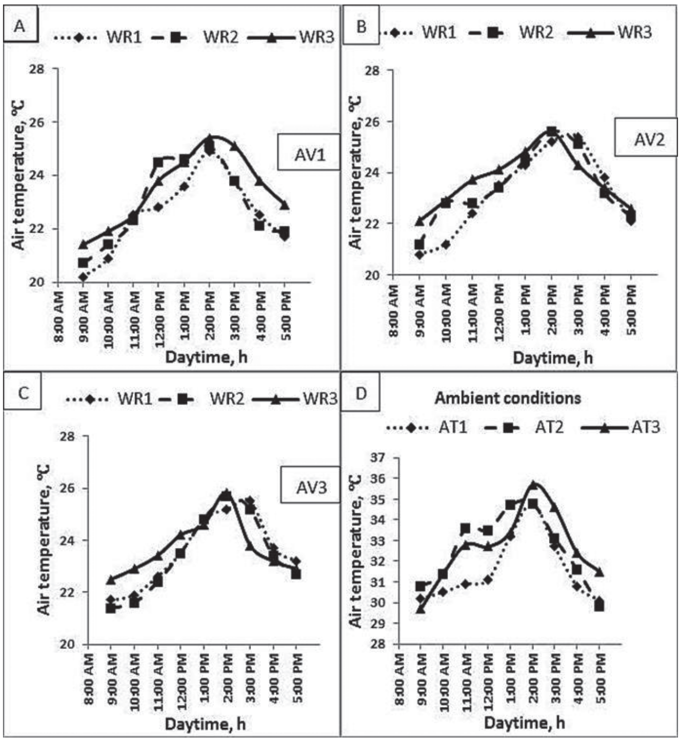
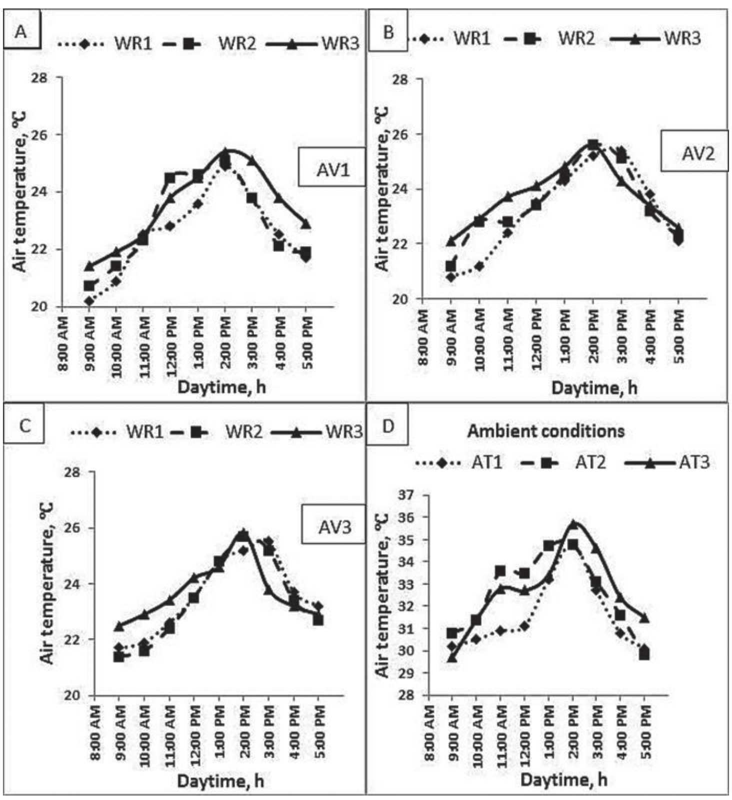


Fig. 6 Air temperature of the evaporative cooler under: different watering rates of WR1, WR2 and WR3; superficial air velocities of AV1, AV2 and AV3; ambient air temperature of AT1, AT2 and AT3 of experimental runs of charts of A, B and C, respectively, at pad thickness of 10 cm



on cooling air temperature and relative humidity for various pad configurations. The weight loss of Jew's mallow can be calculated as a percent of original weight. Initial and final weight of the Jew's mallow was determined at time zero and after storage inside the evaporative cooler. The weight loss percentage was determined using the following equation (AbdurRab et al., 2012) as:

Weight loss, % = (Weight of fresh mallow − Weight after storage interval) / Weight of fresh mallow Eq. 5

Results and Disccussion

Heat inside the product has to be removed to prevent it from deterioration. The amount of heat to be removed from Jew's mallow depends on the required storage temperature. Proper design and fast cooling and relative humidity control in cooling environment can extend the period of fresh appearance of the product. The results of the experiments are given in **Figs. 3**, **4**, **5**, **6**, **7** and **8** showing the effect of superficial air velocity on air relative humidity, cooler temperature and mallow instantaneous weight at different pad wetting rates and thicknesses of jute fibre. As superficial air velocity increased from 0.13 to 0.21 m/s, relative humidity and air temperature were found to increase and decrease, respectively. The air temperature was lower inside evaporative cooler than the ambient. However, the instantaneous weight reduction percentage of Jew's mallow was found to decrease as superficial air velocity increased from 0.13 to 0.21 m/s. The instantaneous weight was found to decrease slowly inside evaporative cooler compared by stored Jew's mallow under the ambient conditions. From **Figs. 3**, **5** and **7**, as superficial air velocity increased from 0.13 to 0.21 m/s, water flow rate increased from 1 to 4 L/h and pad thickness of 7 cm, relative humidity and air temperature were found to increase from 84.2 to 87.4% and decrease from 23.9 to 22.1 °C, respectively. Meanwhile, the instantaneous weight of Jew's mallow decreases with the weight reduction percentage of 4.2%. **Figs. 4**, **6** and **8** show that at pad wetting rate of 4 L/h, superficial air velocity of 0.21 m/s and pad thickness of 10 cm, air relative humidity and air temperature were found to be increased to 98.7% and decreased to 20.2 °C, respectively. The instantaneous weight was found to be decreased to 699 kg with a weight reduction percentage of 0.85%. **Figs. 3** and **4** show the relationship between air relative humidity and daytime for the three superficial air velocities of 0.13, 0.17 and 0.21 m/s, three water flow rates of 1, 2, and 4 L/h and pad thicknesses of 7 cm and 10 cm, respectively. It can be noticed that air relative humidity increases with the increase of superficial air velocity and water flow rate. Air relative humidity was found to be increased from 87.4 to 98.7% for pad thickness of 7 and 10 cm, respectively. Figs. 5 and 6 show the relationship between air temperature and daytime for three superficial air velocities (0.13, 0.17 and 0.21 m/s), three water flow rates (1, 2, and 4 L/h) and pad thicknesses of 7 and 10cm. In general, air temperature decreases with the increase of superficial air velocity and water flow rate. Air temperature was found to be decreased from 22.1 to 20.2 °C for pad thicknesses of 7 and 10 cm, respectively.

Under ambient conditions of air relative humidity and temperature illustrated at **Figs. 3D** & **4D** and **Figs. 5D** & **6D**, respectively. Air relative humidity and temperature inside the evaporative cooler can be predicted by using the equations of 6 and 7, respectively. Boundary conditions should be considered for model applications shown at **Table 2**.

$$RH = -135.4AV^2 - 0.261WR^2 + 0.25PT^2 + 82.67AV + 3.248WR + 1.38AV.WR - 1.11AV.PT - 0.066WR.PT + 56.7$$

$R^2 = 0.987$ Eq. 6

$$T_c = -88.54AV^2 + 0.225WR^2 - 0.03489PT^2 + 41.04AV - 0.74856WR - 5.2223AV.WR - 1.25AV.PT + 0.0151WR.PT + 24.51$$

$R^2 = 0.971$ Eq. 7

Figs. 7A and **B** compare the experimental data with those predicted by Equations 7 and 8 for air temperatures and relative humidity of the evaporative cooler (inside the evaporative cooler where the Jew's mallow is stored). The prediction used the equations showed air temperature and relative humidity values banded along the straight line, which showed the suitability of the developed equations in describing the values of air and relative humidity of the investigated evaporative cooler.

Fig. 8 shows the relationship between instantaneous weight and

Fig. 7 Scatter distribution of the measured versus the predicted air temperature and relative humidity of the evaporative cooler by Equations 6 and 7

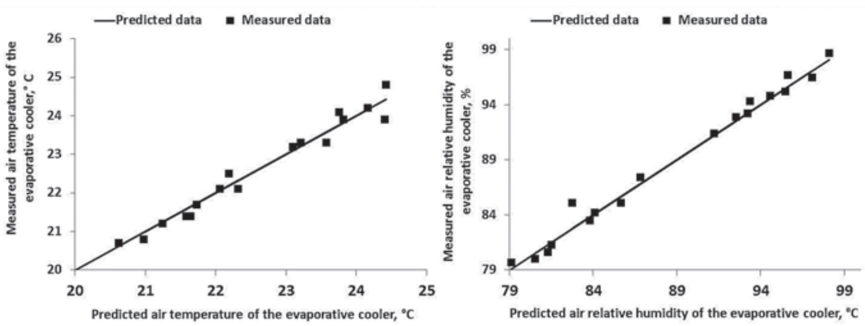
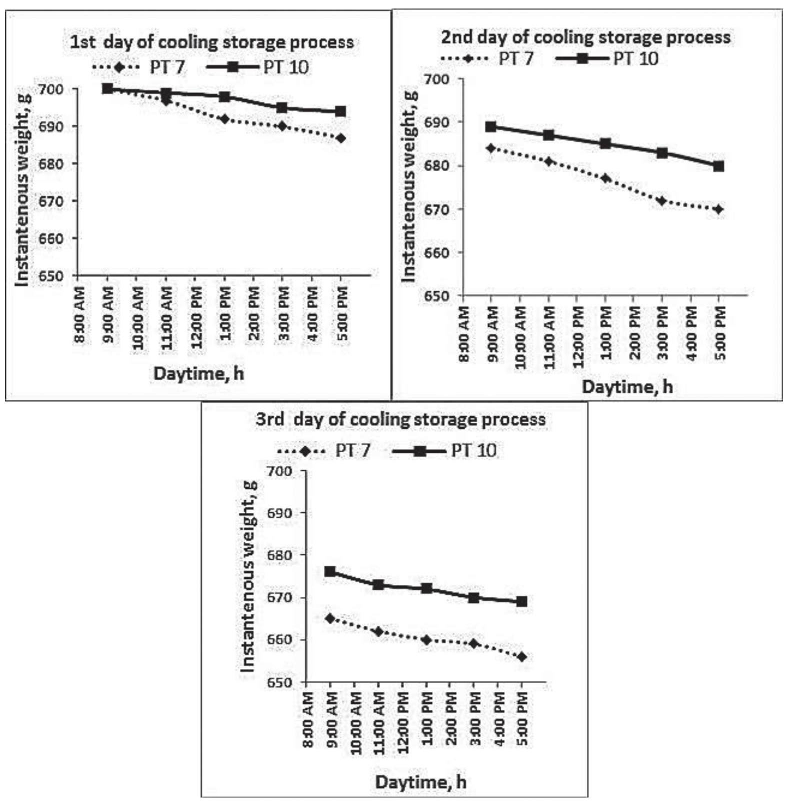


Fig. 8 Instantaneous weight of Jew's mallow behaviour through daytime in the evaporative cooler under: two different pad thicknesses of PT7 and PT10 of 7 and 10 cm at watering rate of 4 L/h and superficial air velocity of AV1



daytime at water flow rate of 4l/h, superficial air velocity of 0.21m/s and two different pad thicknesses of 7 and 10 cm. Pad thickness affect tremendously the instantaneous weight reduction. Instantaneous weight reduction percentage was found to be lower by 4.2 to 0.85% for pad thickness of 7 and 10 cm, respectively. **Fig. 9** shows the instantaneous weight reduction during daytime at water flow rate of 4 L/h and pad thickness of 10 cm for the three superficial air velocities of 0.13, 0.17 and 0.21 m/s. Instantaneous weight tends to gently decreasewith the weight reduction percentage of 0.85, 1.5 and 2% at the first processing day for 0.21, 0.17 and 0.13 m/s, respectively. However, under ambient conditions, it was dramatically decreased from11.4, 11.1 to 10.2%.

Conclusions

The obtained results from the experiments indicated that the optimum performance of the modified evaporative cooler was at superficial air velocity of 0.21 m/s, pad wetting rate of 4 L/h, and pad thickness of 10 cm, to increase safe storage period for fresh consumption or marketing. The obtained results can be summarized as follows:

- The achieved air relative humidity, air temperature and weight loss were of 98.7%, 20.2 °C and 0.85%, respectively at superficial air velocity of 0.21 m/s, pad wetting rate of 4 L/h, and pad thickness of 10 cm.
- The storage under ambient conditions can decrease dramatically the Jew's mallow weight to be 11.4%.
- At optimum operating conditions, the modified evaporative cooler had cooling potential of 9.1 °C at ambient air temperature of 29.3 °C and air relative humidity of 68.8%.

An empirical mathematical model can predict the values of air temperature and relative humidity obtained by the modified evaporative cooler under different weather conditions of relative humidity and air temperature of 40-74% and 29-37 °C, respectively using the following equations;

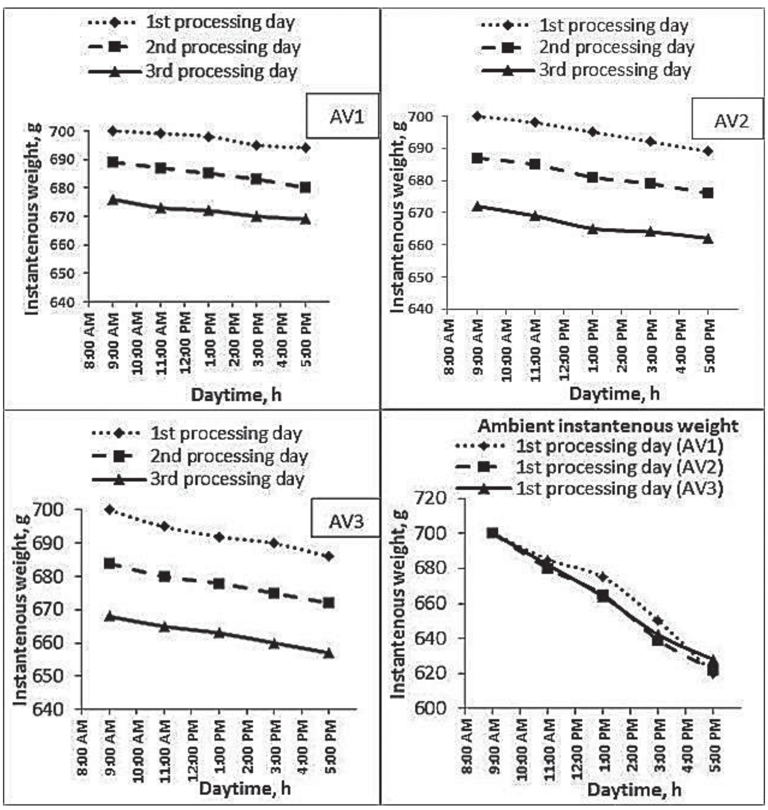
$$RH = -135.4AV^2 - 0.261WR^2 + 0.25PT^2 + 82.67AV + 3.248WR + 1.38AV.WR - 1.11AV.PT - 0.066WR.PT + 56.7$$

$R^2 = 0.987$

$$T_c = -88.54AV^2 + 0.225WR^2 - 0.03489PT^2 + 41.04AV - 0.74856WR - 5.2223AV.WR - 1.25AV.PT + 0.0151WR.PT + 24.51$$

$R^2 = 0.971$

Fig. 9 Instantaneous weight of Jew's mallow in the evaporative cooler under: watering rate of WR1 and superficial air velocities of AV1, AV2 and AV3 at pad thickness of 10 cm



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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.

1817

Effects of Weed Control Mrthods and Row Spacing on Maize Yield: J. K. Omisore, A. I. Afe, O. A. Oyelade, N. Y. Pamdaya

The use of cultural method and other weed control methods was tested to see if it could serve as reliable means of increasing maize yield or reducing production cost. Field experiments were conducted at the research farm of the National Centre for Agricultural Mechanization (NCAM), Ilorin in 2008 and 2009 cropping seasons with the aim of evaluating the effects of some weed control methods and different row spacings on maize yield. The experiment consisted of two factors, namely weed control method and row spacing. The row spacing used were 50, 75 and 100 cm while weed control methods used were no-weeding, weeding once, weeding twice and pre-emergence herbicide application. Results obtained showed that the highest dry weight of weed was obtained from the no-weeding plot while the chemical weed controlled plot produced the least dry weight of weed both in 2008 and 2009 cropping seasons. Interaction between weed control methods and plant spacing were not significant. High weight per 1000 seeds in the two cropping seasons were obtained in the chemical weed controlled plot. Seed weight was not influenced by row spacing employed. Biological dry weight and grain yield were significantly affected by the different weed control methods and highest yield were obtained at the plots weeded twice. Highest grain yield of 2.26 t/ha and 2 t/ha was obtained at the weeding twice plots in 2008 and 2009 cropping seasons, respectively.

1822

Practicability of Topological Optimization to Design a Chassis-type Tractor Frame: Napat Kamthonsiriwimol, Hideo Hasegawa

To reduce the mass of chassis-type tractor frame, an aluminum alloy was adopted instead of mild steel to verify its practicability. In search of an optimized shape of the frame, its topological optimization was conducted by using a finite element software, or ANSYS version 10.0. At first, the target structure simplified by applying aluminum was proposed and analyzed. A thickness of the aluminum frame was increased by two-fold while the one of mild steel maintained its original stiffness. Compared with a mild steel frame, e.g. Kubota-GT80, Japan, the aluminum frame was found to help save a mass by 19.8% which resulted in technical and commercial advantages. Next, further investigations including structural, static and modal analysis of the aluminum frame were numerically done in comparison with the mild steel frame. The findings suggested that the aluminum frame kept a lower maximum von Mises stress than that of the mild steel frame while its maximum displacement remained almost the same as the one of mild steel. What is more, as for natural frequency, the first five eigenfrequencies were found to be higher than the ones of the mild steel frame because of the effect of mass reduction. In addition, the third and the forth eigenmode were facilitated to the torsion in the middle portion of the frame. However, it was only mass of engine, radiator and clutch that were applied to the frame as external loads. Therefore, other combination of loading set may be discussed in getting more realistic results.

Current Status and Perspectives on Agricultural Engineering in Central Asian Countries

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Abstract

This paper presents an analysis of the current status of agricultural technical support and agricultural engineering in Central Asian countries. In addition, key issues relating to the construction and development of agricultural machinery in these countries are identified within the areas of investment, innovation, competition, management, organizational and legal issues, and personnel.

Keywords: agricultural machinery, Central Asia, technical equipment, machine and tractor fleet, assembly production, joint venture.

Introduction

Existing quantities of agricultural technical equipment in Central Asian countries (Kazakhstan, Uzbekistan, Kyrgyzstan, Tajikistan, and Turkmenistan) are insufficient to ensure increased agricultural production and crop yields and enhanced labor productivity (**Fig. 1**).

Insecurity relating to the availability of agricultural machinery, which results in violations of technology of work agro-technical periods of their production, has detrimental impacts on the performance of veneer-field and harvesting operations. In turn, these impacts lead to under-harvesting, a decline in the quality of soil processing and sowing, and a reduction in labor productivity, with additional costs incurred through non-rational consumption of fuels and lubricants. The situation relating the agro-industrial complex (AIC) can only be expected to improve if levels of use of progressive and modern agricultural technology increase substantially in these countries.

In recent years, the weight of energy-saturated tractors within the structure of the tractor fleet has decreased significantly in of Central Asian countries. There is practically no tractors of traction classes 30, 40, and 50 kN used for irrigated agriculture, with only a small number of tractors of thrust class 20 kN being evident. Thus, there is limited use of modern cropping technologies integrated within mechanized units entailing a combination of high-performing combined tools that can simultaneously perform several energy-intensive operations, such as basic and pre-sowing soil cultivation and reclamation work. Currently, in the vast majority of farms in this region, basic tillage operations are performed using tractors of a thrust class of 14 kN. These tractors do not have the capacity to achieve the required depth of tillage, resulting in a low rate of work performance.

After the collapse of the Soviet Union, the agricultural machinery industry in Kazakhstan, Kyrgyzstan, Tajikistan, and Turkmenistan was no longer prioritized. There was no strategic vision for developing this industry as a single integrated system capable of efficiently designing, producing, and selling agricultural machinery within domestic and foreign markets and for attracting and managing the necessary resources for achieving such a vision. As a result, unregulated imports of foreign equipment are rising in these countries. Currently, there are significant economic hurdles associated with agricultural machinery in Central Asian countries. The main categories into which these problems can be characterized are investment, innovation, competition, management, organizational and legal issues, and personnel (**Fig. 2**).

A Case Study of Uzbekistan

Our analysis of the production of agricultural machinery in Uzbekistan revealed the existence of a wide range of products in this sector.

Agricultural machinery represents the most important industry in Uzbekistan. Until 1991, monoculture cotton production predominated in the republic. There were over 300 types of machines and tools used in agriculture, of which only about 30 types of machines (including cotton tractors) were produced in Uzbekistan. These machines enabled the mechanization of almost all operations relating to cotton cultivation. A dozen types of general-purpose machines (e.g., plows, harrows, machines for dispensing fertilizers, and forklifts) as well as engines and arable tractors, were imported from the countries within the Commonwealth of Independent States (CIS) and from other more distant countries (Matchanov et al., 2014).

The shift away from cotton monoculture production, entailing the conversion of significant areas of land for the cultivation of irrigated grain crops (notably rice), fodder, and other crops that yielded two annual harvests required a radical change in the structure of the machine base and tractor fleet.

The production of raw cotton was and still remains a priority economic activity in Uzbekistan. However, now, along with cotton, the main areas of agricultural production include cultivation of grains, potato and vegetables, and tobacco; horticulture; and animal husbandry.

This expansion of the agricultural sector necessitated the development of new, highly efficient machines tailored to regional specificities that were not produced previously in the country and that required extensive inputs of foreign expertise.

Corporate structures, formed within the industrial sector and focusing on the construction of agricultural machinery in Uzbekistan, are functioning effectively. A holding company, Uzagroprommash Holding (Uzselkhozmash Holding, 1996-2008), has been created for establishing agricultural machinery plants. Its goal is to provide modern machinery and methods of mechanization for the agricultural sector, achieve stable and efficient operation of enterprises within this industry, and increase the competitiveness of products.

A program has been developed to achieve technical re-equipment of enterprises and is currently being implemented. Essentially, it entails the successful production of new, modern, high-performing machines and tools that meet international standards for the production of a large number of agricultural machines and consumer goods.

The implementation of this technical project, which has relied on domestic and foreign technical and productive inputs, is aimed at fostering conditions for the production of modern agricultural machinery that is of sound quality for use within the AIC in the Central Asian republics and for sale in global markets.

The share of domestic agricultural machinery within the domestic market is about 80%. Based on the efforts of design departments, in accordance with the strategic framework for the industry established two decades ago, more than

Fig. 1 A Map of Central Asian Countries

300 names of machines have been developed and modernized, some of which are produced serially at the enterprises and some of which are produced according to specific consumers' orders, including 100 machines manufactured in return for machines previously imported from the CIS countries and from more distant countries.

Enterprises within the industry, together with their foreign partners, have created more than 10 joint ventures (JVs). These include the following JVs developed with Case New Holland: the UzKeystractor JV for the production of tractors, the UzKeysmash JV for the production of cotton harvesters and seeders, the UzKeysService JV for service maintenance and repair of "Case" equipment, and a joint venture specialized in the development of advanced technologies and new machine designs in the republic. Other JVs include the UzClaasAgro JV for producing tractors and grain harvesters and the UzClaasService JV, which provides after-sales services for the produced equipment, and the Lemken Chirchig JV for producing tillage machinery developed with Class; and the Agrikhim JV for the production of machines used for providing plant with chemical protection developed with Agri-mondo. The level of localization of technology in these JVs is 40-60%.

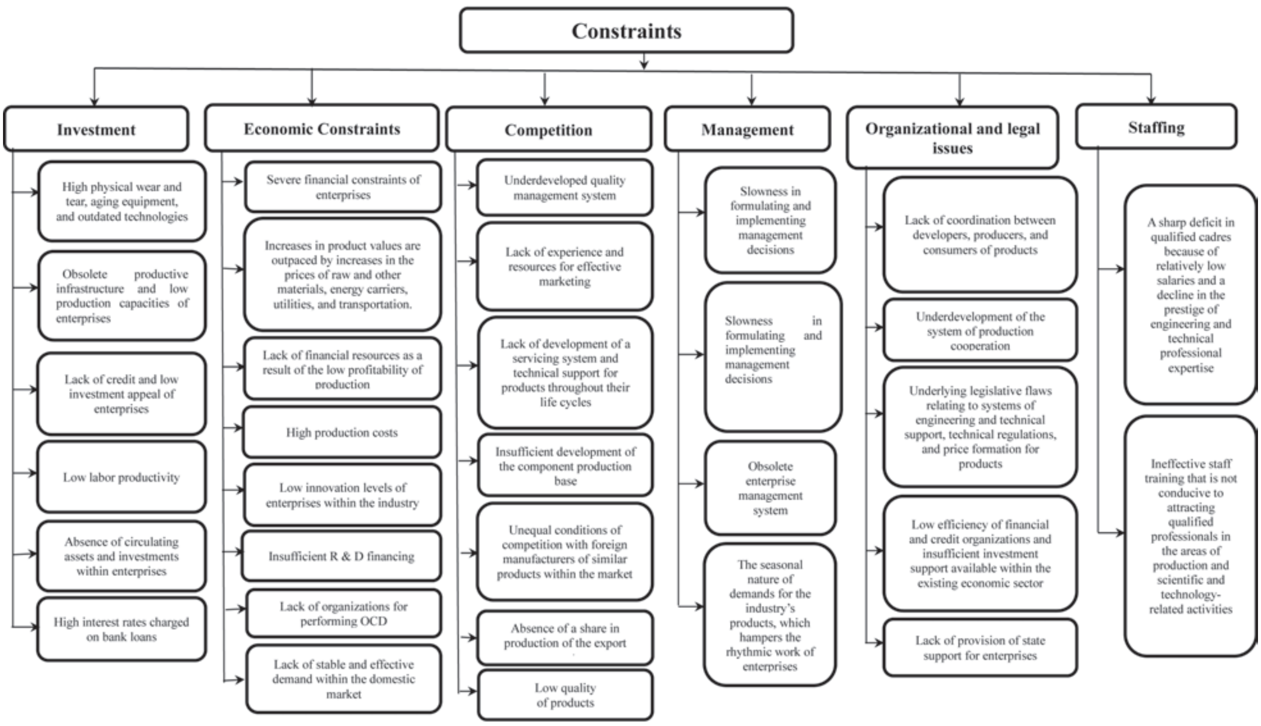
The enterprises' main objective in cooperating with foreign investors is to attract investments, new technologies, technical methods, and expertise for producing modern, high-performing machinery for consumers within Uzbekistan's AIC.

New samples for implementing scientifically based technologies required to produce basic agricultural crops are developed in accordance with the machine system every 5 years.

The industrial development strategy is based on the implementation of the "State Scientific and Technical and Other Programs" scheme involving enterprises, ministries, and departments, through which a variety of different kinds of agricultural machinery are developed. These include tractors with different traction forces, combine harvesters, trailers, soil cultivation equipment for basic and pre-seeding tillage, sowing machines, machines for the introduction of organic and mineral fertilizers, machines for combating plant diseases and weeds, and other technologies.

More than 10 enterprises are involved in the production of machinery for Uzbekistan's AIC and component parts. Within the agricultural machinery industrial sector, a number of corporate structures have been formed and are functioning effectively. They include the Tashcent Tractor Plant, Chirchikselmash, Urgenshcormmash, Agregate Plant, and Agromash, a state bureau specializing in design. This development has enabled greater specialization of their component enterprises to ensure a sufficient concentration of scientific-technical and production potential in the main areas, shorten the duration of time for the development of new equipment, expand sales in markets, and reduce the costs of building a commodity and service network. At the enterprise level 1,900 tractors, 1,000 trailers 600 sprayers, 500 cultiva-

Fig. 2 Main Constraints Relating to Agricultural Engineering in Central Asian Countries



tors, 500 harrows, 300 seeders, 150 mowers, 120 machines dispensing organic fertilizers, and 100 plows have been produced.

The enterprises within this industry prioritize servicing of their outputs. The company structure includes 13 regional technical centers, encompassing more than 100 divisions and alternative of the machine and tractor fleet. Their functions include organizing the provision of technical services for the enterprises' products during the entire period of operation of the equipment.

A Case Study of Kazakhstan

Kazakhstan is a major agricultural producer within Central Asia. The area of agricultural land within the country is 215 million hectares, of which arable land accounts for 25 million hectares. In recent years, the economy has reached a certain level of stability, although the process of economic growth has not yet acquired the characteristics of sustainability and innovation. Accordingly, attention should focus on the economic processes occurring within the machine construction industry, with an emphasis on the agricultural machinery industry, as the basic industry involved in the technical re-equipment of the AIC (Golikov et al., 2015).

Kazakhstan's transition to a market economy has been particularly difficult and problematic for its AIC in terms of agricultural machinery production. During the first half of the 1990s, the decline in the production in agricultural machinery was unprecedented. Over the years of reforms implemented in the country, the composition of the machine and tractor fleet has evidenced a twofold decrease compared with its composition in 1990.

In Kazakhstan, about 1,200 technical means and equipment are required for the production, processing, and storage of products for cultivating plants and producing animal products. In addition to tractors and combines, around 400 kinds of trailed and mounted agricultural machines and implements are required just for mechanized crop production. Of this equipment, not a single machine or gun is produced within domestic enterprises; all of these items are imported from distant countries and from countries within the CIS. Up to 1991, domestic enterprises produced about 330 units of the nomenclature of technical means and equipment, or 27% of the entire requirement of the AIC (Keshuov et al., 2011). The share of domestic agricultural technology in Kazakhstan's market is about 5%, with the remaining technology comprising either imported or screwdriver assembly products under license from foreign manufacturers.

The composition of the machine and tractor fleet does not correspond to the needs of the AIC in terms of its quantity, structure, or level of technology. The quantity of imported agricultural machinery is 1.5-3 times higher than the quantity of domestically produced agricultural machinery in the CIS countries. There are serious issues associated with the production of a large number of tractors (about 30 brands produced by 20 firms), grain combine harvesters (about 20 brands produced by 15 firms), sowing complexes (about 25 brands produced by 20 firms), and other machines associated with the availability of servicing, the provision of spare parts, fuel and lubricants, and adequate numbers of personnel and engineers for constructing the machinery.

Uncontrolled imports of agricultural technology that is not adapted to local soils and climatic conditions and lack of proper servicing of equipment have exacerbated problems relating to the provision of technical support within the AIC. This in turn has impacted on the development of domestic agriculture and mechanical engineering in the country.

Based on the findings of this analysis, it is advisable to provide for domestic production of machines and their components at a level exceeding 70% of consumption in areas such as soil cultivation, sowing equipment, forage harvesting equipment (except for combines), equipment for crop protection, equipment for post-harvest processing of crops (cleaning and drying), and livestock and poultry. For technologies entailing a large number of components (tractors, combines, and seeders), diversification and the development of JVs with foreign producers would be expedient, with the level of localization gradually increased to above 50% through the adaptation of the constructed machines to conditions in the country.

A critical situation has arisen within the agricultural machinery industry relating to the lack of an effective coordinating body (structure) within the industry. A number of measures are required for the development of this structure, including technical re-equipment of enterprises and increasing the industry's appeal for investors through the provision of sub-certification for finished products along with meeting other preferences.

There are 76 enterprises registered in Kazakhstan for the production of agricultural machines and their components, of which about 30 are registered. In addition, there about 35 repair and maintenance companies offering technical services and spare parts for agricultural machinery.

In recent years, there has been a dramatic rise in screwdriver assembly of agricultural machinery in Kazakhstan. This can be attributed to the desire of suppliers of imported technology to receive state support, that is, make out foreign machinery as produced in the country.

A mechanism for providing state support to consumers in the areas of production-related technology development and modernization has been developed. This enables purchases of prioritized types of equipment (e.g., tractors, grain combine harvesters, and sowing complexes) to be subsidized.

Currently, agricultural machinery in Kazakhstan is produced by several joint assembly plants established through specialized joint ventures (SJVs) with foreign partners. These include SemAZ LLP (producing Belarus-80/821221 tractors with MTZ Belarus); Agrotekhmash LLP (producing Kazakhstans K-744R1 tractors with SPbTZ Russia); Karatal-Agrotech LLP (producing Arlan-200/244/404/804 tractors with the YTO Croup, China); JSC Agromash Holding (producing KhTZ-181 tractors with KhTZ, Ukraine); Essil (producing KZS-740/760 grain-harvesting combines and Polesie-600 (producing KSK-600 forage harvesters) through SJVs with Gomselmash Belarus; Combi-new plant Vector LLP (producing combine Vektor-410kz harvesters with Rost-selmash, Russia); Kazakh-Finnish Plant LLP (producing Sampo-3000/3085 combine harvesters with Sampo Rosenlew, Finland); KazBelAgropromMash LLP (producing Kyzylzhar-1300 grain harvesters with LidaAgropromMash, Belarus); DonMar LLP (producing DonMar-2009 reapers with Donmar Canada); and Azov AralAgroMash JV LLP (producing RRV-5 Syr Oragy rice cutters and ZHVP-4.9 travian and t.p. PVP-351 Dana-Press balers).

Based on the current structure of production, out of the total volume of assembly produced agricultural machinery, 93% comprises assembled tractors and combines and 7% comprises attachments. Between 25 and 30% of SJVs cover the required delivery volumes of tractors and combines and almost in a minimal degree of attachments. The level of localization of the technology is below 20%. In 2015, the SJVs produced 1,163 tractors, 452 combine harvesters, 320 harvesters, 235 sprayers, 50 balers, 91 mowers, 49 rakes, 18 cultivators, and 3 sowing complexes.

There is a need for an in-depth structural reorganization of the discipline of agricultural engineering within the country and its reformation through radical technical modernization.. New and innovative restructuring methods are being developed by governmental organizations to facilitate the production of agricultural machinery, technological equipment, and services and to attract other-strange investments for the development of the industry.

A list of the most in-demand, missing, or promising technologies for the cultivation of agricultural crops along with machines required for the organization of production, including the organization of JVs and SJVs, has been developed. Hence, the production of attachments should be prioritized in the continued development of this industry.

Case Studies of Kyrgyzstan, Tajikistan, and Turkmenistan

Of the five Central Asian countries, Kyrgyzstan, Tajikistan, and Turkmenistan rank lowest in terms of the development status of their agricultural machinery.

Attempts to revive the agricultural machinery industry in Kyrgyzstan have not produced the desired results yet. Several SJVs formed with foreign partners (e.g., Avtomash-Radiator and Belarus) have led to the creation of enterprises producing this machinery along with simple products and consumer goods.

Thus, the following key constraints apply to the current situation relating to the development of agricultural machinery in Central Asian countries. The first constraint is the inadequate number and nomenclature of agricultural technologies developed by enterprises that cannot fully solve problems relating to engineering and technical support in the AIC. The second main constraint is the heavy financial constraints experienced by most enterprises, limiting investment possibilities required to modernize production, accomplish technical re-equipment, and develop competitive products. The third constraint is the low level of localization of existing JVs and SJVs.

To conclude, determination of the nomenclature of the following types of machines is necessary for the successful development of agricultural machinery within the region: machines for developing agricultural machinery within enterprises; machines for import acquisitions; and machines for developing more advanced machinery. In addition, the possibility of organizing more JVs with foreign partners and creating modern enterprises for the production of agricultural machinery with a high added value should be explored.

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Comparative Evaluation of Four Different Cassava Peeling Devices

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Abstract

Manual method predominates in the cassava peeling industry in Nigeria as more than 70% of the processed cassava in the market passed through manual process. Mechanical option has come to the forefront since other processing methods are discouraged based on their deficiencies. This work investigates improvements recorded with mechanical method over the manual method, and the inherent challenges of stakeholders in the industry. Three cassava peeling machines namely, BASICON, FATAROY and WAMABCO, were selected under the mechanical method. Manual method was also evaluated under similar test conditions. Performance evaluation was carried out on each cassava peeler to assess their fuel and power utilization, cost and ease of operation. Manual peeling process recorded an average peeling efficiency of 100% and average percentage tuber flesh loss of 5.5%. The BASICON cassava peeler had an average peeling efficiency of 96% and average percentage tuber flesh loss of 75%. The FATAROY cassava peeler had an average peeling efficiency of 72% with 23% average percentage tuber flesh loss. The WAMABCO cassava peeler had an average peeling efficiency of 64% and average percentage tuber flesh loss of 14%. The energy consumption rate obtained for the FATAROY cassava peeler was the best of all. The three cassava peelers evaluated performed 10 times faster than the manual method adopted for cassava peeling operation. The capacity of each of the machines was less than 800 kg/h, which is too small for industrial application. Manual method was the slowest and the most expensive, but offered a superior quality output. Small-scale processors therefore require suitable cassava peelers to aid the peeling operation of cassava in Nigeria's cassava processing industry.

Keywords: Mechanical peeler; Root peeler; Tuber flesh loss; Peeling efficiency

Introduction

Peeling is required at the beginning of every processing of root and tuber crops such as yam, potatoes, banana, plantain, cocoyam, etc. Peeling becomes a necessity in any processing operation when the product is not meant for feed. Traditionally, this is done carefully to ensure that most of the flesh is recovered during peeling process, especially when there are no provisions to make feed from the peels. Peeling operation determines the way for subsequent processing steps or unit operations, making its research very important.

Two key problems are usually involved in peeling. First is to ensure only the peels are removed, and not the flesh; second is to perform this operation without stress and within a short time. The traditional method of peeling is not uniform. In manual peeling, the root is held in one hand and the knife in the other, while the operator scrapes off the peel, this may normally remove some of the flesh along with the peel. The other method is the complete removal of the peel without flesh loss but this require more time than the scraping method. The peeling activity may not be as simple as it seems. The problems are worth investigating when it is to be done in commercial quantity when speed and efficiency would be ascertained with little flesh loss and perhaps quality difference may be experienced about the intended end product of the processing of the root and root crop at hand. The drudgery and probable injury to the operator that may result from this action, the total output per unit time of operation and the economic returns of the chosen method.

Considering all these parameters, search for improved method over the traditional method becomes inevitable. Methods under consideration include chemical means whereby roots are soaked for a short while in a non-harmful liquid compound and are later removed and washed thoroughly to remove both the peel and the chemical compound, as well as application of mechanical means whereby the periphery of the root and tuber crop is rubbed against hard objects without human handling the metal directly as noticed in manual peeling. The latter seemed to gain acceptance particularly in the rural areas and among the small-scale processors for obvious reasons. In the first instance, chemical application is alien to many communities and apart from the fact that it may be beyond their technical awareness, they may not be able to exercise the necessary precaution required to avoid food poisoning in the process of food preparation. Hence, mechanical method remains relevant (Evuti et al., 2010).

Mechanizing the processing stages as noted by Abass et al. (2017), is needed to turn the roots into food but peeling is a difficult process. The root corky and the cortex are not good as human food (Rickard, 1985), making peeling important. The use of chemical and steaming methods are not encouraging (Evuti et al., 2010). The mechanical methods involving the abrasive means of peeling within three minutes of operation serve better (Wheatley and Scott, 1993). Hand peeling is common by shaving of the roots with knife (James et al., 2012). The attention of the International Institute of Tropical Agriculture (IITA), Ibadan was drawn into the search for effective cassava peeler at small and medium scale level (Olukunle et al., 2010).

Peeling efficiency, peel loss and peel retention as observed by Olukunle (2010) were test parameters considered for machine evaluation. Mechanical peeling operation at smallholder farmers' level is required to overcome the drudgery and fetch better return (Oriola and Raji, 2013). This is the basis for equipping them for commercial production. Cassava root is non-uniform in size and shape (irregular). It is best suited to peel within the first day of harvest or not more than two days after harvesting, otherwise, the ease of removing the peel reduces, the longer peeling is delayed. The cortex has a layer of about 3 mm thick at the periphery of the root and the attachment to the flesh gets firmer with the passing days. Mechanical peeling method always seek to perform operations en-mass, but for the aforementioned reasons, particularly the irregularity of the shape and size, makes it a difficult to achieve unless perhaps genetic technology is employed for uniformity of the cassava shape. Various approaches have been used to perform the peeling task mechanically. This includes abrasion, cutting and shearing methods. These approaches have also given rise to many machines found in the market claiming superiority for the same purpose. The objective of this study was to assess the available cassava peeling machines so as to ascertain their suitability for use in Nigeria's cassava processing industry.

Fig. 1 Manual peeling (a) root shaving (b) (root peeling), Source: James et al. (2012)

(a) (b)

Materials and Methods

2.1 Description of Cassava Peeling Devices

2.1.1 Manual Method

Fig. 1 shows the description of manual peeling method where peeling is done through shaving.

2.1.2 FATAROY Cassava Peeler

The working principle of FATAROY's cassava peeler consists of rotating knives/roller and auger. The machine has a dimension of 1.5 m × 0.62 m × 0.95 m, made of a metallic frame mounted at angle 30o to the horizontal and fitted with an inlet hopper and two outlet ports. **Fig. 2** shows the pictorial view of FATAROY cassava peeler. The machine is powered by a 5.5 hp diesel engine. The peeling effect comes from the impact of repeated hit and the sliding of the roots against the rough surfaces of the auxiliary rollers in motion. It is a continuous peeling process that allows for the separation of peels.

2.1.3 WAMABCO Cassava Peeler

The WAMABCO cassava peeler has a dimension of 2.04 m × 0.96 m × 1.1 m as shown in **Fig. 3**. The peeling of cassava is achieved through the principle of abrasion. This machine is made up of metallic frame, an abrasive surface with transmission mechanism made of a pulley-and-gear arrangement as shown in **Fig. 3**. The machine frame consists of a rectangular container filled with water and the peels. The working mechanism consists of a cylindrical drum with holes, having a metallic rough surface and a central shaft. Cassava roots are fed through an inlet, located at the middle of the drum while the outlet for the peeled roots is located at the opposite end of the driving mechanism. The drum when loaded with roots through the central inlet allows rotation through motion created by the prime mover with the roots rolling against the rough surface of the drum. The peeling effect comes from rubbing the roots against the rough surface of the drum.

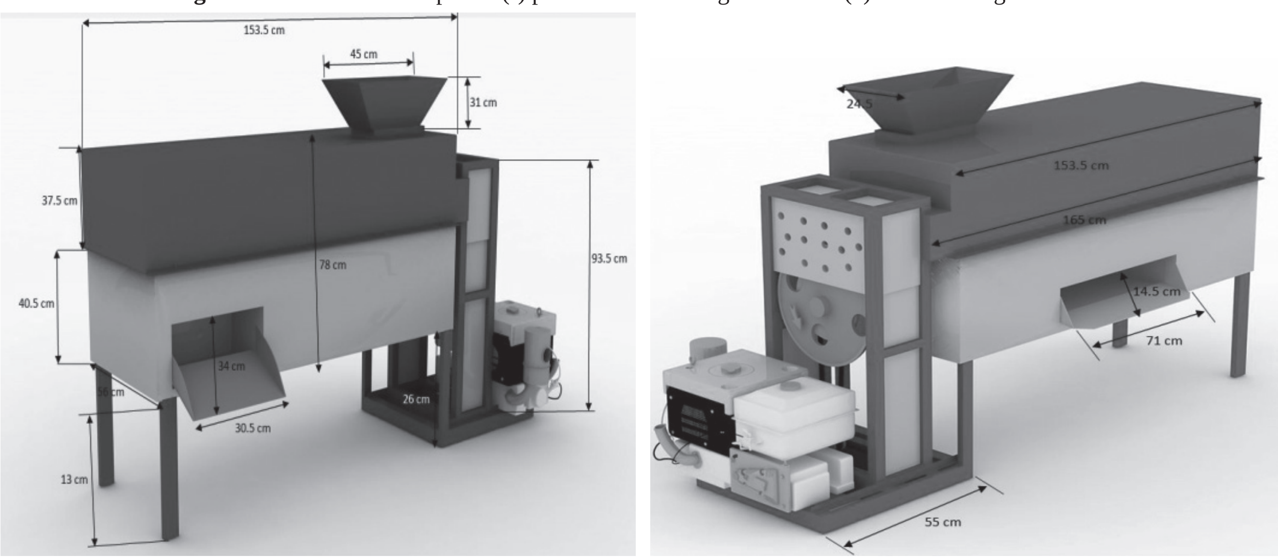
2.1.4 BASICON Cassava Peeler

The BASICON cassava peeler consists of a vertical abrasive platform. The machine as shown in **Fig. 4** is cylindrical in shape having a dimension of 0.92 m diameter and height of 0.61 m, which is mounted on three stands raising the machine 0.47 m above the ground, but coated with rough cemented wall for abrasive action. The whole machine comprises a frame, abrasion mechanism, water system, and a prime mover. The frame consists of three openings: (i) at the top of the frame for feeding cassava roots; (ii) for the wastewater; and (iii) for the peeled roots. The peeling mechanism comprises of the cemented plate on which the roots are loaded and a central pole covered with abrasive materials. Water is drawn under pressure into the container from the mains through a PVC pipe. The prime mover consists of a 5.4 hp electric motor connected to two pulleys through two transmission belts. The operation starts when the machine is put on motion while cassava roots are fed into the peeling chamber with inlet and outlet ports closed. The pipe allows spraying of water which is prompted by the rotation of the platform, causing a circular motion of the whole batch of cassava roots, thereby making them to rub against each other both on the surface of the platform and on the central pole. Peeling is achieved by hulling the roots against the rough surface. The peels are discharged from the system by the circulating water and ejected through the peel outlet at the lower side of the machine. Removal of peels continues as the machine is still in operation. To complete the peeling action, the outlet is opened for the removal of peeled roots.

2.2 Crop Information

Three varieties of cassava roots were planted and harvested for this study. A total of 500 kg cassava roots were collected from the Cassava Breeding Unit at 100 kg per day. Details of the cassava variety, field

Fig. 2 FATAROY Cassava peeler (a) peeled root discharge side view (b) root discharge side view



(a) (b)

description, planting and harvesting dates are shown in **Table 1**.

Table 1 Cassava varieties used for the mechanical and manual peeling evaluation

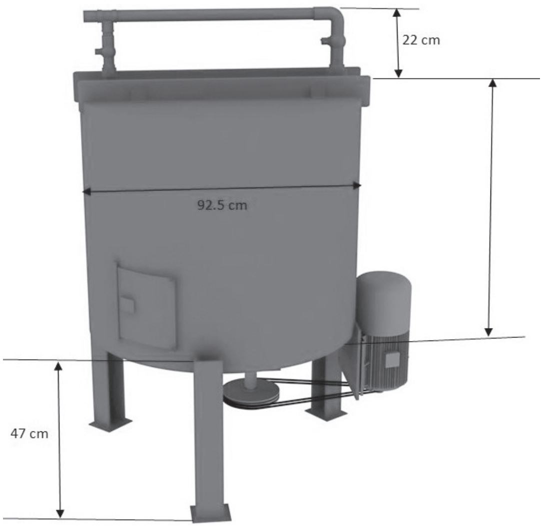
Field	Variety	Planting date	Date of harvest	Duration of crop
BS14	30572	22/10/2013	24/10/2014	One year, two days
BS14	30572	22/10/2013	25/10/2014	One year, three days
BS14	I 9 61089A	22/10/2013	26/10/2014	One year, three days
EE9	I 9 50289	18/10/2012	27/10/2014	Two years, nine days
EE9	I 9 50289	18/10/2012	28/10/2014	Two years, ten days

The roots were sorted out such that the over-matured root, woody, extremely small and big roots were eliminated. Each 100 kg batch (from the same field) were further sorted randomly into four equal parts (25 kg); the length and breadth (big and small end) were measured using caliper.

2.3 Experimental Procedure

The tests were carried out from 24th to 28th of October, 2014. The mass of cassava root before and after peeling were measured and recorded. The mass of peel obtained from peeling were measured using weighing scale (PM 30 digital scale SALTER MODEL 2356S). Stopwatch and tachometer, measuring tape, caliper were used to measure time elapsed and revolutions per minute of the revolving shaft. The length of tuber, weight and diameter of roots were measured.

Fig. 4 BASICON Cassava Peeler



During machine evaluation, the machine owners and their operators were invited to ensure for the effective operation of their machine before measurements were taken. Test parameters considered for this evaluation include mass of roots peeled per unit time, vis-a-vis number of operators required (capacity), quality of peeled roots related to tuber flesh loss and cleanliness of the peeled root (degree of manual peeling required - when necessary), fuel and power consumption of the machine, peeling efficiency and total cost incurred during mechanical peeling.

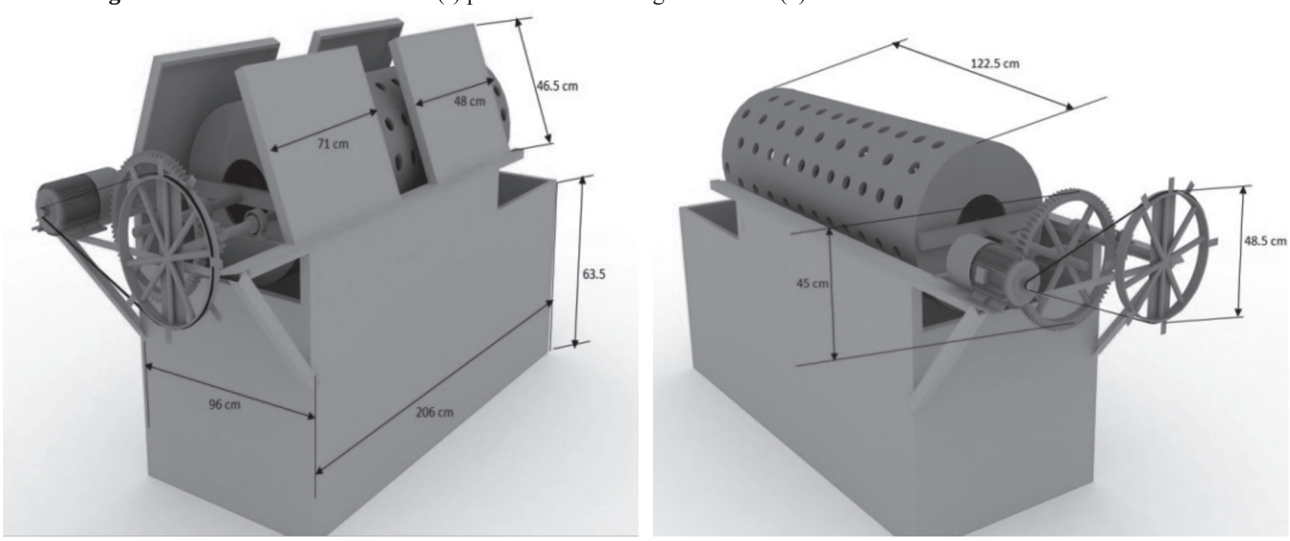
2.3.1 Evaluation Procedure for Manual Peeling

Three skilled workers having minimum of ten years' experience in manual peeling at IITA's Cassava Processing Unit were engaged. The workers were provided with 25 kg of freshly harvested roots each while the three different types of mechanical peelers received 25 kg each of freshly harvested roots. After peeling, the roots and the peels were collected and weighed. The manual peelers hired were paid using the IITA's agreed peeling rate.

2.3.2 Evaluation Procedure for WAMABCO Cassava Peeler

Root sample of 25 kg of freshly harvested roots were fed manually into the machine which was allowed to operate for 3 minutes. The weight

Fig. 3 WAMABCO Cassava Peeler (a) peeled root discharge side view (b) WAMABCO container filled with water



(a) (b)

of the cassava roots were recorded before and after peeling. Some unclean (not perfectly peeled) roots were re-peeled by the same women who were employed for the manual peeling of cassava. The electrical energy consumed (measured in kWh electrical unit) during the operation was recorded. This procedure was repeated 5 times with their average values noted down.

2.3.3 Evaluation Procedure for FATAROY Cassava Peeler

Root sample of 25 kg of freshly harvested roots were continuously fed into the cassava peeler. The time the machine was first fed and the time when the last root came out was recorded. Some unclean roots were also re-peeled manually. The prime mover of the machine had the fuel tank filled up. The quantity of fuel used was determined with the use of a measuring cylinder filled with diesel fuel which was used for refilling the machine after the completion of the peeling process. The unit cost of diesel fuel was obtained from the Supply Chain of IITA while the unit price of electrical energy was obtained from IITA's Electrical Unit. Time duration, labour, fuel consumption and other variable costs were recorded. This procedure was repeated 5 times with their average values noted down.

2.3.4 Experimental Procedure for BASICON Cassava Peeler

Root sample of 25 kg of freshly harvested roots were simultaneously fed into the peeler which was allowed to operate for 3 minutes. After the peeling process, the roots were observed to have reduced. Re-peeling was again done manually by these same women. The electrical energy consumed (in kWh) was calculated. The entire procedure was repeated 5 times with their average values noted down.

2.4 Test Parameters

In this study, the ratio of cassava peels to main tuber used was 1:4. This same ratio was also used by Kamal et al. (2011).

2.4.1 Percentage Weight of Peel

The percentage weight of peel was calculated using the expression given by Oluwole and Adio (2013) as:

$$A = B / C \times 100\% \quad (1)$$

where,
A = Percentage weight of peels (%)
B = Weight of peels (kg)
C = Weight of unpeeled tubers (kg)

2.4.2 Peeling Efficiency

The peeling efficiency was calculated using the expression given by Oluwole and Adio (2013) as:

$$D = E / F \times 100\% \quad (2)$$

where,
D = Peeling efficiency (%)
E = Weight of peel removed by machine (kg)
F = Total weight of expected peels (kg)

2.4.3 Percentage Tuber Flesh Loss

The percentage tuber flesh loss was calculated using the expression given

Table 2 Cassava root size sorting data statistics

Replication	Larger diameter (mm)	Smaller diameter (mm)	Length (mm)
1	83.2[a]	43.8[a]	221.9[a]
2	72.8[b]	35.0[b]	248.1[a]
3	60.9[c]	39.7[ab]	232.0[a]
4	56.1[c]	34.8[b]	148.1[b]
5	83.3[a]	46.1[a]	239.2[a]

Different letters in the same column indicate significant differences at a probability level of 5%

Table 3 Test result using manual peeling method

Peeling date	Initial mass (kg)	Final mass (kg)	Time (min)	Peels (kg)
24/10/2014	25	18	40	7
25/10/2014	25	17.5	40	7.5
26/10/2014	25	19.5	30	5.5
27/10/2014	25	19	29	6.0
28/10/2014	25	20.5	21	4.5

Table 4 Test result using BASICON cassava peeler

Peeling date	Initial mass (kg)	Final mass (kg)	Time (min)	Peel (kg)	Re-peel Time (min)	Electricity (kWh)
24/10/2014	25	4	3	0.117	5.03	0.20
25/10/2014	25	7.5	3	0.178	6.3	0.20
26/10/2014	25	5.5	3	0.27	4.78	0.20
27/10/2014	25	3.5	3	0.268	7.1	0.20
28/10/2014	25	4.5	3	0.151	5.78	0.20

Table 5 Test result using FATAROY cassava peeler

Peeling date	Mass of root before peeling (kg)	Mass of root after peeling (kg)	Time	Mass of peel on the root after peeling (kg)	Re peeling time (min)	Diesel used (litres)
24/10/2014	25	14.5	2 min	0.622	13.2	0.029
25/10/2014	25	15	2 min 51 s	0.720	13.48	0.032
26/10/2014	25	16	2 min 39 s	1.5	13.8	0.031
27/10/2014	25	16	1 min 53 s	1.5	15.98	0.024
28/10/2014	25	15.5	1 min 12 s	2.5	7.1	0.025

by Oluwole and Adio (2013) as:

G = H / I × 100% (3)

where,

G = percentage tuber flesh loss (%)

H = weight of tuber flesh removed by machine (kg)

I = total expected weight of tuber flesh (kg)

2.4.4 Machine Throughput Capacity

The machine throughput capacity was calculated using the expression given by Oluwole and Adio (2013) as:

J = K / L (4)

where,

J = machine throughput capacity (kg/h)

H = weight of mass of peeled cassava (kg)

I = total time taken to peel (h)

2.4.5 Machine Capacity

The machine capacity was calculated using the expression given by Kamal et al. (2011) as:

M = N / O (5)

where,

M = Machine capacity (kg/h)

N = Overall weight of material fed into the machine (kg)

O = Total time of operation (h)

2.4.6 Energy Consumption Rate

The energy consumption rate was calculated using the expression given as:

P = Q / R (6)

where,

P = Energy Consumption Rate (kJ/kg)

Q = Energy consumed (kJ)

R = Weight of cassava after peeling (kg)

Results and Discussion

3.1 Results

Results of analysis are presented in **Tables 2** to **6**. The result of mean difference carried out on the freshly harvested roots used for testing the four different peeling devices is presented in **Table 2**.

The manual peeling test result is presented in **Table 3**.

The test result obtained for the peeling of cassava using BASICON cassava peeler is presented in **Table 4**.

The test result obtained for the peeling of cassava using FATAROY cassava peeler is presented in **Table 5**.

The test result obtained for the peeling of cassava using WAMABCO cassava peeler is presented in **Table 6**.

Other test results of importance to this study are also presented in **Tables 7** and **8**.

3.2 Discussion

3.2.1 Root Size

Table 2 showed that the mean diameter size for large cassava root used for the experiment varied from 56.1 mm to 83.3 cm. Likewise the mean diameter size for small cassava root used for the experiment also varied from 34.8 mm to 46.1 cm. The mean length for all the cassava roots involved varied from 148.1 mm to 248.1 mm. The mean difference result as shown in **Table 2** for the different sizes of cassava root involved showed that every size of cassava root available were used for this study.

3.2.2 Manual Peeling

Test result for manual peeling

Table 6 Test results using WAMABCO cassava peeler

Peeling date	Initial mass (kg)	Final mass (kg)	Time (min)	Peel (kg)	Re-peeling Time (min)	Electricity (kWh)
24/10/2014	25	16	3	0.94	12.2	0.375
25/10/2014	25	19	3	2	13.67	0.375
26/10/2014	25	17	3	2	22.9	0.375
27/10/2014	25	16.5	3	1.7	10.2	0.375
28/10/2014	25	17.5	3	2.5	12.62	0.375

Table 7 Test results for the four different cassava root peeling methods

Cassava root peeling method	Average mass of cassava root before peeling (kg)	Average mass of cassava root after peeling (kg)	Average mass of peel left on the root (kg)	Average mass of totally peels/ flesh removed (kg)	Average process loss (kg)	Average peeling efficiency (%)	Average percentage tuber flesh loss (%)
Manual	25	18.9	0.0	5.56	0.54	100	5.5
BASICON	25	5.0	0.2	19.37	0.63	96	75
FATAROY	25	15.4	1.4	9.42	0.18	72	23
WAMABCO	25	17.2	1.8	0.0	7.8	64	14

Table 8 Cassava root peeling methods processing and costing

Peeling method	Power rating (kW)	Peeling time (min)	Variable cost (N)	Energy spent (MJ)	Machine capacity (kg/h)	Machine throughput (kg/h)	Energy spent rate (kJ/kg)	Cost (N/kg)
Manual	0.075	32	50.00	0.14	46.9	35.4	7.41	2.65
BASICON	4.0	3	5.47	0.72	500.0	100.0	144	1.09
FATAROY	8.5	2.1	4.66	1.07	708.7	436.5	69.5	0.30
WAMABCO	7.5	3.0	10.25	1.35	500.0	344.0	78.5	0.60

as shown in **Table 7** showed that manual peeling had an average peeling efficiency of 100%. It also had an average percentage tuber flesh loss value of 5.5%. This is an indication that despite the total removal of peels from the freshly harvested root, the peeling method still sustained losses amounting to 5.5% average percentage tuber flesh loss. It can be deduced from Table 8, that manual peeling takes a longer time of operation for the peeling process of same quantity of cassava root provided the other peeling devices. It can also be shown in **Table 8** that manual peeling method accounted for the highest variable cost value of ₦50 when compared to the other peeling devices used. This in terms of Naira per kilogram (₦/kg) as shown in **Table 8**, showed that manual peeling method still gave the highest cost value of ₦2.65 indicating it is not even economical to adopt manual peeling approach for the peeling of cassava in Nigeria's cassava processing industry.

3.2.3 BASICON Cassava Peeling Device

Test result for BASICON cassava peeler as shown in **Table 7** showed the peeling device had an average peeling efficiency of 96%. It also had an average percentage tuber flesh loss value of 75%. Despite the removal of almost all the peels from the freshly harvested root, the peeling device still sustained very high losses amounting to 75% average percentage tuber flesh loss. It is an indication that this peeling device would create tremendous loss to the owner of the machine if purchased for the peeling operation of cassava in Nigeria's cassava processing industry. Other useful variable such as cost in terms of Naira per kilogram (₦/kg) as shown in **Table 8**, showed that BASICON cassava peeler recorded the second highest cost value of ₦1.09 indicating it is not even economical to adopt this peeler for use in Nigeria's cassava processing industry.

3.2.4 FATAROY Cassava Peeling Device

Test result for FATAROY cassava peeler as shown in **Table 7** showed that the peeling device had an average peeling efficiency of 72%. It also had an average percentage tuber flesh loss value of 23%. It can be deduced from **Table 8**, that FATAROY peeling machine had the lowest variable cost value of N4.66 when compared to the other peeling devices used. This in terms of Naira per kilogram (₦/kg) as shown in **Table 8**, showed that FATAROY cassava peeler gave the lowest cost value of ₦0.30 indicating that the peeler is economical to use in Nigeria's cassava processing industry. **Figs. 5** and **6** show the pictorial views of peeled tuber and cassava peels obtained when the peeling device was used for peeling cassava.

3.2.5 WAMABCO Cassava Peeling Device

Test result for WAMABCO peeling device as shown in **Table 7** showed that the peeling device had an average peeling efficiency of 64%. It also had an average percentage tuber flesh loss value of 14%. It can be deduced from **Table 8**, that WAMABCO peeling machine had the second lowest cost value of ₦0.60 in terms of Naira per kilogram (N/kg). The WAMABCO cassava peeler acts as both peeling and washing machine. The pierced and roughen coated steel drum surface shown in **Fig. 7** peels the root.

3.2.6 Comparative Study between the Four Peeling Devices

During mechanical peeling operation, some parts of the remains on the root unpeeled were as a result of the irregular shapes of the root. From the test results, it was observed that tuber flesh losses were more with the use of BASICON cassava peeler than the other peeling devices (**Table 7**). However, the overall test showed that the performance of FATAROY had the highest machine capacity and throughput capacity values of 708.7 kg/h and 436.5 kg/h, respectively, which can be further improved upon to meet industrial demand capacity for cassava processing operation in Nigeria. Variable cost indicated that all the peeling machines used for this study had lower cost than that of manual peeling method. The mechanical peelers are better in operation than the use of manual peeling. Energy usage was based on the quantity of cassava root processed, time taken and number of women involved. The test result shows the need for more research

Fig. 5 Peeled roots obtained from FATAROY Cassava Peeler

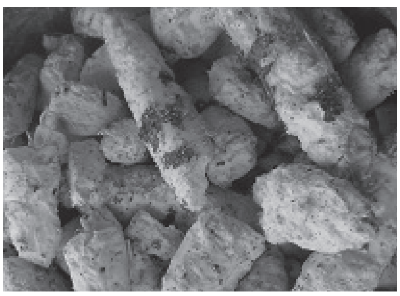
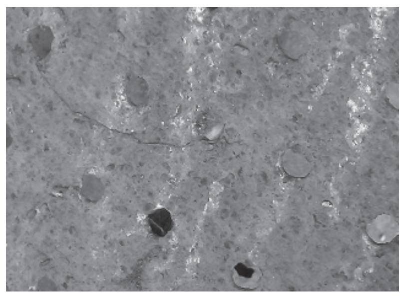


Fig. 6 Cassava peels obtained from FATAROY Cassava peeler

Fig. 7 WAMABCO metallic roughing surface



efforts in ensuring that commercial cassava peeler is being accepted by farmers. The percentage tuber flesh loss, is an indication of the amount of useful tuber flesh removed with the peels. The BASICON cassava peeler was found to have the highest percentage of tuber flesh loss among the peeling devices adopted for peeling of cassava in this study.

Conclusion

The varying shapes and sizes of cassava roots have influence on cassava peeling, and still remains the major problem in the mechanization process of cassava. WAMABCO cassava peeler had an average peeling efficiency of 64% and average percentage tuber flesh loss value of 14%. FATAROY cassava peeler had an average peeling efficiency of 72% and average percentage tuber flesh loss value of 23%. BASICON cassava peeler had an average peeling efficiency of 96% and average percentage tuber flesh loss value of 75%. Peeling with the BASICON cassava peeler is not economical because it has an average tuber flesh loss value of 75%. The energy consumption rate shows FATAROY cassava peeler as the most economical among the peelers used. All the cassava peeling machines performed the function of peeling 10 times faster than manual peeling. The cost of manual peeling was found to be the highest, and the capacities of each of the machines were less than 800 kg/h which is too small for industrial application, further development to produce commercial viable peeler for cassava processing industries in Nigeria is recommended. The search and development of cassava peelers continue towards even better option.

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Increasing Rice Production in Nigeria Through Sawah Eco-Technology: 2005-2018

by

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Abstract

The Sawah rice on-farm research project was brought to the National Centre for Agricultural Mechanization (NCAM) in 2005 by Prof. Wakatsuki of Kinki State University, Japan for adoption by the Nigerian rice farmers. It has gained wide spread as the project through NCAM's effort over the years has extended to rice farmers in 22 states of the federation for quick adoption of the technology. The traditional method of producing rice in Nigeria was found lacking as it could no longer feed the ever-teeming population resulting from its very low yield. There is need to adopt a better alternative such as the Sawah rice on-farm project, which has seen gaining wide spread in some African countries. It became necessary to promote its adoption in a country like Nigeria - known as the seventh most populous nation in the world and the first in Africa. The continuous import of rice to supplement the short fall in the local production of rice for consumption by the masses became a matter of urgent discussion by the present administration. The government decided to promote the local production of rice by creating a programme called Anchors Borrowers Programme (ABP) in 2015 which is anchored by the Central Bank of Nigeria. The programme that kicked off in Kebbi State of Nigeria adopted the Sawah Eco-technology, extended to their rice farmers by NCAM for high yield production of rice in the State. This paper discusses the journey so far on how NCAM have extended her Sawah Eco-technology to rice farmers in Nigeria.

Keywords: rice, sawah, production, technology, on-farm research, demonstration.

Introduction

Rice is an important grain food to the world (Okeke and Oluka, 2017). Rice is consumed by over 4.8 billion people in 176 countries and it is the most important food crop for over 2.89 billion people in Asia, over 40 million people in Africa and over 150.3 million people in the Americas (USAID, 2009). According to WARDA (2003), rice (Oryza Sativa) is a cereal crop which has become a staple food of considerable strategic importance in many developing countries, where its consumption among urban and rural poor households has increased considerably. Imolehin and Wada (2000) reported that Nigeria ranks the highest as boll producer and consumer of rice in the West Africa Sub-region. However, in terms of area of land under food crop production in the country, rice ranks sixth after sorghum, millet, cowpea, cassava and yam.

Rice is both a food and a cash crop for farmers, contributing to smallholders revenues in the main producing areas of Nigeria. Rice is grown on approximately 3.7 million hectares of land in Nigeria, covering 10.6 percent of the 35 million hectares of land under cultivation, out of a total arable land area of 70 million hectares; 77 percent of the farmed area of rice is rain-fed, of which 47 percent is lowland, while 30 percent is upland (Ojehomon et al., 2009). Most rice farmers representing 90 percent of the total rice farmers in Nigeria are smallholders, applying a low input strategy to agriculture, with minimum input requirements and low output (IFAD, 2009). Nigeria rice productivity is among the lowest within neighbouring countries, with average yields of 1.51 tonne per hectare (Cadoni and Angelucci, 2013). Onimaes (2013) noted that rice can be grown conveniently in Nigeria because the climate is good. It can be grown both in the forest and savannah areas of Nigeria. According to Baksh (2003), Nigeria, Cote d'Ivoire, Zaire and Madagascar are among the biggest producers of all types of rice in Africa.

The average annual rice production in Nigeria is dominated by smallholder farmers who cultivate small hectares of land using traditional method of farming; yields are low and hence there is a wide gap between demand and supply (Idiong, 2005). There is food crisis in the country because, increase in the demand for staple food, such as rice, has not been accompanied with corresponding rise in production (Okpiliya, 2003). Statistics from the European Association of Agricultural Economics (EAAE), (2005) cited by USAID (2010) reveal that Nigeria is the largest rice importer in West Africa, with an average yearly import of 1.6 million metric tonnes since the year 2000. Total consumption stands at 4.4 million tonnes of milled rice while annual consumption per capital stands at 29 kg and this has continued to rise at 11 percent per annum; induced by income growth. Nigeria produces only about 2.8 million metric tonnes (MT) with a deficit of 1.6 million MT excluding the large quantity smuggled through the porous borders (USAID, 2010).

In order to increase rice production in the country, the federal government of Nigeria has designed policies and programmes aimed at boosting domestic production to meet domestic demand since 1989 (Idiong, 2005). These include amongst others, the Fadama Rice Programme and as well as the River Basin Development Rice Programme. Various Research institutes have been established in the country in order to boost rice production, some of which are the National Cereals Research Institute (NCRI) and National Seed Service (NSS). To further address this problem of low rice production in Nigeria, research institutes such as IITA and NCRI introduced high yielding varieties of rice purposely to boost food security. Upon the release of some improved high yielding varieties of rice for utilization in Nigeria, there still exists low rice production in the country due to the continuous use of the traditional method of rice cultivation where soil fertility which is a special ingredient needed in the soil could not be sustained. A technology called Sawah which is referred to a leveled, bunded and puddled rice field with water inlet and outlet for controlling water and managing soil fertility was introduced to Nigeria in the year 1986. This technology has made significant impact in developing countries like Ghana in the area of rice production and this called for the need for the adoption of such technology in Nigeria to boost our rice production level so as to meet the future need of the country. The country needed to promote the consumption of local rice as it is making tremendous effort to ban the importation of foreign rice into the country. Therefore, this paper discusses the impact of Sawah technology to the rice production system in Nigeria.

An Overview of Rice Cultivation and Processing in Nigeria

The cultivation of rice, according to Okeke and Oluka (2017), begins with seed bed preparation which includes land clearing, tillage, ploughing etc depending on size of farm. After land preparations, planting begins by planting either water-soaked rice or dry rice seeds. Seeds can be sown using a machine that places the seed in the soil in large farms but in developed countries low flying planes broadcast rice seeds on the already prepared fields. After one month or less of growth, the seedlings are transplanted in bunches from nursery beds to main field if it is not planted directly to the field. First weeding commences 1 month after transplanting or 21 days after germination for those planted directly to the field. Second weeding may be done 36 days after first weeding. Prior to transplanting fertilizer may be broadcasted and puddle into the soil according to the farmers schedule. Some farmers may schedule for first top dressing or broadcasting 2-3 weeks after transplanting. Application of fertilizer depends on the farmers' schedule.

At maturity stage (approximately four months after planting) the grains begin to ripen, the tips begins to drop and the stem yellows - the water in the field is drained if it is a flooded field (Jahn et al., 2005). As the field dries up, the grains ripe further and rice is due for harvesting. Depending on the size of the farm and the level of mechanization, rice is either harvested by mechanized means or manual labour. According to FAOSTAT (2014), 60 percent of farmers in Africa uses manual labour. Threshing of rice follows the harvesting operation, but in a full mechanized system where rice is being harvested with rice combine, harvesting and threshing are done simultaneously with combine harvester. After harvesting and threshing, the paddy rice is parboiled and milled using manual or mechanical method. Before milling, rice grain is dried in order to reduce the moisture content to about 19 percent to avoid breakage of the seeds during milling. The drying can be done through sun drying. In developed countries drying can be done with artificially heated air. Rice is processed at mill using automated processes. The paddy rice undergoes many processes like hulling, polishing, grading, de-stoning etc. before marketing or storage.

After hulling which is the removal of the outer husk to get the bran rice, polishing of the bran rice begins by removing the outer bran layer to get the white rice. Grading follows after polishing. Grading is the process of separating the long rice from the broken rice. De-stoning follows immediately after grading. Foreign rice at stage of polishing do undergo further processes which is also called coating which is either done by coating with protein material or any other substance (Okeke and Oluka, 2017). Various agricultural wastes such as rice straw, and groundnut husk have been used to produce bricks. Rice husk ash was used to treat the compressibility characteristics of black cotton soil as fillings for embankment (Akinyele et al., 2015).

Problems Associated with Rice Production in Nigeria

In Nigeria, rice has emerged as one of the fastest growing agricultural sub-sector and has oved from a ceremonial to a staple food in many Nigerian homes within the last two decades, such that some families cannot do without eating rice in a day. Nwachukwu et al. (2008) reported that as a staple food in Nigeria, rice accounts for 40 percent of the diet of the country's population but production has been growing at a slow rate relative to consumption within the last years. Idiong et al. (2006) quoting Akpokodje et al. (2001) reported that rice is an important food and cash crop in Nigeria and that it serves multipurpose roles. It immensely contributes to internal and external African Sub-Regional trade as well as food security for the nation. Also, rice contribution in Nigeria has been on the increase over the years.

Olatoye (2011) noted that a farmer can harvest close to 3-5 tonnes of rice in one hectare depending on the variety which is about 100 bags (25 kg). A 25 kg of rice is about ₦3,500. So about ₦350,000 can be realized from 1 hectare of land. An investment on 100 hectares of land will yield ₦35,000,000 and rice can be grown twice a year if it is mechanized. Uba (2013) noted that rice milling could be done on cottage, small, medium and large scale bases depending on availability of capital and the raw materials paddy rice. Output could be from 2 MT to 150 MT per day. Generally, 1 MT of paddy rice yields about 60 kg - 70 kg of milled rice, depending on milling efficiency company management practice and the variety of rice purchased.

The potential in investment in rice production in Nigeria cannot be overestimated. This is why both indigenous and foreign investors are seriously going into it. It has also been found out that our local rice (Ofada for example) is more nutritious than the imported ones (Nwalieji, 2016). However, rice cropping system in Nigeria is beset with problems associated with low-labour output, low yield, relatively high production costs, poor producer price and marketing system.

Fig. 1 Lead farmers and government officials at green field day at a farmer managed SERIF field day in Kebbi State of Nigeria

Fig. 2 Monitoring SERIF rice field at Badegi, Niger State of Nigeria

Fig. 3 Using power tiller to carry out ploughing operation in Kebbi State of Nigeria

Fig. 4 Leveling operation in SERIF at Gbajigi, Niger State of Nigeria

Adeniyi (1987) and Oni and Ikpi (1979), observed that related problems of that nature have led to the low yield and hence to the decline in the local production of this crop.

Rice is one of the most valuable staple food for large chunk of Nigerian population; but despite its nutritional and economic values; mechanization of its production and/or processing in some rural areas have not received much attention making the production, processing and even storage difficult for the local farmers. One major reason for the low level of output most times is low level of agricultural mechanization resulting from poor financial background of the farmers to procure farm machineries (Oduma et al., 2014).

Introduction of Sawah Technology into Rice Production System in Nigeria

Origin of Sawah Technology

According to Wakatsuki et al. (2009), Sawah is a man-made, improved rice-growing environment with demarcated, bunded, levelled, and puddle fields, for water control. Sawah is soil based eco-technology. In a more simpler form the term Sawah refers to leveled, bunded and puddled rice field with water inlet and outlet to control water and manage soil fertility, which may be connecting irrigation and drainage facilities including Sawah to Sawah irrigation and drainage. The term originated from Malayo-Indonesian. In the absence of water control, fertilizers cannot be used efficiently. Consequently, the high yielding varieties performed poorly and soil fertility cannot be sustained. The potential of Sawah based rice farming is enormous in Sub-Sahara Africa (SSA), especially in West Africa. Ten to twenty million hectares of Sawah can produce additional food for more than 300 million people in future. The Sawah based rice farming can overcome both low soil fertility and scarce water resources through the enhancement of multi-functionality of Sawah type wetlands as well as geological fertilization processes in watersheds.

Fig. 5 Women returnees empowered by SERIF at Tisi, Salamat region; Tchad 2016

The Beginning of Sawah Technology in Nigeria

On-farm research for the introduction of Sawah-based rice farming was initiated in 1986 in two Inland Valleys in Gara and Anfani near Bida area of Niger State of Nigeria by Prof. Toshiyuki Wakatsuki through the International Institute for Tropical Agriculture`s Hirose Project. In 1987, an additional Inland valley in Gadza which is in Bida area of Niger State of Nigeria was also included in the study. The initial research efforts were not adopted due to low level of innovation and interaction with the farmers.

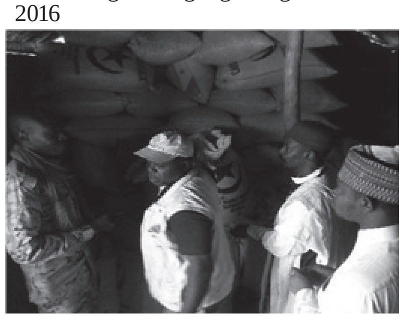
Nigerian researchers were invited to Ghana's Sawah sites for observation and replication in Nigeria. This led to another on-farm research and demonstration study in 2001 at Ejeti, Bida area of Niger State of Nigeria. The success of these activities led to the innovative adoption of the technology in the demonstration site from where further research activities were carried out and dissemination activities started in earnest.

Between 1987 and 2001, extensive agronomic and irrigation research continued for the adoption and adaptation of Sawah among local farmers around the study area. In 2001, Watershed Initiative Nigeria 2001 (WIN2001) started a collaborative adaptive research with the National Cereal Research Institute (NCRI), Bida with support from Kinki University, Nara, Japan through Action Research. The Japanese Ministry of Agriculture, Forestry and Fisheries (MAFF) sponsored several On-the-job training and capacity building (OJCB) in collaboration with the International Cooperation Centre for Agricultural Education (ICCAE) of Nagoya University, Nagoya and Institute for the Studies of Advanced Sustainability of the United Nations University (UNU-IAS), Tokyo, Japan for the extension of Sawah Eco-

Fig. 6 On-the-Job training for returnees on SERIF at Gos taguela near Haraze, Tchad 2017

Fig. 7 A project Coordinator inspecting SERIF rice field at Massamagre, Tchad 2017

Fig. 8 Sawah expert and government official inspecting rice paddy store at Massamagre, Maguegeu region; Tchad 2016



technology in Nigeria.

The Sawah Eco-technology has been researched, tested, improved, demonstrated, and implemented successfully in Nigeria, Ghana, Togo, Benin and Chad from 1997 to 2018. **Figs. 1** to **8** show some of the activities carried out on Sawah Eco-Technology in Nigeria. The research on machinery application in Sawah fields started at the National Centre for Agricultural Mechanization (NCAM), Ilorin in 2005 and has continued till date.

Benefit of Sawah Eco-Technology over Traditional Method of Rice Production

The benefits of Sawah Eco-technology over the traditional method of rice production in Nigeria include:

i. Increase in rice yield from 1-2.5 ton/ha to 4-8 ton/ha;
ii. If appropriate lowlands are selected, developed and managed, sustainable rice productivity of lowland Sawah is more than ten times that of upland rice fields;
iii. Minimal rouging and no weeding is observed in a well prepared Sawah field;
iv. Sustaining the soil nutrients by utilizing geological and irrigation fertilization resulting from mineralization of nutrients and translocation due to movement of top soil from upland;
v. Sawah help combat global warming and other environmental problems;
vi. Carbon sequestration through control of oxygen supply. Methane emission under submerged condition, nitrous oxide emission under aerobic rice;
vii. De-nitrification of nitrate polluted water;
viii. Watershed agro-forestry, SATOYAMA describes active Sawah in the lowland and forestry in the upland; this encourages conservation of the environment, forest generation, enrichment of the lowland through various geological processes;
ix. Sawah contributes to control of flooding and soil erosion;
x. Sawah has the potential to generate hydro-electricity; and
xi. Sawah in its terraced form can create a beautiful cultural landscape;
xii. In communal settings, Sawah promote fair water distribution systems for collaboration and fair society.
xiii. The Sawah systems are the field laboratory for research and technology generation and the factory for dissemination of the technology developed.

Presented in **Table 1** is the dissimilarity that exists between the use of Sawah and the traditional system of rice production.

Journey so Far

In the year 2005, a team of researchers visited NCAM, Ilorin from IITA, Ibadan and NCRI, Badeggi. This visit was the point of introduction of Sawah to NCAM. The success of this embryonic visitation and collaborative research activities led to the involvement of some of NCAM researchers in Capacity Building Research programme sponsored by the Japanese government between 2007 and 2009 in several hosting Institutions in Ghana and Nigeria.

The NCAM Sawah Eco-technology has been extended to different States in Nigeria which include Akwa Ibom, Anambra, Benue, Cross River, Delta, Ebonyi, Ekiti, Enugu, Kaduna, Kano, Katsina, Kebbi, Kwara, Kogi, Lagos, Nasarawa, Niger, Ogun, Ondo, Osun, Taraba and Zamfara states with proven results in the communities that adopted the technology. The rice revolution which is currently being experienced in Kebbi state was made possible by the wise intervention by the then governor of the Kebbi state through this similar method. More than 2,000 lead farmers have been trained and about 2,000 hectares of sawah infrastructures have been developed.

The NCAM-hosted Sawah Eco-technology project in the past years has entered into effective collaboration for speedy adaptation, adoption and technology transfer with different organizations and agencies such as Third National Fadama Development Project (Fadama III); Soil Research Institute (SRI), Kumasi, Ghana; International Cooperation Centre for Agricultural Education (ICCAE); Sawah, Market Access and Rice Technology in Inland Valleys (SMART-IV project) of the Africa Rice Center (ARC); Shimane University, Matsue, Japan; Nagoya University, Nagoya, Japan; International Organization for Migration (IOM), Chad Republic; United Nations University - Institute for

Table 1 Difference between the use of Sawah and the traditional system of rice production

S/No.	Sawah method	Traditional system
1.	Relatively high yield that is greater than 7 tons/ha.	Low yield that is less than 2 tons/ha.
2.	Requires land development.	Relies on natural landform.
3.	Ploughing operation carried out using power tiller.	Manual scattering of mounds.
4.	Puddling operation carried out for proper pulverization.	No puddling operation.
5.	Nursery establishment followed by transplanting.	Direct sowing followed by broadcasting.
6.	Defined plant spacing operation.	Plant spacing undefined.
7.	Tillering is profuse.	Low tillering.
8.	High fertility management.	Low fertility management.
9.	Water control is high.	Minimal water control.

Sustainability and Peace (UNU-ISP); United Nation University - Institute for Advance Studies of Sustainability (UNU-IAS); Commercial Agricultural Development Project (CADP); Ekiti State Agricultural Development Programme; Kwara State Fadama II; Osun State Quick Impact Intervention Program (QIIP); and Some private farms.

Conclusion

The National Centre for Agricultural Mechanization (NCAM), Ilorin which is saddled with responsibility of promoting agricultural mechanization in Nigeria has over the years made tremendous effort in promoting the increase of rice production in Nigeria by training rice farmers in Nigeria on Sawah Eco-technology. The NCAM Sawah Eco-technology have been extended to rice farmers in 22 states of the federation. In few years to come, it is expected of the nation through the dissemination of NCAM Sawah Eco-technology to all states of the federation to be food sufficient in the area of rice production.

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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.

1820

Effect of Separating Sieve Parameter on Average Height of Potatoes and Soil Mixture and Performance of Separating Sieve: Xie Shengshi, Wang Chunguang

In order to achieve the effect of separating sieve parameter on the average height of potatoes and soil mixture and performance of separating sieve, the experiment on average height of potatoes and soil mixture and performance experiment on swing separating sieve were performed, respectively. Taking the crank rotational speed, sieve inclination and machine forward speed as experiment factors, taking average height of potatoes and soil mixture as the experiment indicator, the significant between factors and indicators were determined; taking obvious rate and abrasion rate as the index of swing separating sieve, through single factor test, the effect of swing separating sieve parameter on performance of separating sieve were determined. Test results are as follows. The crank rotational speed, sieve inclination and machine forward speed had the significant influence on the average height of potatoes and soil mixture, and the correlation coefficient were -0.846, -0.98 and 0.988, respectively. With the growth of crank rotational speed, the obvious rate and abrasion rate were first increased and then decreased. The obvious rate and abrasion rate reduced first and then increased with the increase of sieve inclination. The abrasion rate showed a tendency of first decrease and then increase with the increase of machine forward speed. The appropriate parameter of swing separating sieve are: the crank rotational speed is 230 r/min, the machine forward speed is 2.03 km/h. The study results may be of help and provide reference for the design of swing separating sieve on potato digger.

1823

Strength Analysis of a Thai-made Walking-type Tractor-Structural Modification of a Mainframe: Napat Kamthonsiriwimola, Hideo Hasegawa

In this study, a Thai-made walking-type tractor, e.g. Hongthong, Thailand, was analyzed through modification of a prototype. Major related factors including maximum von Mises stress and eigenfrequency were discussed by using a finite element method (FEM). To implement numerical approach, a side-member of mainframe was changed from L-shape to C-shape to gain more stiffness. Cross-members and ribs were placed to the mainframe while the cross-member was attached to a handle for further reinforcement. The FEM results indicated that the maximum von Mises stress and the maximum displacement of the modified model were the same as the ones of conventional model. As for the vibrational feature, the first five eigenfrequencies exhibited saliently bigger value under heavier mass condition. This may be useful to discuss the applicability in conjunction with the strength-related constraints. Furthermore, the presence of second eigenmodes suggested a possibility in improving torsional capability, particularly in the front portion of mainframe. Accordingly, a modified model was manifested to cause an increase of mass by 1.8% compared with the conventional model. To improve this impractical result, the replacement of material which can be characterized by higher durability and lighter mass were used as an alternative mainframe. In addition, since its complicated shape tended to cause the rise of a manufacturing cost, low-cost materials available in a marketplace were adopted for further designing innovation which might lead to encourage the medium-sized manufacturers.

1826

Single Locking Cotton Feeder for Enhancing Ginning Efficiency of Double Roller Gin: V. G. Arude, S. P. Deshmukh, P. G. Patil, S. K. Shukla

Single locking cotton feeder was designed and fabricated with an aim to maintain constant feeding rate of individual locules at the ginning point of Double Roller (DR) gin. It comprises of a pair of feed roller, spiked cylinders, grid, feeder hopper and distributor chute. Spiked cylinder has spikes, its tips were spaced closer to the feed rollers than the thickness of a lock of cotton. The spiked cylinder travel at a greater linear speed than the feed rollers, whereby cotton bolls held between the feed rollers are struck by the spikes of spiked cylinder, thus ensuring single locking of cotton. The effect of single locking of cotton on ginning efficiency of DR gin was studied. Extent of unlocking was determined by measuring the change in bulk density of cotton before and after passing through the feeder which decreased with increase in spike cylinder speed. DR gin output was found to increase by 15-20% with use of single locking feeder as compared to conventional feeding system comprising of auto-feeder and micro-feeder. Cotton quality was also found to improve in terms of colour grade. Single locking feeder observed to be highly useful for Indian cotton ginneries.

1840

Development and Evaluation of Walnut Cracking Machine: Jagvir Dixit, K. Ravindra, R.M. Shukla

In traditional method, walnut cracking done manually using hammer or stone is laborious, time consuming, and cumbersome with huge wastage. A prototype machine was developed and evaluated under three different levels of shell moisture content (db) (25-30%, 15-20% and 8-12%) and three different levels of roller speeds (25 rpm, 43 rpm and 69 rpm) of the cracking unit. The machine consists of motor, frame, hopper, conveying tray, cracking unit, conveying chute and collecting bin. The main working principle of cracking unit is based on the compression of the walnut between two rollers rotating in opposite direction. The rupture force was recorded minimum (90.16 N) along Z-axis (suture line) and at 8-12 % (db) shell moisture content while it was found maximum (200.90 N) along X-axis and at shell moisture content of 25-30% (db). The effective throughput capacity significantly increased with rotational speed of the rollers. The cracking efficiency was found highest (82.1%) at 43 rpm and 15-20% shell moisture content, while it was lowest (70.9%) at 63 rpm and 8-12% (db) shell moisture content. The kernel damage increased linearly with the rotational speed of roller and found highest (21.8%) at 69 rpm and 8-12 % (db) shell moisture content, while it was lowest (11.7%) at 25 rpm and 15-20% (db) shell moisture content. At standardized speed of operation (43 rpm) and shell moisture content (15-20%), the throughput capacity of the machine was recorded as 56.1kg/h with cracking efficiency of 82.1% and kernel damage of 13.8%. While throughput capacity observed with traditional method was 2.5 kg/h with cracking efficiency of 85.9%, and kernel damage of 8-9 %.

1842

Development and Evaluation of Single Row Power Weeder for Rice: Ajay Kumar Verma, Aditya Sirmour

Weeding is the most arduous job in rice farming. Mechanical weeding is preferred to chemical weeding as weedicide application is usually harmful, selective and expensive. Mechanical weed control not only uproot the weeds between the crop rows while keeping the soil surface loose, ensuring better soil aeration and water intake. Lack of man-power has been identified as one of the major problems for the sustainability of rice crop. Consequently seeders, planters and transplanters were well adopted as a step for rice mechanization in India. However, mechanized weeding is still not well developed as it is performed under submerged heavy soil condition and narrow row spacing. In order to assess the possibility of mechanization of the weeding operation of row seeded or mechanical and manual transplanted rice, the power operated single row rice weeder was designed and developed by Southern Agro Engine Private Limited, Chennai, India. It was further improvised by Indira Gandhi Agricultural University, Raipur, Chhattisgarh for the row seeded/ transplanted rice crop. The weeder consists of a 1.4 kW 6,000 rpm, 2-stroke petrol engine, a centre driven transmission box with worm gear box, rotor shaft with L-shaped blades, plastic float, handle, mudguard, mud flap, accelerator lever and an engine on/off switch. The tine width of the developed weeder can be adjusted at 140 mm, 190 mm or 240 mm. It is equipped with rotating blades with 176 rpm. Its compactness and low weight (14.5 kg) makes it easily maneuverable.

The developed power weeder was tested in the System of Rice Intensification (SRI) check row (25 × 25 cm) transplanted fields at 15 and 30 days after transplanting (DAT). The working speeds of operation were found to be 0.69 and 0.72 m/s for 15 & 30 DAT respectively. The fuel consumption, field capacity and weeding efficiency of power weeder at 15 DAT were found to be 0.74 l/h, 0.054 ha/h and 84.6% respectively. Similarly at 30 DAT it was found as 0.71 l/h, 0.059 ha/h & 86.3% respectively. Improvement in soil aeration and root growth after using the equipment has prompted higher production of tillers. The cardiac cost involved and energy expended in the operation of power rice weeder were 108 beats/min and 19.50 kJ/min, respectively. The oxygen uptake in terms of VO_2 max was 46% which was above the acceptable limit of 35% of VO_2 max. The work- rest study clearly indicates 6-8 min of rest can be provided to the operator after every 25-30 minutes of work (4 h work then 2 h rest followed by after 3 h work in a day of 8 h). ■■

Co-operating Editors


B Kayombo

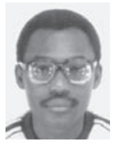

M F Fonteh


S A Ndindeng


S E Abdallah


A A K El Behery


Ahmad Addo


R J Bani


I K Djokoto


A N GITAU


D K Some


K Houmy


A F Alonge


O A Oyelade


Umar B Bindir


J C Igbeka


E U-Odigboh


K C Oni


U L Opara


N G Kuyembeh


A H Abdoun


A B Saeed


A I Khatibu


S Tembo


H A Cetrangolo


I de A Nääs


A E Ghaly


E J Hetz


M A L Roudergue


R Aguirre


O Ulloa-Torres


Y M Mesa


P P Rondon


S G C Magaña


H Ortiz-Laurel


A I Luna Maldonado


G C Bora


M R Goyal


A K Mahapatra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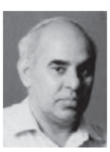
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M Z Bardaie


Enkhbayar Gonchigdorj


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H P W Jayasuriya


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R P Venturina


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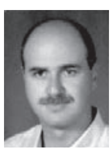
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N Hay


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E Gasparetto

Y Lobachevsky

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