DESIGN, FABRICATION AND PERFORMANCE EVALUATION OF A SMALL DRUM TYPE POTATO GRADER

A THESIS

BY

MD. NAZMUL HUDA

Examination Roll No.: 1505282

Session: 2015-2016

Thesis Semester: July-December, 2017

MASTER OF SCIENCE (MS)
IN
FARM POWER AND MACHINERY

DEPARTMENT OF AGRICULTURAL AND INDUSTRIAL ENGINEERING

HAJEE MOHAMMED DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR

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December, 2017

DEDICATED

TO

MY BELOVED PARENTS

&

HONOURABLE TEACHERS

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The Author

ABSTRACT

Grading potatoes by size is an important operation for preparing tubers for seed and for commercial purposes. Potatoes are sold in the market without grading in Bangladesh. If potatoes were sold after grading, this would be beneficial to both producers and consumers. Since mechanical graders are not available, potatoes are graded, when necessary, by hand. This is a time consuming, costly, and inefficient method. In view of this fact, the present work was undertaken to design, fabricate and evaluate the performance of a small drum type potato grader for village level operations that will provide a practical means of grading marketable potato tubers by size. The grader consists of a hopper, grading unit, prime mover and catchment tray fitted on a frame. The grader was made of locally available materials to keep the cost low. The grading unit was made up of plastic oil container, hopper and catchment tray made up of Mild Steel sheet and the frame was made up of Mild Steel angle bar. A 0.75hp, single phase electric motor was used as a prime mover with a gear box (30:1) for reducing the rpm.

Machine parameters for the evaluation included the speed of the grading unit (RPM) and inclination of the grading unit. These were tested on potato tubers taking note their influence on grading system efficiency, capacity, damaged tubers and power consumption as independent variables. Data were analyzed and the results indicated that optimum set-up of the grader was at 6 RPM speed of the grading unit, inclination of 3^0 giving a system efficiency of 88.40%, capacity 280.90 $kghr^{-1}$, less damaged tubers of 2.22% and low power consumption of 13.95 W-hr. The cost of the grader was estimated to be Tk45,000.00 with a break-even quantity of 63 tons of tubers in one year. Further improvement, of the device could be done to reduce the percentage of damaged tubers and cost effectivity together with ease of loading and operation of the machine.

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INTRODUCTION

CHAPTER I

INTRODUCTION

Potato (*Solanum tuberosum* L.) popularly known as 'The king of vegetables', has emerged as fourth most important food crop in Bangladesh after rice, wheat and maize. In Bangladesh, it is consumed generally as vegetable. Bangladeshi vegetable basket is incomplete without potato. Because, the dry matter, edible energy and edible protein content of potato makes it nutritionally superior vegetable as well as staple food not only in our country but also throughout the world. Now, it becomes as an essential part of breakfast, lunch and dinner worldwide. Being a short duration crop, it produces more quantity of dry matter, edible energy and edible protein in lesser duration of time than cereals like rice and wheat. Hence potato is a crop of great economic significance in national agriculture (Rashid, 1974).

Potato is a prominent crop in consideration of production and its internal demand in Bangladesh. It is the number one vegetable crop of Bangladesh both in terms of area and production (Rashid, 1974). It alone constitutes more than 50% of the total annual vegetable production in the country (Anonymous, 1978). Many modern potato varieties are commercially grown in Bangladesh at present. In the northern parts of Bangladesh, modern potato varieties are getting popularity among farmers which possess some excellent characteristics like high yielding, resistant to insects and pests and diseases. These are also very palatable in taste.

Potato cultivation has been getting popular over the last many years Bangladesh maintained its seventh position among top potato-producing countries by showing consecutive bumper production in the last four years. Potato output was a record 9.47 million tons on 4.75 million hectares in FY'16, against 9.254 million tons on 4.62 million hectares in FY'15. The yield growth was measured at 2.33 per cent over that of FY'15, according to provisional estimates by Bangladesh Bureau of Statistics (BBS). Potato production was 8.95 million tons in FY'14, 8.60 million tons in FY'13 and 8.205 million tons in FY'12, the BBS data showed (BBS, 2015-16).

Potato consumption such as seed, presenting to bazaar for selling, starch preparation, feed of domesticated animals and production as chips, peel, conserve and so on, needs special conditions and it should be prepared before delivery to that particular application.

The objective of gradation is preparation of this background and product uniformity and coordination for each usage. Advantage of accreting such conditions is control simplicity of production process, increase of efficiency, system mechanization and desirable design performance and so on. This question is propounded considering ability of potato gradation based on different characteristics like weight, dimensions, density and volume, that which is the gradation criterion? Whether are graded uniformly other product characteristics with selection of each mentioned items? For response, it should refer to gradation goal. For example, length, density, shape and size respectively are noteworthy for chips preparation, potato drying and selling at market. Seed preparation is important and essential than other various usages and it is based on mass. Many researchers worked in this field. Seed piece was bigger; the yield became greater but utility of seeds above 2.5 ounces reduced (Iritani et al., 1984). Seed suitable mass for cutting about 3-10 ounces and cut pieces for planting 1.5-2.5 ounces (Bohl et al., 1995). Seed ideal mass about 1.5-2 ounces. Therefore mass was based for gradation as criteria regarding recommendations and importance of potato seed preparation (Johnson, 1997).

Grading is an important factor in production and in the marketing process of potato. Sorting and grading are terms which frequently used interchangeably in the food processing industry. Sorting is a separation based on a single measurable property of raw material units, while grading is “the assessment of the overall quality of a food using a number of attributes”. Grading of fresh product may also be defined as ‘sorting according to quality’, as sorting usually upgrades the product (Brennan, 2006). Grading is basically separating the material in different homogenous groups according to its specific characteristics like size, shape, color and on quality basis (Narvankar and Jha, 2005).

The benefits of potato grading are: 1) It saves time and energy in different processing operations and reduces the handling losses during the transportation. 2) Grading helps the potato producer and seller to determine the price. 3) It reduces the cost of marketing and helps the consumers to get standard potato at fair price. 4) It facilitates the scope to widen the avenue for potato export. 5) It has a direct influence on utilization point of view, as the small to medium sized tubers are prepared for ‘seed tubers’ and large sized tubers are preferred for processing purpose.

On the other hand, grading is considered a very important operation in the marketing line as it can fetch higher price to the farmers (Dattatraya L et al., 2013).

Potatoes are sold in the Bangladesh market without grading. Large, medium and small potatoes are sold together. Large potatoes are used for processing, especially for making chips, and for baking. Medium and small size potatoes are preferred for culinary use seed potatoes should be between 28 and 55 mm and are graded into two sizes of 28 to 40 mm and 40 to 55 mm. Since mechanical graders are not available, potatoes must be graded by hand through eye estimation which is very laborious, time consuming, costly and inefficient. Manual grading of potato tubers particularly in the village is often inconsistent since quality perception varies from one person to another. Also, it is not possible to grade potatoes accurately by eye estimation. In developed countries, potatoes are sold in the market after properly grading by mechanical means.

There are four basic types of potato-grading machines in current use: (1) Endless Screen Grader (conveyor); (2) Roller Grader; (3) Cribriform Drum Grader; and (4) Reciprocating Riddle Grader (Kolchin 1982). These machines are designed for medium- to large-scale farms and are not suitable for most farmers in developing countries.

In Bangladesh, Bangladesh Agricultural Research Institute (BARI) developed a potato grader, which one not available in the market. Since mechanical graders are not available, seed potatoes are graded by hand through eye estimation when necessary. This is a very laborious, costly and inefficient method. If a low cost grader could be developed and extended to cold storage owners and whole sale businessmen, then graded potatoes could be available in the market. Marketable tubers will command a premium price in the market when properly graded. Bringing ungraded tubers in the market will affect marketing system making a delay on the disposal of other products. This causes significant loss due to physiological degradation of the crops as a result of long queue. In view of this fact, the present work was undertaken to design, fabricate and evaluate the performance of a small drum type potato grader.

Specific objectives of the research

The specific objectives of the research are;

1. Determine the physical properties of potato
2. Design and fabricate a machine for grading potato tubers by size;
3. Evaluate the performance of the grading machine in terms of grading system efficiency, capacity and damaged tubers, and
4. Economic analysis of the machine.

CHAPTER II

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

Various researchers developed many kinds of graders according to market demand and processing aspects. Generally grading is done on the basis of size, shape, weight, color etc. Here a number of studies are demonstrated the application of various types of sorter and grader used in the processing of sorting and grading different types of fruits, vegetables and other agricultural products.

2.1 Size grading

Hunter and Yaeger (1970) conducted a series of tests on a roller table and considered variables like feed rate, percentage defective tubers, speed of translation and rotation of the rollers, as well as direction of rotation, manner of removal of tubers and lighting levels. It was concluded that the feed rate could be adjusted to allow removal of defective tubers. Considering the mean weight of tuber as 160 grams, around 6250 defective tubers removed each hour. Rollers were reversed so that the top surface of the potatoes rotated in the direction of translation at 6 r m^{-1} of translation. At defect level of 20% a lower rotation speed was used. In a typical test above 90% of defective tubers were removed when the flow rate was about 450 potatoes min^{-1}. In the test they correlated the feed rate, translation of crop and rotation of the rollers to remove the maximum defective tubers.

Grover and Pathak (1972) designed and developed a wire belt type of potato sizer capable of sizing the tuber into four sizes. The prototype was operated with 2hp electrical motor. The output was found to be 20 to 24 quintal h^{-1} with 1% to 10% of brushing and about 94% of sizing efficiency.

Brantley et al., (1975) developed a multiple belt adjustable V-size grader for use in stationary sweet potato and cucumber packing line application and tested for reliability and endurance in commercial operation. Results showed that product damage was negligible and average sizing accuracy (with wobble) was 95% to 98% for sweet potatoes and 94% for cucumbers. Best results were obtained with a sizing belt speed of 1.07 ms^{-1}, orienting the belt at velocity ratio 2.25: 1, and product feed rate less than 2040 kgh^{-1}, though feed rates up to 2610 g h-1 did not produce excessive error.

Verma and Kalkat (1975) designed and developed an expanding pitch rubber spool potato sizer. A prototype of potato sizer comprises of mainly a sizing conveyor containing rubber spool and two identical driving rollers with helical groves of gradually increasing pitch. The performance of expanding pitch rubber spool potato sizer was studied at three different speed of sizing bed corresponding to the helical shaft speed of 190, 110, and 75rm^{-1}. The result showed that there was no appreciable difference in the percentage variation of tuber weight collected in different size grade at different speeds. The output of potato sizer was found to be about 25 bags per hour. The overall performance of the sizer was found to be quite satisfactory.

Morgon and Constantin (1976) developed a compact laboratory seed separator to operate without the limitation of screens. The separator grader was designed primarily to sort kernels of cereal grains and it adjusted to permit selection of numerous size classes on ascending order. The range of each size class could be changed to meet a requirement for a variety of kernel dimensions. The divergent rollers were mounted side by side in an inclined position. One roller was rotatable while the other one was stationary but adjustable so that the spacing between the rollers could be controlled. Seeds were metered through a vertical plastic cone to the high-end junction of the paired rollers. The seed moved down the inclined-paired rollers for separation according to size range. The roller speed could be varied by changing diameter of the v-belt drive sheaves. The angle of inclination of the paired rollers could be varied through a range of 0 to 7 degree of control flow rate of seed along the roller length. The separator grader proved effective in uniformly sizing cereal grains.

Naugle and Brien (1976) carried out engineering analysis of a mechanized fruit grading table. The results of the study showed that by using the mechanized table system, saving in the amount of labor requirement for manual grading would be realized. Use of spiral drum sub-sampler could effectively replace the interim.

Frank et al, (1978) developed a research tool for sorting strawberries by size. A sorter consisting of a box shaped frame 47 × 47 × 62 cm, with five removable drawers was constructed of 6 mm clear Plexiglas. The top drawers had a mesh of 3.81 cm diameter and the bottom one 1.91 cm.

McClure and Holmes (1979) investigated an inclined vibrating plate as tomato sorter. Separation into red and green fractions was successful for an angle of tilt of 40° at a frequency of 72 h and amplitude of 0.18 cm, because the green tomatoes bounced down while the red tomatoes sided up the incline.

Carlow (1980) designed a roller conveyor and fitted an electronic aid, when unwanted potatoes were touched by hand held wand and a vertically polarized radio frequency signal was emitted. The signal was received by a matrix of longitudinal and transverse coils situated under the roller deck. Changes in voltage in the coils were caused when the wand was energized and used to identify the coil intersection nearest to the wand. A signal was transferred to shift registers, synchronized with the grading table motion to operate a solenoid-actuated rejecter linger when the unwanted potato reached the end of the conveyor. In tests with rubber balls marked to signify a damaged area, it was found that in comparison with a standard roller table, the semi-automatic grader gave 20% improvement in grading efficiency, with a 15% defect level and from 50% to 60% improvement at 20% defect level.

Singh (1980) developed differential belt speed expanding pitch type potato grader. The main components of the grader were feed conveyor, frame, grading unit, and collection platform and power transmission unit. The grader required 1hp to drive its various components at full load. The maximum separation efficiency at optimum speed (35 r min^{-1} of grader shaft, 4.4 m min^{-1} of belt speed, 17.24 quintal h^{-1} of feed rate) was found to be 87%.

Gadakh and Gangarde (1981) tested the groundnut grader for effect of speed and angle of inclination of rollers on feeding rate and separation efficiency. They graded the groundnut pods of varieties JL-24 and SB-11 into four different size grades at various combination of speed (360, 440 and 560 r m-1) and angle of inclination (3.5°, 6.0°, and 9.0°) of rollers. They observed that as the speed and angle of inclination of rollers increased, the feed rate increased in variety JL-24. However, this relationship was not holding well in variety SB-11. While separation efficiency decreased, angle of inclination of rollers increased. The overall efficiency of the grader was observed to be 71.2%.

Akinaga and Khoda (1982) developed a sorter in which sorting was done on the basis of dimension of the fruits and vegetables (e. g. length, width). Compared with manual sorting accuracy of the sorter was found to be satisfactory.

Farher and Bruter (1983) described apparatus for sorting fruit and vegetables. It comprised rollers mounted on traction elements, guides and an inclined board. To reduce susceptibility to damage of the fruit, by preventing them from jamming the output section, there was a bracket in the output region turning the rollers.

Firus and Unbekannt (1985) described the potato grading accuracy. Grading characteristics at the limit of the set size accuracy were examined in terms of tuber size range. It was noted that separation function was independent of the size composition of the tuber mixture to be separated. Separation function was used to demonstrate that criteria of separation accuracy (proportion of undersized tuber mixture in a graded lot, losses of market size tubers, overall grading accuracy and degree of separation) were dependent upon the size composition of the mixture to be separated.

Davenel et al, (1988) designated four quality grades extra, No. 1, No. 2, and No. 3, having size range >65 mm, 60-65 mm, 55-60 mm and <55 mm respectively.

Anonymous (1989) developed a hand operated orange size grading machine which was based on tapering roller principle. The taper rollers required for this grader was fabricated from mango wood. A handle was provided to rotate the rollers meshed by gears at one end, and to operate the feeding mechanism. The collecting chutes were made out of gunny bags. Rest of the mechanism was similar to the separation part of the previous machine. The total 160 oranges consisting of 40 of each four grade were mixed and fed to grader. The distributed lot was collected and passed through the measuring rings, to confirm its size individually. Six replications were given with same fruits. The results showed that the new orange grader had around 80% separation efficiency with 5000 oranges per hour capacity.

Nevkar (1990) developed and tested the divergent roller type grader for effect of roller speed, angle of inclination of rollers, gap between the rollers on capacity and separation efficiency. The fruits were graded into four different size grades at various combination of speed (195, 216 and 278 r m-1), angle of inclination (4.59°, 5.6° and 6.1°) of rollers, gap between the rollers (2.83- 5.00, 2.84-5.20 and 2.87-5.40 cm) for lemon fruits and (3.07-7.00, 3.13-7.20, and 3.16-7.40 cm) for chiku fruits. He observed that the capacity of the machine increased with increase in roller speeds, inclination of rollers and gap between the rollers. A decreasing trend was observed for separation efficiency with increase in roller speed, angle of inclination and gap between the rollers for both fruits. The overall separation efficiency for lemon fruits was 71.71% and 66.75% for chiku fruits. The overall sorting capacity for lemon fruits was 603.94 kg h-1 and for chiku was 1,189.92 kg h-1.

Shyam et al. (1990) designed and developed a power operated sieve type potato grader that was capable of sorting potatoes into 4 or 5 different sizes or grades. The grader gave high sizing efficiency and 20-25qh^{-1} throughput capacity. The grader employed 10-14 attendants and achieved 80%-90% efficiency with average tuber damage within range of 2%. High labor requirement and re-orientation of the product in sieve opening were considered as problems and a little bit higher skin bruising was observed.

Suppavit and Butta (1995) described four grades of onions on basis of size. They developed a belt type grader to sort exported onions on basis of size. A Belt conveyor was also designed to carry onions from a container to a set of metering device. The grader graded the onions into four sizes <70 mm, 70-80 mm, 80-90 mm and >90 mm. These sizes were acceptable for abroad marketing. They further evaluated its performance at different belt velocities and lend the optimum velocity 0.13 ms^{-1} of the belt for maximum grading capacity of 3,150kgh^{-1} with an error of 2.46%.

Tariq et al, (1995) described four grades of potatoes for marketing purpose i.e., extra-large size (>70 mm), over size (55-70 mm), medium size (35-55 mm) and small size (<35 mm). Both the researchers had considered the same range (17 to 70 mm) but one had designated four grades while other had designated five grades.

Patil and Patil (2002) designed, developed and tested performance of sapota fruits grader. The machine developed was of divergent roller type. The effect of roller speed and gap between the rollers on capacity and separation efficiency was also studied. Three roller speeds (300, 360 and 450 r min-1) and three different gap between the rollers (3.0-5.5, 3.3-6.5 and 3.6-7.5 cm) were taken for testing the performance of machine. The maximum capacity of 1,800 kgh^{-1} and minimum capacity of 1,152 kgh^{-1} were obtained for sapota fruits. The overall machine sorting capacity for sapota was 1,727 kgh^{-1}. The maximum and the minimum separation efficiency was 87% and 54%, respectively. The overall separation efficiency of the machine was 72%.

Anonymous (2003) designed and developed a divergent roller type of onion grader Separation of onion was achieved on the basis of size. The spacing between the rollers was 35-80 mm from feed end to discharge end. The spacing between the roller increases feed end to rear end. The onions were graded into four different grades. The capacity of the grader was 500 kgh^{-1}. Sized onions passing between the rollers were collected in separate compartment.

Anonymous (2004) designated three grades on the basis of size for local market and these grades were large (>60 mm), medium (40-60 mm) and small (20- 40 mm) while Maharashtra State Agricultural Marketing Board made a standard for grading of onion on basis of size and designated five grades 25-35 mm, 35-45 mm, 45-55 mm, 55-65 mm, and above 65 mm.

Ghuman and Kumar (2005) studied on development of low cost rotary disc size grader for fruits and vegetables. Grading of fruits and vegetables is an important operation affecting quality, handling and storage of produce. Manual grading is costly, time-consuming and inefficient. A low cost, on-farm rotary disc size grader was designed and fabricated for grading spherical fruits and vegetables using rubber balls of different diameters in the laboratory. It was observed that the disc speed of 60- 70 r min^{-1} was the most suitable for proper separation of different grades. The grader was tested for various fruits and vegetables both in laboratory as well as in the field.

Mangaraj et al, (2005) studied on a stepwise expanding pitch fruit grader based on the principle of changing the flap spacing along the length of movement of fruits. The main components of the fruit grader were grading unit, elevator feeding unit, inspection platform and power transmission system. The grading unit consisted of two tracks of conveyor chains, matching sprockets, stainless steel flaps, conveyor supporters, flap space adjusting mechanism, power source, power transmission system and fruit collection trays. The elevator feeding unit was provided for constant and uniform feeding of fruits into the grading unit. The inspection plat form was provided for removal of damaged, diseased and unwanted fruits before they were fed to the elevator feeding unit. Cushioning material has been glued to the inspection platform, fruit collection tray and flaps to avoid impact damage at the time of grading. The grader had the provision to separate fruits into four grades by adjusting flap spacing between 45 to 140 mm. Testing of the fruit grader showed overall grading efficiency of 91.50% and 88.50% for sweet lemon and orange, respectively. The capacity of the grader was 3.5 $tonh^{-1}$ at grading conveyor speed of 6 m min^{-1}.

Ashraf et al., (2007) mentioned that under competitive market conditions of those days agriculture fruit and vegetables quality was of great importance. Grading of agricultural produce especially the fruit and vegetables had become a perquisite of across the borders trade. In Pakistan grading was mainly done manually that required significant labor work. Human operations might be inconsistent, less efficient and time consuming. New trends in marketing as specified by World Trade Organization (WTO) demand high quality graded products. , Farmers were looking forward to have an appropriate agricultural produce-grading machine in order to alleviate the labor shortage, time saving and graded products' quality improvement. Keeping in view the market requirements as desired by the WTO and quality conscious consumers, a spool type mobile grader machine was designed and developed, using locally available indigenous materials. Three functional units were fabricated: take-in conveyor, grading unit and take-away conveyor, all mounted on a main frame. For optimizing feed rate of the grader, three take-in conveyor speeds 10, 15 and 20 m/min were selected to load the crop on the grading unit at 6, 9 and 12 t/hr respectively. A drive mechanism with three speed levels 25, 50 and 75 rpm were developed to accommodate the different feed rates. To convey the graded produce to the packing point take-away conveyors were developed that operated at three speeds, 5, 10 and 15 m/min without causing the mutual collusion of the falling produce from grading unit. Increased grading speeds of about 75 rpm resulted in increased damage index whereas higher take-in conveyor speeds of about 20 m/min resulted in more grading errors. Effective human supervision was found important for ensuring smooth operation of the grader. The average grading charges were about Rs.4 /100 kg of produce.

Ghanbarian et al., (2008) observed that grading potatoes by size was an important operation for preparing tubers for seed and for commercial purposes. Farmers in Iran and in developing countries grade potatoes by hand, which was very slow and costly. This work concerned the development of a potato-grading machine for small-scale farmers. The design was characterized by a spiral structure covered with a capron net to form a cribriform rotating drum as the grading surface. Potato tubers were fed into the drum, moved forward by the spiral structure, and dropped through holes of the net according to their dimensions. The design parameters included net stiffness (T), rotating drum speed (n) and feeding rate (q). The grading accuracy of the machine was evaluated to determine optimum condition of machine performance. An acceptable grading accuracy of about 70% with a low tuber damage of 5.5% were obtained at T = 0.14 N/mm, n = 27 rpm and q = 2,500 kg/h as optimum condition.

Valentin et al., (2008) studied aim to come up with a functional potato grader for village level operations that would provide a practical means of grading marketable potato tubers by size. The grader operates on the principle of rotating spiral, grading unit, with increasing gaps starting from the inlet. Tubers of smaller minor diameter passed through the gaps. Machine parameters for the evaluation included the speed of the grading unit (RPM), inclination of the grading unit and feed rate (kg/min). These were tested on potato tubers taking note their influence on grading system efficiency, capacity, damaged tubers and power consumption as independent variables. Data were analyzed and the results indicated that optimum set-up of the grader was at 15 RPM speed of the grading unit, inclination of 100 and feed rate of 30 kg/min. giving a system efficiency of 94.5%, less damaged tubers of 1.85% and low power consumption of 18.1 W-hr. The cost of the grader was P37, 000.00 with a break-even quantity of 28 tons of tubers in one year.

2.2 Weight grading

Stephenson (1974) developed an electronic detection and high-speed rotary gate controls for sorting machine of harvested tomatoes. First on a sequence of operation, a means of singulation of fruits was accomplished, followed by scanning of each fruit for color by reflected light. Photocell sensors, an integrated circuit comparator and a controlled rotary gate detected and rejected green fruit at speeds up to eight fruits per fruit per channel. Sorting accuracies of 95 to 98% were obtained, sorting speeds up to six fruits per second per channel. Performance at higher speeds showed reduction in sorting accuracies.

Rana and Chauhan (1985) described four grades and these grades were designated on weight basis. Mostly the researchers designated grades to potatoes on the basis of size as per demand of the market as described by Roy, Wohab and Mustafa (2005). They designated four grades to potatoes (<28 mm, 28-40 mm, 40-55 mm and >55 mm.

Omre and Saxena (2003) designed and developed a multi-fruit grader that was capable of grading fruits into four grades (A, B, C and D) on the basis of weight. Grade A (>200 g), Grade B (150-200 g), Grade C (100-150 g) and Grade D (<100 g). The performance of the grader was evaluated at different speeds (5, 10, 15, 20, 25 and 30 $rmin^{-1}$) and was found satisfactory at carrier speeds of 12 and 15 r min^{-1} with overall grading efficiency of about 96%.

Mazara et al., (2010) was carried out an investigation to develop weight grader for sapota [*Manilkara achras* (Mill)]. Weight grader fitted with singulation unit was found to be more precise than any other. Since singulation unit would feed the fruits individually to electronic balance, single fruit grading could be achieved. The singulation unit fed the fruits to the load cell individually, where in fruits were weighed and carried to the grading unit, which actually consisted two gates which were operated electronically using the signal generated by the load cell depending on fruit weight. The overall separation efficiency of the grader was found to be 93.8%. The separation efficiency of W_3 grade (>120g) was found to be best. The speed was optimized for 20 rpm, which gave best overall efficiency.

Badhe et al, (2011) developed and evaluated a mango grader. A computerized grading machine was developed and evaluated to grade Alphonso mangoes on weight basis in five grades. Logistic software was developed to run the grader. The performance of the grader was evaluated at four speeds (480, 600, 720 and 840 m s-1), four microprocessor settings (B1, B2, B3 and B4) and their effect was observed on five grades of mango viz., Grade I (326-375 g), Grade II (276-325 g), Grade III (226-275 g), Grade IV (176-225 g) and Grade V (< 175 > 376 g) for single lane. The statistically analyzed data showed maximum capacity of 950 kg h^{-1} with maximum grading efficiency of 95.13% at $720ms^{-1}$ speed and B4 setting. The cost of manual grading was Rs. 350 per t as against Rs. 190 per t for the grader.

Widodo et al., (2012) developed a potato grader machine to classify potatoes into four classes according to SNI 01-3175-1992 based on the weight that was converted into potato diameter, and then it was used for determining the roller distance of the grader machine. Performance test indicated that the machine capacity was 1800 kg/hour with less than 8% of grading error and less than 1% of potato damage (bruise). Manual grading needed 25 persons/day/ha, Rp 27500,-/person/day, with average of potato yield of 15 tons/ha, manual grading cost was 46,-/kg, whereas by potato grader with capacity of 1800 kg/hour, grading cost was Rp 26,-/kg, it reduced grading cost down to 43% lower than manual grading cost.

Farhadi et al., (2012) studied that one of the main potato usages is seed consumptions. According to researchers, seed potatoes should position on the 50-80 g mass range. Two hundred potato samples were selected from the conventional varieties (Morfana and Agria) in Iran. Dimension and mass was measured and regression equations were calculated at Excel software. These equations solution at Matlab software eventuated numbers of 36.36 and 42.68 mm corresponding with 50-80g for Morfana, also 31.66 and 29.55 mm for Agria. These numbers indicated the situation of separator plates on the system. A new mechanism was suggested for gradation included a helix with variable distance. Effective parameters on the gradation helix were identified and attempts were done for their suitable selection. Hence, computer model prepared from the system. Then, coefficient of friction between polyethylene pipe and potato was obtained respectively 0.5583 and 0.4531 for Morfana and Agria using inclined plane at ten repeats. Finally, effective parameters on the system were chosen according to software analyses, conditions and limitations. Some experiments were done after set construction for achieving maximum gradation precision with optimal place determination of separator plates. Experiments results were numbers of 35 and 45 mm for Morfana, 28 and 33 mm for Agria. Theoretical and actual product transfer volumes were acquired 4.36 and 3 tons/hour. System required torque and power were 75 N.m and 71 Watt.

2.3 Screen grading

Balls (1986) described the screen or sieve type grader i.e. the perforated and mesh screen, which is the commonest method for two dimensional grading and, like the bar screen, is made either as a rigid screen or in the form of a conveyor. The grader screens normally have square holes, but for some crops, other shapes are preferable, for example, slotted for narcissus bulbs and round for tulips. He further described that set of screens could easily be changed to obtain a wide range of grading capability of the grader.

Hann and Van (1987) studied grading and sorting of potatoes using a square mesh riddle system with reference to uniformity, accuracy, damage and capacity. Quality sorting by hand selection, semi-automatic and electronic methods was discussed. Ergonomic aspects of hand sorting, densities of potatoes to be sorted, disposal arrangement for rejecting potatoes, positioning of inspectors, sorting table construction and attainable sorting capacity were included.

Shyam and Singh (1988) studied on sorting of potatoes into different size graded by mechanical sieving. They studied the effect of various parameters on the performance of the experimental power operated sieves for sorting potatoes into four different size grades. Results indicated that screen efficiency and blinding of sieves increased with decrease in sieve speed, stroke length and sieve slope. Screen efficiency was also increased with feed rate in the lower range but decreased as the feed rate was progressively increased. High screen efficiency upto 93.67% was obtained by providing little manual assistance to take care of blinding of sieves. However, tuber damage was consistently high.

Shyam and Singh (1988) developed a simple indigenous manual and power operated mechanical size grader with and without feed conveyor attachments which used successfully for sorting seed potatoes at the Central Potato Research Institute, Simala. The machine worked on the conventional principle of sieving. It comprised a steel frame, a set of two or three oscillating sieves, a power transmission unit, a stationary sieve feeding chute, a sorting platform and a bag filling device. The average field performance, power source, labour requirement and estimated operational costs of the manual and power operated size graders were noted.

Shyam et al, (1990) designed and developed a potato grader. Design consideration, constructional details, method of operation and performances was reported. On an average, the grader sorted 20 to 25 q h-1 of seed potato into 4 to 5 sizes employing 0 to 14 attendants. The screen efficiency of the oscillatory sieves ranged from 80 to 90% and average tuber damage was to be within 2%.

Doriaswatny (2000) developed a sieve type grader for grading groundnuts into three different sizes. The output capacity was 600 kg h-1 and was powered by one horsepower 3-phase electric motor. Re-orientation of pods in sieve holes was observed that required modification in shaking system.

Roy et al., (2005) was investigated that potatoes were sold in the market without grading in Bangladesh. If potatoes were sold after grading, this would be beneficial to both producers and consumers. Since mechanical graders were not available, potatoes were graded, when necessary, by hand. This was a time consuming, costly, and inefficient method. In view of this, a power-operated potato grader was designed and fabricated using M.S. angle, M.S. shaft, G.I. wire, and rubber tubes. The grader consisted of a frame, feeding mechanism, sieve, collection mechanism, and power transmission. The first prototype was developed and tested in the laboratory in 1998 to observe its performance. Based on the performance test the grader was modified especially the feeding mechanism. The maximum power consumption was found to be 1,637 watts. The average capacity of the grader was 2,030 kg/hr. The cost of grading was only Tk 0.03 per kg. No injury occurred to graded potatoes.

Narvankar and Singh (2005) studied on rotating screen grader suitable for fruits like lemon, ber, aonla to grade the samples into 4 grades. The grader was tested for capacity and optimum grading performance as a function of rotating speed of screen, diameter of screen, exposure length and input each at four levels by using second order response surface design in 80 design points. Capacity of the grader varied from 45 to 327.27 kg h^{-1} for lemon, 43.63 to 464.51 kg h^{-1} for aonla and 46.75 to 436.36 kg h^{-1} for ber. The maximum grading efficiency for lemon, aonla and ber was found to be 79%, 93.8% and 97.96% respectively.

2.4 Electronic color grading and reflectance grading

Heron and Zachariah (1974) studied an automatic sorting of processing tomatoes. A wide belt high capacity concept of color sorting was introduced. The sorter viewer observed three possible states, unripen tomato (rejects), ripe tomato (no action) and background. The amount of background observed by the viewer when a tomato was only partially in view was determined by the inherent focusing of a sorter-viewer. Test results showed that it was possible to increase the scanning speed (for increased capacity) to desired levels without detrimental effects on sorting accuracy.

Stephenson (1974) developed an electronic detection and high-speed rotary gate controls for sorting machine of harvested tomatoes. First on a sequence of operation, a means of simulation of fruits was accomplished, followed by scanning of each fruit for color by reflected light. Photocell sensors, an integrated circuit comparator and a controlled rotary gate detected and rejected green fruit at speeds up to eight fruits per fruit per channel.

Sorting accuracies of 98 to 95% were obtained, sorting speeds up to six fruits per second per channel. Performance at higher speeds showed reduction in sorting accuracies.

Noordam and Otten (2000) studied on high-speed potato grading and quality inspection based on a color vision system. A high-speed machine vision system for the quality inspection and grading of potatoes had been developed. The vision system graded potatoes on size, shape and external defects such as greening, mechanical damages, rhizoctonia, silver scab, common scab, cracks and growth cracks. A 3-CCD line-scan camera inspected the potatoes in flight as they passed under the camera. The use of mirrors obtained a 360-degree view of the potato and the lack of product holders guaranteed a full view of the potato. To achieve the required capacity of 12 t h^{-1}, 11 SHARC Digital Signal Processors performed the image processing and classification tasks. The total capacity of the system was about 50 potatoes per second. The color segmentation procedure used Linear Discriminant Analysis (LDA) in combination with a Mahalanobis distance classifier to classify the pixels. The procedure for the detection of misshapen potatoes used a Fourier based shape classification technique. Features such as area, eccentricity and central moments were used to discriminate between similar colored defects. Experiments with red and yellow skin-colored potatoes showed that the system was robust and consistent in its classification.

Ahmad et al, (2010) studied on development of automatic grading machine prototype for citrus using image processing. The grading machine consisted of a rotating fruit feeder, a belt conveyor, a color CCD camera placed in an image acquisition chamber, four openings each for a different grade of citrus, four collecting boxes to accommodate the graded citrus, a logic control panel, a computer with an image frame grabber, and developed software to run all the installed hardware. The performance test for the grading machine then was conducted, and the result of citrus classification was observed visually to determine the performance of the machine. The testing results showed that the machine prototype could work properly, and the classification of citrus could be done based on the fruit size as conventionally done, added by the skin color of citrus as an improvement to the manual sortation.

Golmohammadi et al, (2013) carried out a research to design and develop a potato sorting machine by means of image processing in the framework of a machine vision project. Following steps were considered: design of a feeder system, selection of a proper camera, optimization of the connection between the camera and computer, selection of a proper lighting system, design of input and output boards with least errors, selection of an accurate synchronizer, online commands and selection of accelerators based on their proper capacity. The system consisted of three major parts: the feeder, the processing and the accelerators. Each part was designed and made separately and then put together as a sorting system. In the design of the feeder system, based on the stabilization angle of different potatoes, an adjustable inclined belt conveyor was used. After testing a variety of light sources, 6400k fluorescent lamp was selected as the lighting system. The images were processed using MATLAB software. To separate potatoes, an accelerator system based on Pneumatic control valves and air pressure was used. As the system was online, all of timings related to image processing, product transferring and accelerators operation were calculated and applied based on the speed of the potatoes being fed to processing and sorting system. For the primary evaluation of the system, 100 kg of potatoes were manually sorted into three categories. Then the same potatoes were fed to the system, which sorted them out with an accuracy of 97.4% with the speed of two potatoes per second.

2.5 Miscellaneous grader

Srivastava et al, (1995) developed a potato-cum-onion grader. It consisted of a frame, an elevator, feed conveyor, a sizing conveyor, an intermediate receiving conveyor, a sizing conveyor with rubber spools and power transmission system. Sizing accuracy was better round shaped varieties than oblong or irregular shaped varieties.

Atwal and Gulati (2001) designed a prototype of rubber rollers type of potato grader. It consisted of main frame, grading rollers, conveyor belt and power transmission systems. Hollow rubber rollers resembling the shape of a tambourine/reel and having square hole (21mm diameter) in the center, mounted on steel shafts (21mm square) constituted the grading mechanism of this prototype. Power transmission system of the grader includes a 2HP electric motor and a reduction gear box with speed ratio of 15:1. Six categories of grades, viz. less than 10gm 10-25g, 50-75g, 75-100g and more than 100g could be obtained with this grader with almost negligible bruising. More than 6000 kg of potatoes could be graded in an hour when the speed of conveyor belt was 14m/ min and roller revolves at 83 rpm. Twelve persons were engaged for feeding and moving the gunny bags filled with graded tubers.

Butler et al., (2005) observed that the move away from subsistence to commercialized farming, combined with the rapid growth in demand for processed agricultural products in developing countries, implies that small-scale farmers and researchers alike must begin to respond to these market changes and consider post-harvest treatment as a critical aspect of the potato farming system. They developed a low cost potato-grading machine that was designed explicitly to enable small-scale potato growers to sort tubers by size for supply to commercial processors. The results of ten experiments revealed that the machine achieved an accuracy of sort similar to commercially available graders. The machine, which uses parallel conical rollers, had the capacity to grade different tuber shapes and to adjust sorting classes, making it suitable for locations with high potato diversity. Its relatively low cost suggested that an improved and adapted version of the machine might enhance market integration of small-scale potato producers not only in Peru, but in other developing countries as well.

Farhadi et al., (2012) examined that maximum of gradation precision and reasonable damage was conceivable at optimum speed and feed. Response surface statistical model was applied in MINITAB software for machine optimization and achieving suitable quantities. Thus, factorial design based on completely randomized design was done with two factors of speed and feed at three repeats. Speed and feed levels were selected respectively 9, 14, 20 RPM and 0.1094, 0.2188, 0.6565 kg/s. Precision was measured as correct graded mass divided by total mass at a specific grade. Results of statistical data analysis indicated 99% significant difference between factors and their interactions. In addition, optimum speed and feed respectively was obtained at 9 RPM and 0.1094 kg/s. System included precision of 70.45% for Morfana variety and 68.33% for Agria. Damages were under 5% in these conditions. Two series experiments were done at angle of 20º for machine. Mean precision respectively was acquired 69.8% and 65.31% for Morfana and Agria.

Londhe et al., (2013) observed that grading of agricultural produce especially the fruits and vegetables had become a perquisite of trading across borders. In India mostly fruit growers grade the fruit manually. Manual grading was carried out by trained operators who considered a number of grading factors and fruit were separated according to their physical quality. Manually grading was costly and grading operation was affected due to shortage of labor in peak seasons. Human operations might be inconsistent, less efficient and time consuming. New trends in marketing as specified by World Trade Organization (WTO) demand high quality graded products. Farmers were looking forward to having an appropriate agricultural produce-grading machine in order to alleviate the labor shortage, save time and improve graded product's quality. Grading of fruits was a very important operation as it fetches high price to the grower and improves packaging, handling and brings an overall improvement in marketing system. The fruits were generally graded on basis of size and graded fruits are more welcome in export market. Grading could reduce handling losses during transportation. Grading based on size consisted of divergent roller type principle having inclination, expanding pitch type, inclined vibrating plate and counter rotating roller having inclination type graders. Weight grading based on density and specific gravity of agricultural commodities. They needed to be responsive to market demand places a greater emphasis on quality assessment, resulting in the greater need for improved and more accurate grading and sorting practices. Size variation in vegetables like potatoes, onions provided a base for grading them in different categories. Every vegetable producing country had made their own standards of different grades keeping in view the market requirements.

Xiong et al, (2016) carried out a study based on the analysis of existing grading methods. The study focused on developing a new grading scheme for southern potato, which could automatically adjust the distance between two rolling bars. Using ADAMS software the dynamic simulation model of potato grader had been established, and the simulation results showed that the little potato P_1, middle-sized potato P_2 and big potato P_3 were separated successively. It could strongly prove that the design was feasible. There was little motion when the potatoes were under grading, which indicated that the device worked smoothly. The analysis results of contact forces showed that as the weight of the potato increased, the force between it and the rolling bars enhanced, especially for the force between the potato and the movable bars, as in the experiment the maximum value of the contact force between P4 and moving roll was 813.7N. The conclusions could provide the basic data to the optimum design of sample machine.

CHAPTER III

MATERIALS AND METHODS

CHAPTER III
MATERIALS AND MATHODS

This chapter consists of the list of the materials and instruments required for the construction of the potato grader, procedure of measuring the physical properties of the potato tubers, design considerations, procedure and formulas used for evaluation of the performance of the grader. The fabrication of the machine was done in a local workshop in Dinajpur town using locally available materials and the performance study was carried out in the Agricultural Engineering lab-3 under the Dept. of AIE of HSTU, Dinajpur.

3.1. Materials and Instruments Required:

The instruments required for measuring the physical properties of potato are:

i. Slide Calipers (0.1 mm): used for measuring diameter of potato.
ii. Digital Balance with accuracy of 0.01g: used for measuring weight of potato.

Materials required for the fabrication of potato grader:

i. Plastic Oil Container: used for making grading unit.
ii. M. S. sheet: used for making tray and hopper.
iii. M. S. hose pipe: used for making shaft.
iv. M. S. flat bars: used for making frame.
v. M. S. angle bars: used for making frame.
vi. Star joint bolts: used for joining different parts of the grader.
vii. Nut and bolts: used for joining different parts of the grader.
viii. Ball-bearing: attached with the shaft for rotating the grading unit.
ix. V- Belt: used for power transmission system.
x. V- Pulley: used for power transmission system.
xi. Electric motor: used as prime mover.
xii. Gear box: used for speed reduction
xiii. Miscellaneous small items

Instruments required for the fabrication of the potato grader:

i. Welding Machine
ii. Lathe Machine
iii. Drill Machine
iv. Drill Bit
v. Tool box

3.2. Physical Properties of Potato Tubers

Cardinal and Granola are most commonly grown varieties in Bangladesh. Physical characteristics of these two potato varieties were measured. From each variety 100 samples were randomly selected. Their mass and diameter were measured using digital balance with accuracy of 0.01 g and slide caliper (0.1 mm). The mean, standard deviation, maximum, minimum, coefficient of variation, quartile and percentile (33, 66 percent) were calculated using data analysis software SPSS version 22. The equation for the relationship between mass and diameter was estimated for 200 tubers using Excel software.

3.3. Design Considerations and Machine Construction

The grader was made of locally available materials to keep the cost low. It was fabricated at a local workshop in Dinajpur town. Efforts were made to keep the mechanism and operation of the machine as simple as possible. Figure-1 shows the conceptual design and Figure-2 shows the pictorial view of the potato grader. The unit comprised of a hopper, grading unit, prime mover and catchment tray fitted on a frame.

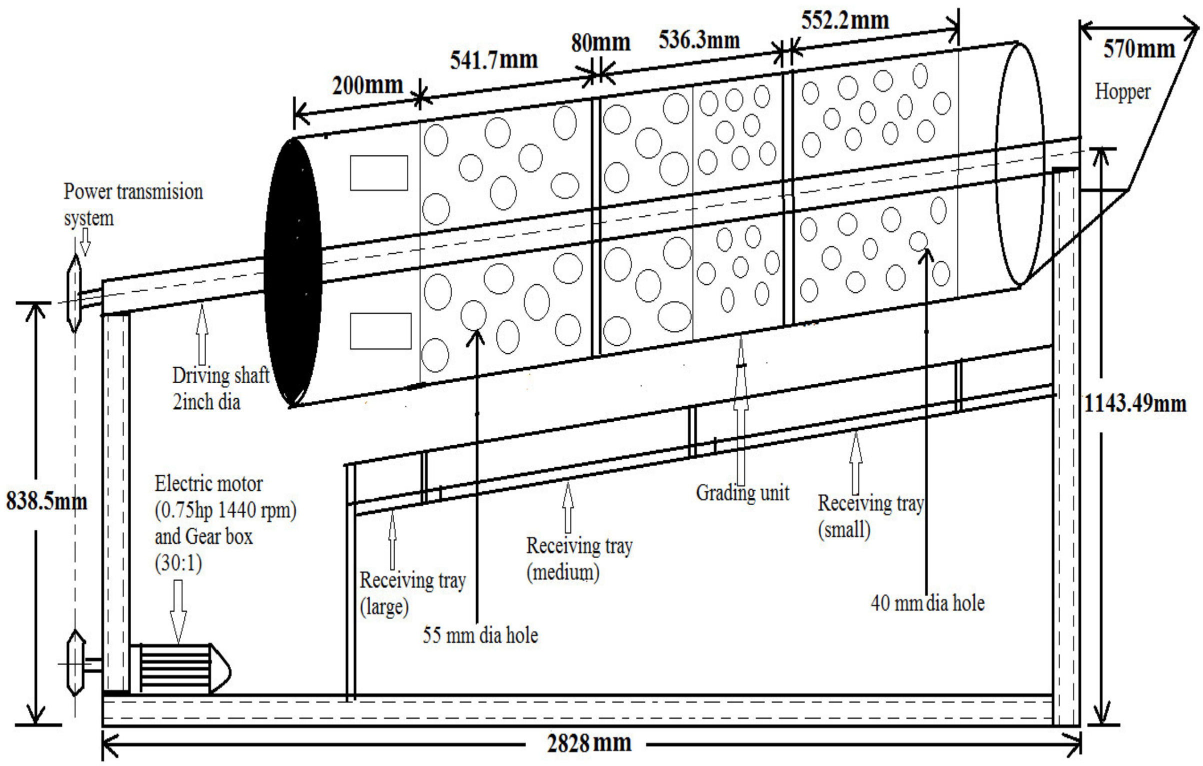

Fig-1: Schematic diagram of the potato grader.

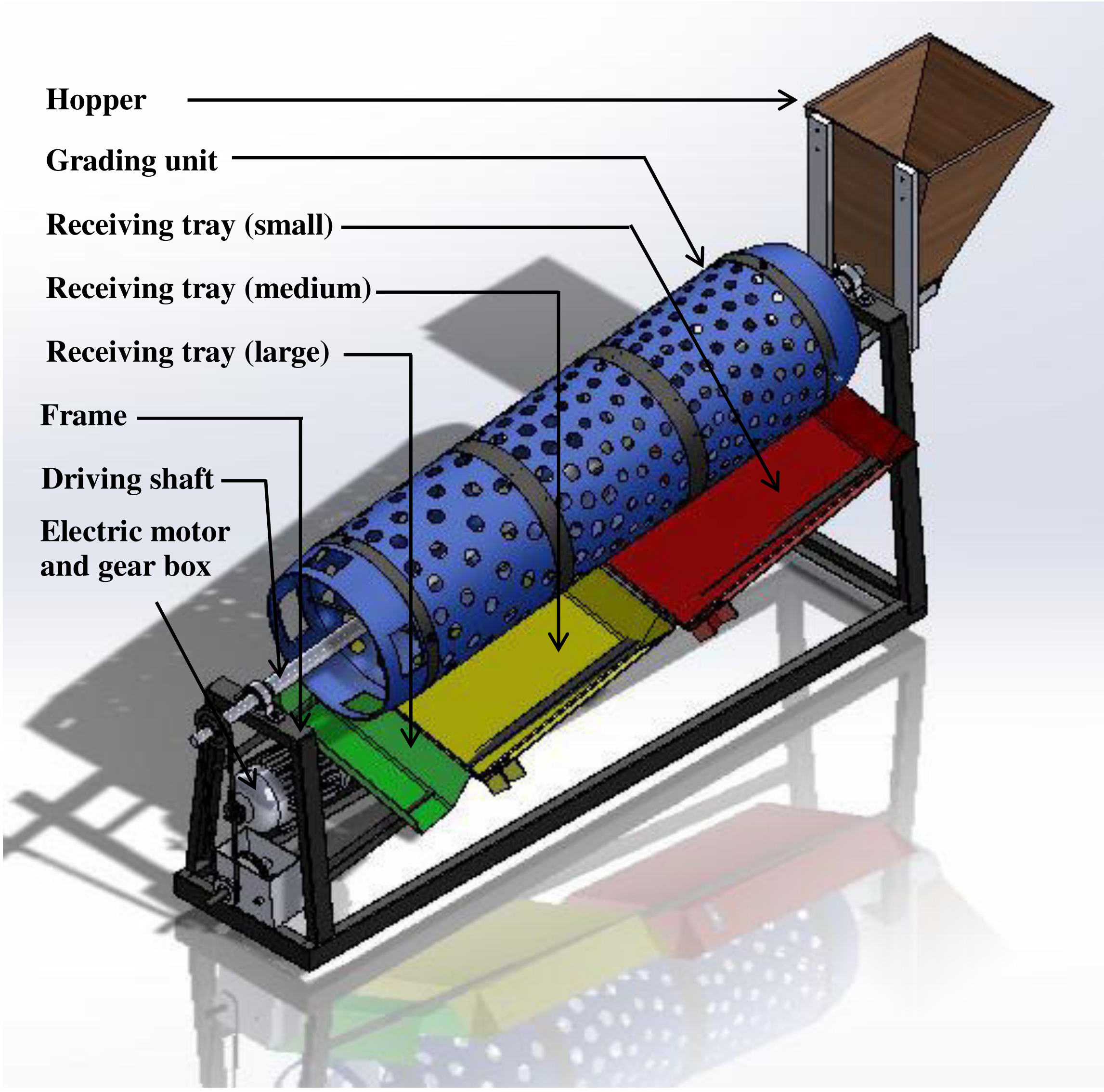

Fig-2: Pictorial view of the potato grader

3.3.1. Grading Unit

Figure-5 shows the engineering drawing of the grading unit. It was cylindrical in shape having 584 mm diameter and 2205 mm long and 5 mm thick, made by connecting three empty plastic oil containers having equal diameter (584 mm) with the help of Mild Steel sheet and star joint bolts. The grading unit were divided into three parts; in the first part 40 mm diameter holes were made for separating small size potato, in the second part 55 mm diameter holes were made for separating medium size potato with the help of specially constructed drill bit and in the last part extra-large holes were made for separating the remaining large size potato. Two mild steel flat bars were connected in the inside wall of the grading unit for uniformly distributing the potatoes.

Fig-3: Special drill bit for making hole

Fig-4: Making hole in the grading unit

3.3.2. Shaft

The grading unit was connected with a shaft with the help of tie rod and nut. Figure-6 shows the engineering drawing of the shaft. The shaft was 63.5 mm diameter and 3075 mm long, made by M.S hose pipe and M.S. shaft and driven by an electric motor. It was fitted to the frame by attaching UCP block bearing-210 at both end with the help of nut and bolt at an inclination angle of 6^0 from inlet to outlet.

3.3.3. Hoper

The hopper was made up of 24 gauge thick steel sheet. It was taper from top (inlet) to bottom (outlet) with an angle of 60^0. The area of the hopper in the top was 570×570 mm and in the bottom 210×270 mm and the height of the hopper was 570 mm. Figure-7

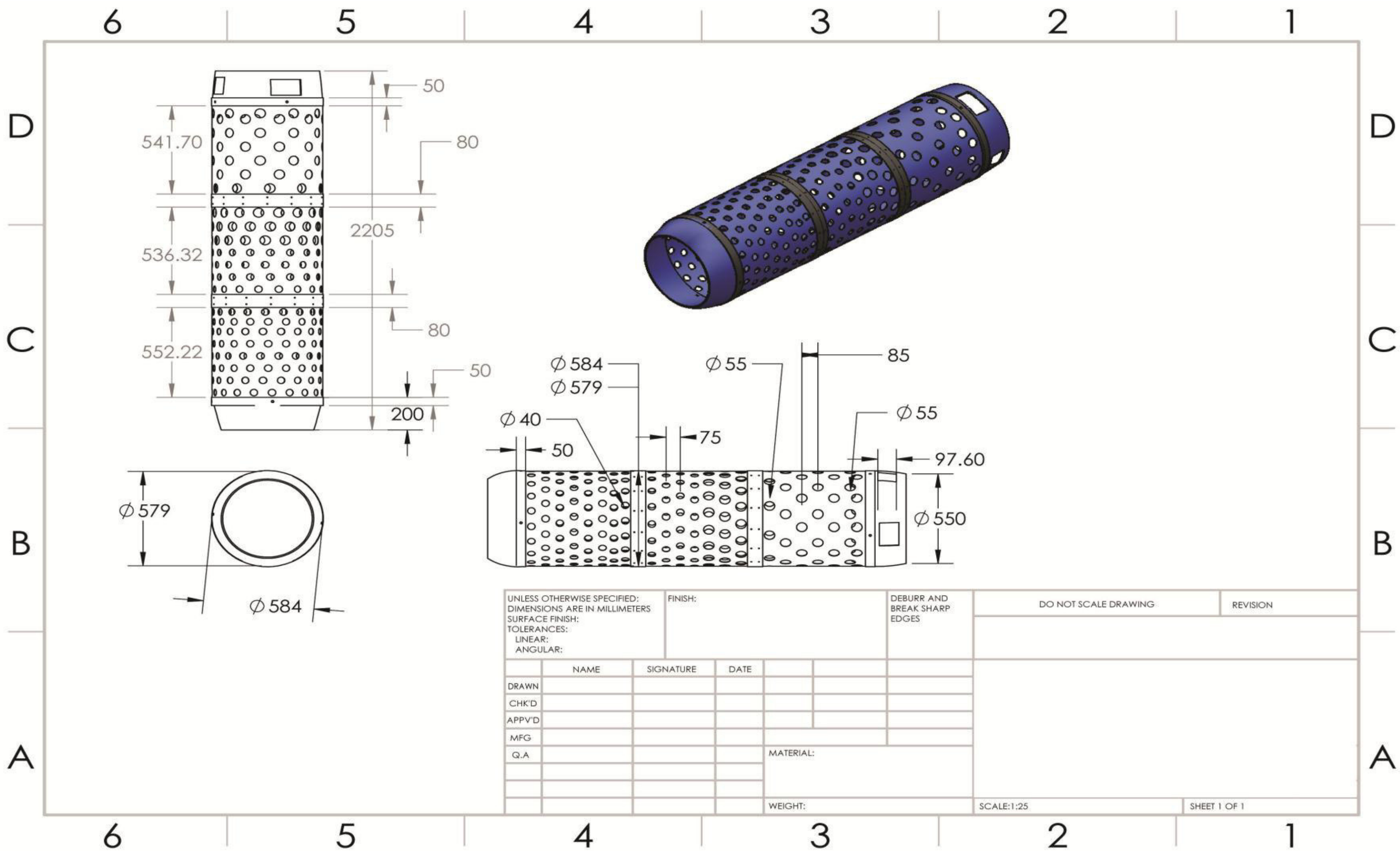

Fig-5: Engineering drawing of the grading unit (Dimensions are in mm)

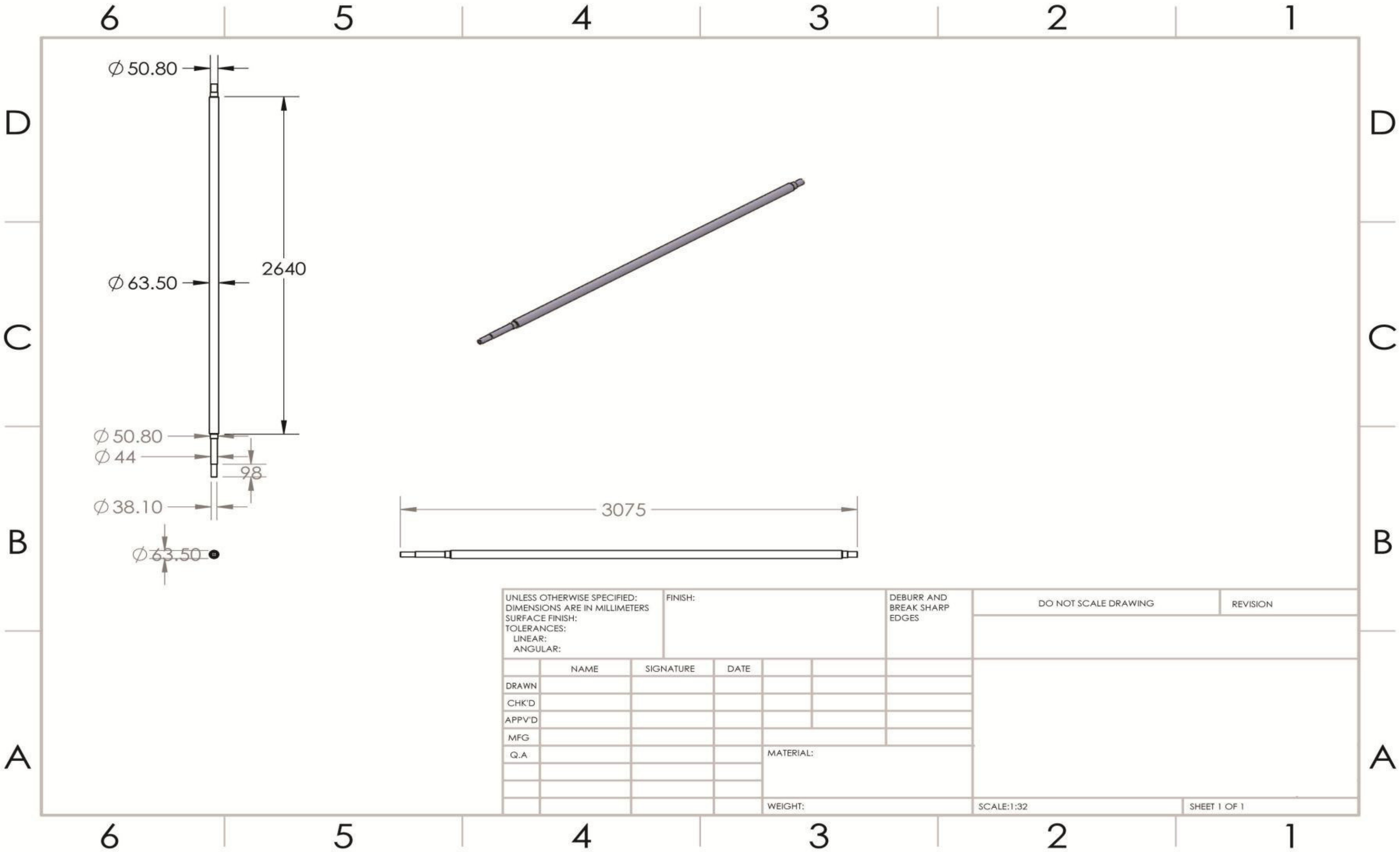

Fig-6: Engineering drawing of the shaft (Dimensions are in mm)

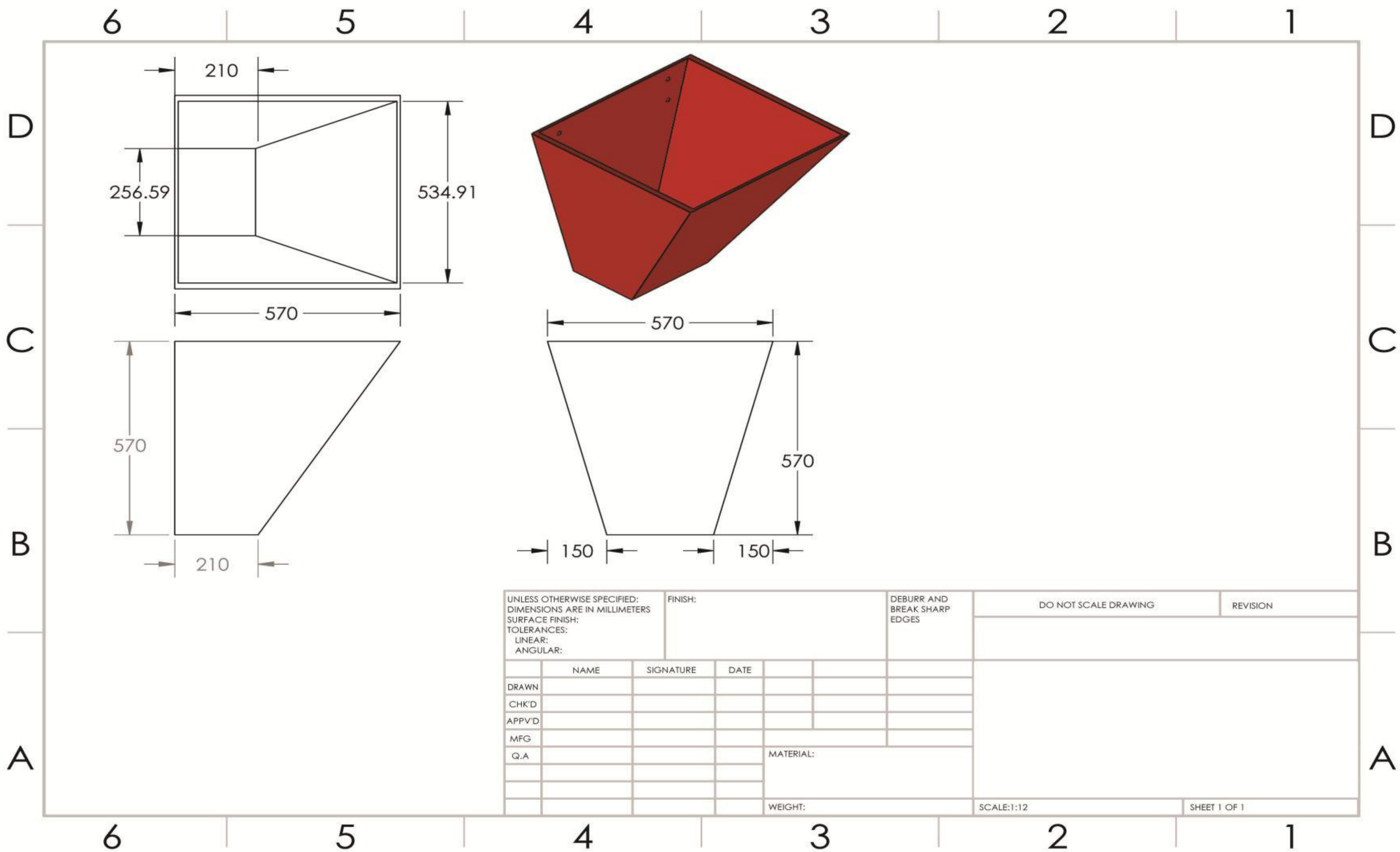

Fig-7: Engineering drawing of the hopper (Dimensions are in mm)

shows the engineering drawing of the hopper. A canal having size 305×305×152.4 mm from the bottom of the hopper was fitted to the grading unit at an angle of 45^0. Potato tubers were placed onto the hopper and then rolled down into the rotating drum.

3.3.4. Frame

Figure-8 shows the engineering drawing of the frame. The frame of the grader was made up of 76.2× 38 mm M.S. canal and was 2828 mm long, 610 mm width, 1143.49 mm height at the inlet and 838.51 mm height at the outlet side for making 6^0 inclination of the grading unit. All the joints were made by welding to make the machine strong, rigid, and to reduce the vibration at the time of operation.

3.3.5 Receiving Tray

There were three receiving trays used in the grader for collecting small, medium and large size potato respectively, which were made by M.S. sheet. These were fitted with the frame by making a stand with the help of 25.4×25.4 mm M.S. angle bar at an angle of 30^0. Figure-8, 9&10 shows the engineering drawing of the three receiving trays respectively. The dimension of the tray for small and medium size was 950×500×150 mm and 7600×500×150 mm respectively but the dimension of the tray for large size was 150×600×150 mm.

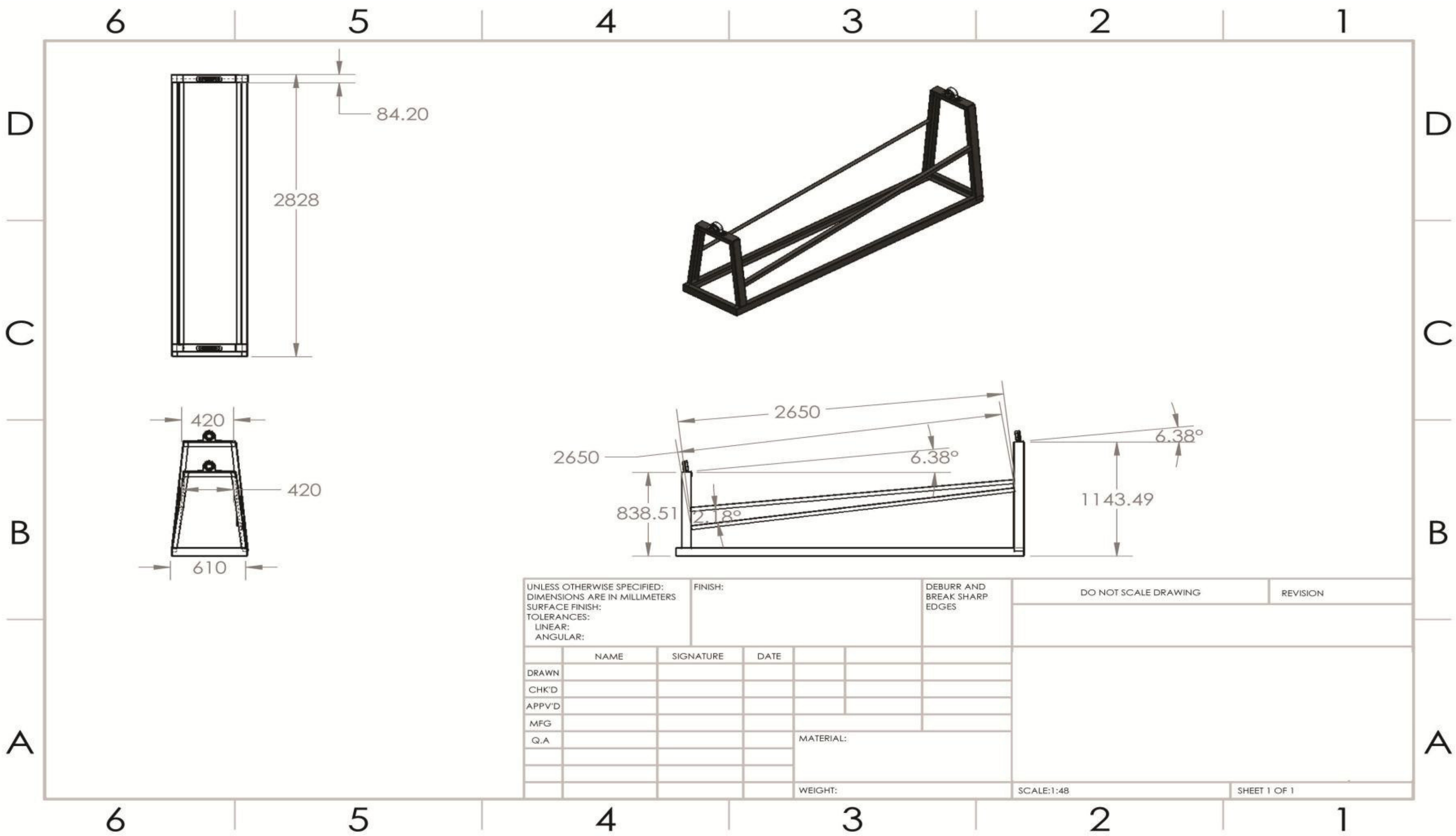

Fig-8: Engineering drawing of the frame (Dimensions are in mm)

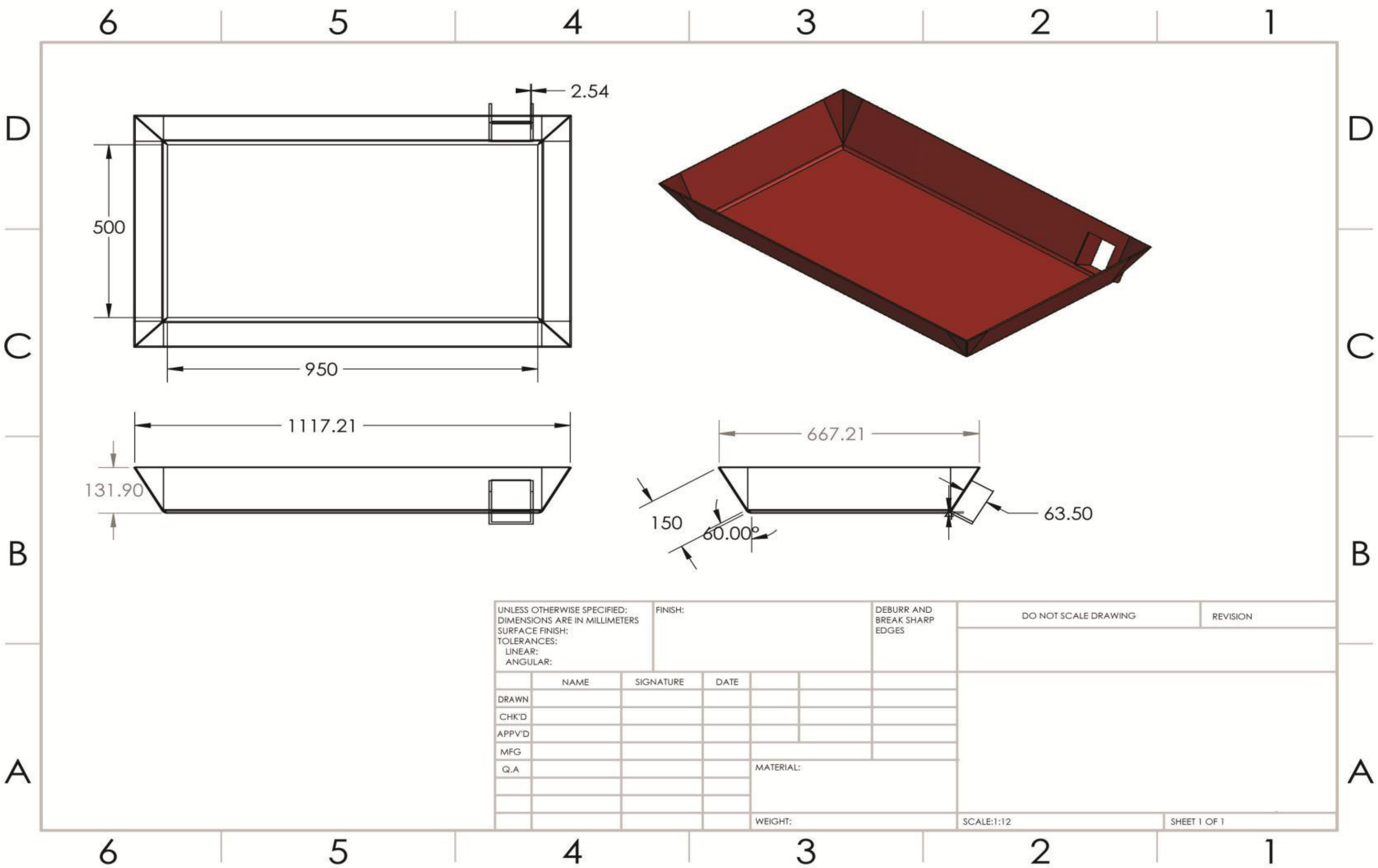

Fig-9: Engineering drawing of the receiving tray-1 (Dimensions are in mm)

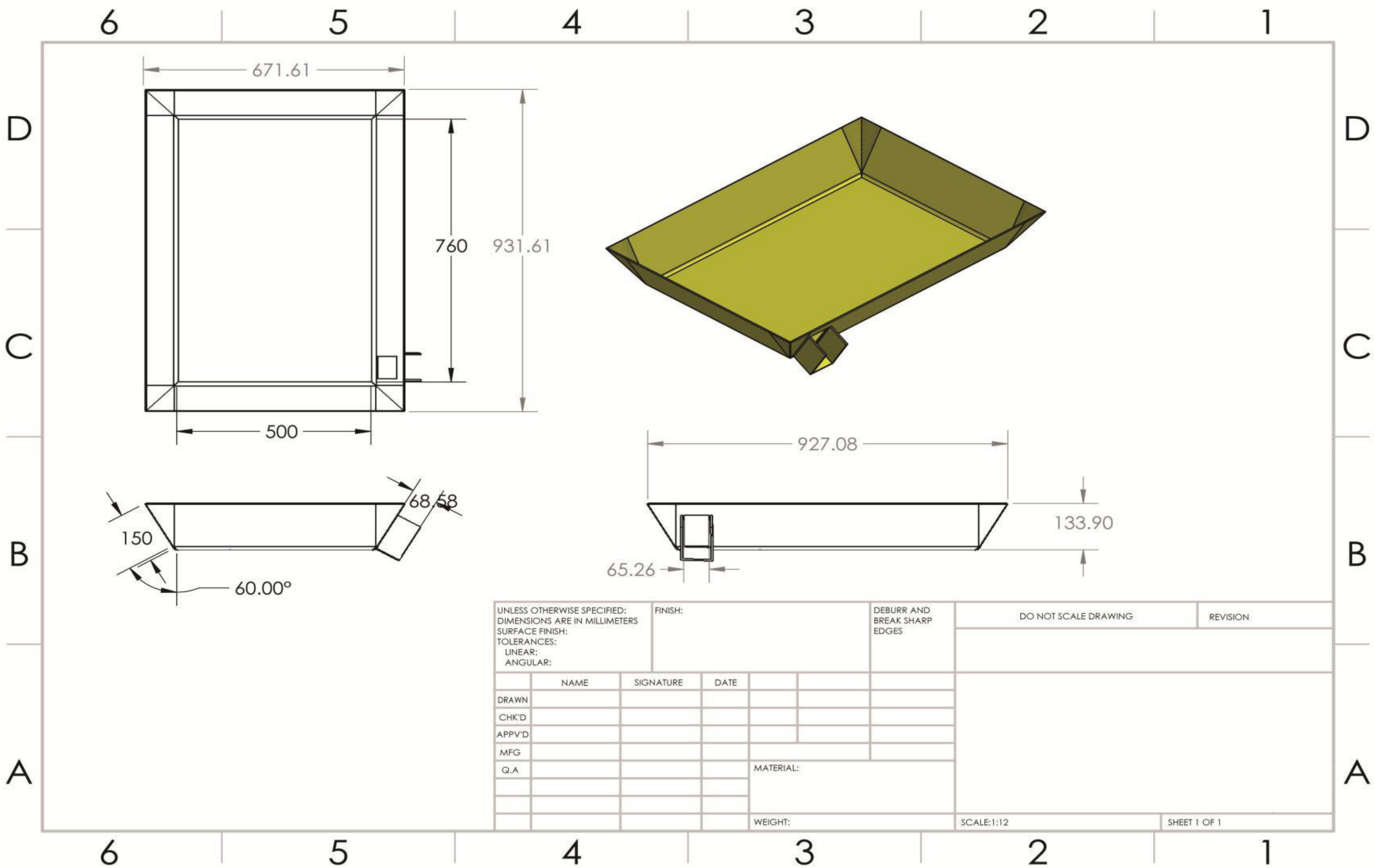

Fig-10: Engineering drawing of the receiving tray-2 (Dimensions are in mm)

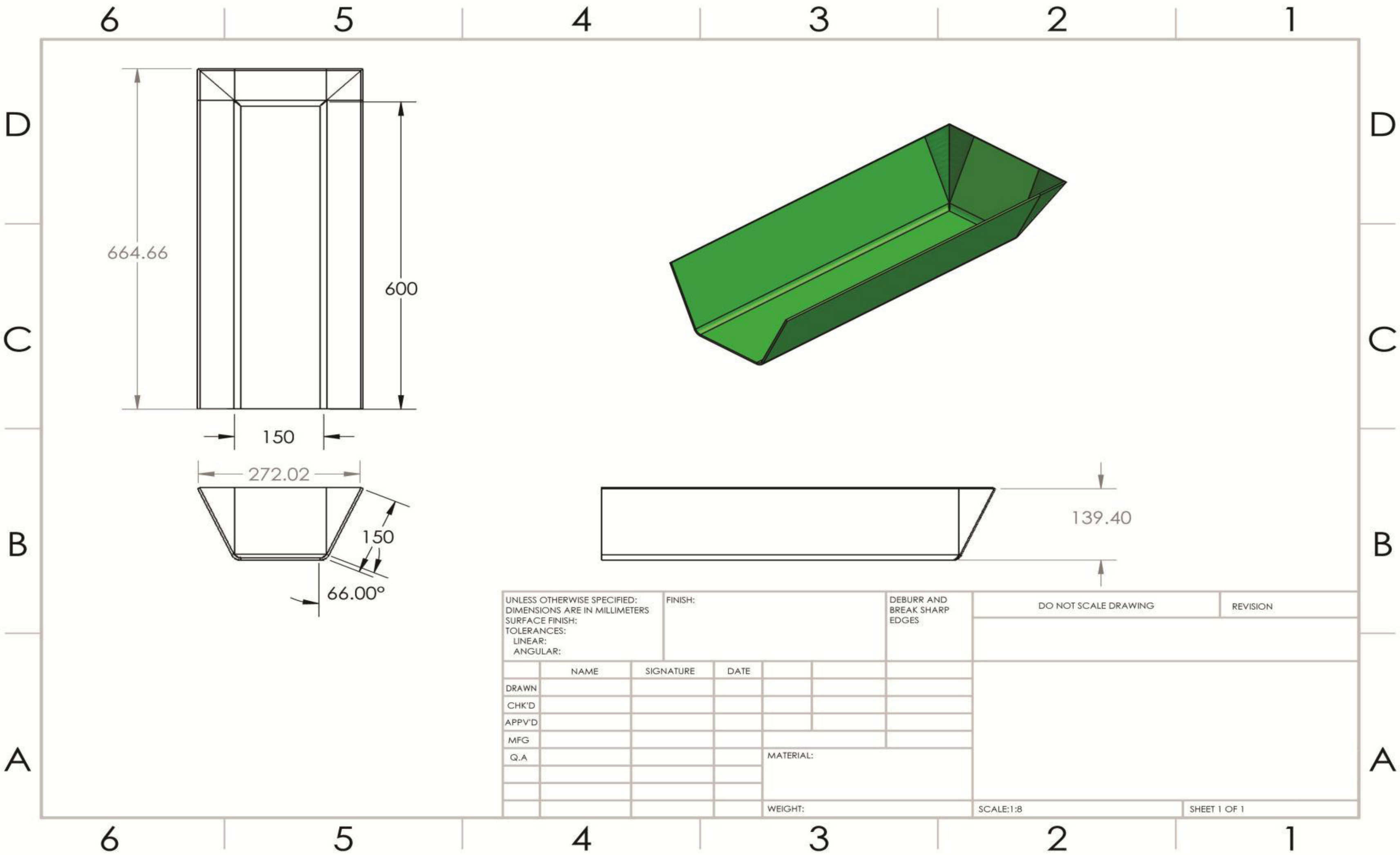

Fig-11: Engineering drawing of the receiving tray-3 (Dimensions are in mm)

3.3.6 Prime Mover

A 0.75hp, 2 phase, 1420 rpm electric motor was fitted at the bottom of the frame at the outlet end of the grader. The power required for rotating the grading unit was calculated by using the following equations,

Find the torque first,

$$T = I * a$$

Where

T = Torque, N-m

I = Moment of Inertia, kg-m^2

a = Angular acceleration, rad/sec^2

Moment of inertia for a hollow cylinder

$$I = MR^2$$

Where

M = Mass, kg

R = Radius of the cylinder, m

Then the required Horsepower

$$P = {}^{2\pi NT}/_{60}$$

Where

P= Required power, W

T= Torque, N-m

N= Required RPM

3.3.7 Power Transmission

Power was transmitted from the prime mover to the grading unit using pulley and V-belt. A gear box (30:1) was also used to reduce the RPM of the motor. The size of the pulley was determined by using this formula,

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

Where,

D_1= Diameter of small pulley

N_1= RPM of small pulley

D_2= Diameter of large pulley

N_2= RPM of large pulley

The pitch length (L) of the belt was calculated from the formula,

$$L = 2C + \pi(D + d)/_2 + (D - d)^2/_{4C} \qquad \text{(Faires, 1965)}$$

Where,

D is the diameter of big pulley, d is the diameter of small pulley and C is the center distance between the pulleys.

The specification and number of V-belts required to transmit the power was determined using the tables compiled by Faires (1965).

Fig-12: Final design of the potato grader in 3D isometric view

3.4. Working Principle

Potato tubers were fed into the hopper and then rolled down into the grading unit. The principle of operation of the device begins with the rotating motion of the grading unit through the prime mover. Tubers with small, medium and large diameters pass through the respective holes during rotation and are collected in the respective tray provided below the grading unit.

3.5 Performance Test

3.5.1. Design of Experiments

The experimental design for performance test of the grading machine was done for three rpm of the rotating unit and three degree of inclination of the grading unit with the horizontal. The experimental design is shown in table-1.

Table-1: Experimental design for performance test

RPM of the grading unit	Inclination angle (degree)
6	3
	6
	9
9	3
	6
	9
12	3
	6
	9

3.5.2. Machine Parameters

Two machine parameters were used during the evaluation. These were the speed of the grading unit (6, 9 and 12 RPM) and the inclination of the grading unit (3, 6and 9 degrees). The influence of these machine parameters to the performance of the machine during the evaluation was observed. Machine performance, response variables, was indicated by the grading system efficiency (GSE) in percent, capacity (C) in kg/min, percent damage tubers and power consumption in W-hr.

Grading System Efficiency (GSE)

The grading system efficiency was determined by taking the products of the efficiency of small, medium and large regions as shown in Eq. 1 (Valentin et al., 2016).Where $\mathrm{eff_S}$ is the efficiency, in decimal, of the small region of the grader to classify the small tubers, $\mathrm{eff_M}$ is the efficiency of the medium region and $\mathrm{eff_L}$ is the efficiency of the large region.

$$\mathrm{GSE} = (\mathrm{eff_S} \times \mathrm{eff_M} \times \mathrm{eff_L}) \times 100,\ \% \qquad \text{Eq. 1}$$

Capacity (C)

The capacity of the grader was determined by considering the time it takes to grade the given quantity of tubers. In this study 7 kg of tubers were used for each experiment. The capacity is expressed in kg/hr as shown in Eq. 2 (Valentin et al., 2016). Where W is the quantity of potato in kg and t is the time in hr.

$$C = \frac{W}{t}, \ \ {}^{kg}/_{hr} \qquad \text{Eq. 2}$$

Power Consumption

The power consumption was taken by simply taking products of the rated size of the prime mover of the grader and the time of operation. In this study 0.75 hp motor was used. Power consumption is related by Eq. 3 (Valentin et al., 2016) where t is the time of operation in hours.

$$P = \text{kilowatts} \times t, \ \ KW - hrs \qquad \text{Eq. 3}$$

Damage Percentage

Damage was accounted as those tubers with abrasion after the grading operation. The percentage of damage tubers were taken by considering the total number of tubers with abrasion after the operation against the total number of tubers prior to the operation. Abrasion was visually inspected and those tubers with abrasion of 5% higher than the surface area were considered damaged as shown in Eq. 4 (Valentin et al., 2016).

$$\text{Damage Tuber}, \% = \frac{\text{Total number of tubers with abrasion}}{\text{Total number of tubers in the sample}} \times 100 \qquad \text{Eq. 4}$$

3.5.3. Samples Preparation

A quantity of 200 kg of Potato tubers for the chosen variety (Cardinal) were procured from the market in August 15, 2017. Tubers with initial damages such as scratches, abrasion, decay and greening were not considered in the sample. Thus, there was no initial damage during the testing of the device. The samples were divided into 27 groups with 7 kg each containing small, medium and large. On the average, each group had 50% small, 30% medium and 20% large-sized tubers. Each tuber was manually measured with slide caliper to determine the size and was given a label to easily distinguish after grading. The samples were prepared by following Valentin et al., (2016).

3.5.4. Test run

A test runs of 27 were used in the study with 9 treatment combination and 3 replications. Each replication used 7 kg of potato tubers as initially prepared.

Fig-13: Performance test of the grader   Fig-14: Expert members visiting the grader

3.5.5. Evaluation procedures

As initially prepared, each 7 kg of potato tubers were loaded into the hopper while the grading unit was rotating. After the grading operation, tubers that dropped on the appropriate region and number of damaged tuber were counted and recorded. This was to determine the grading efficiency of each region as shown in Eq. 4, 5, 6 and 7 (Valentin et al., 2016). The time, in seconds, it took to grade the samples were also recorded.

$$\text{eff}_S = \frac{\text{Number of correctly graded small tubers}}{\text{Total number of small tubers in the sample}} \qquad \text{Eq. 5}$$

$$\text{eff}_M = \frac{\text{Number of correctly graded medium tubers}}{\text{Total number of medium tubers in the sample}} \qquad \text{Eq. 6}$$

$$\text{eff}_L = \frac{\text{Number of correctly graded large tubers}}{\text{Total number of large tubers in the sample}} \qquad \text{Eq. 7}$$

3.6. Economics analysis of the Potato Grader

A Simple cost analysis was done for the potato grader. The analysis included the actual cost of the device, annual fixed cost and variable cost. The annual fixed cost included depreciation, interest and TIS (Taxes, Insurance and Shelter).Variable cost included repair and maintenance cost, labor cost and electricity cost. Assumption was made as interest 13%, tax, insurance and shelter (TIS) 3%, repair and maintenance cost 10%, operation per day 8 hrs, annual use 500 hrs and estimated life span 10 yrs of the machine. The cost was calculated using following formulas:

The annual depreciation was calculated as

$$D = P - S/L \qquad \text{Eqn 8}$$

Where, D is the depreciation, P is the purchase price of the machine, S is the salvage or selling price and L is the time between buying and selling.

Interest on investment was calculated as

$$I = [P + S/2] \times i \qquad \text{Eqn 9}$$

Where, I is the interest on investment, P is the purchase price of the machine, S is the salvage or selling price, i is the current interest rate.

Total cost per year calculated as

Total cost = Annual fixed cost + Variable cost Eqn 10

Break-even point of the device was considered in this study which is expressed in terms of the amount of tubers needed to grade per year. Break even cost of the device is given by Eq. 11 (Valentin et al., 2016) where CR is the custom rate, AFC is the annual fixed cost and VC is the variable cost.

$$\mathrm{BEP} = \frac{\mathrm{AFC}}{\mathrm{CR} - \mathrm{VC}} \qquad \text{Eq. 11}$$

CHAPTER IV

RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

This chapter describes the results obtained from the experimental procedures designed in the methodology section. The result expressed here are on the basis of relationship of the size of potatoes, performance study conducted using the developed machine in respect of grading efficiency and the analysis of cost factors for grading.

4.1. Physical Properties of Potato Tubers

The mean, standard deviation, maximum, and minimum, coefficient of variation, quartile and percentile (33, 66 percent) of physical properties (mass and diameter) of the potato tubers are shown in the table 2:

Table-2: The physical characteristics of the potatoes

Statistical parameters		**Mass(g)**	**Diameter (mm)**
N	Valid	200	200
	Missing	0	0
Mean		40.36	48.91
Median		33.10	46.00
Mode		14.80	35.00
Std. Deviation		31.29	15.56
Variance		979.29	242.13
Minimum		6.10	22.20
Maximum		194.10	108.00
Percentiles	25	18.60	35.00
	33	23.60	39.56
	50	33.10	46.00
	66	41.32	55.23
	75	47.75	57.69

Results in the table 2 indicated that the maximum and minimum diameters of the selected potato variety were 108 mm and 22.20 mm. The mean diameter was 48.91 mm. Also the maximum and minimum mass of the potato tubers were 6.10 gm and 194.10 gm with a mean of 40.36 gm. Diameter ranges of product separation were under 40, 40-55 and above 55 mm selected according to the percentiles. The relationship between mass and diameter of measured potatoes could be expressed by the equation,

$$Y = 10.986X^{0.4179} \text{ Where } R^2 = 0.89$$

Where, Y= Mass, g and

X= Diameter, mm

4.2. Specifications of the Potato grader

The fabricated machine tested in the study was a drum type potato grader which had the following components: hopper, grading unit, receiving tray and power transmission system. Table-3 presents the final specifications of the device after fabrication.

Table-3: Specifications of the drum type potato grader

Item	Specification
A. Capacity, kg/hr B. Grading Efficiency,% C. Damage,%	280 kg/hr 88.40 2.22
D. Main structure Overall Dimensions Length, mm Width, mm Height, mm	 2828 610 1500
E. Grading unit assembly	
Length, mm	2205
Diameter, mm	584
F. Feeding mechanism type	Manual feeding, hopper type
G. Prime mover	220 V, 0.75hp single phase, capacitor type electric motor
H. Gear box	30:1
I. Transmission system	Open drive belt and pulley combination
Pulley 1	38.1mm
Pulley 2	101.6mm
Pulley 3	50.8mm, 76.2mm, 101.6mm
Pulley 4	152.4mm
Belt type	V-belt, A-36, A-64,A-65, A-66

4.3. Performance Evaluation of the grader

The overall performance of the grader was determined by measuring different parameters considered in the study. The grading capacity, grading system efficiency (GSE), damage percentage and power consumption of the grader as affected by speed and inclination angle of the grading cylinder were computed and analyzed.

4.3.1. Combined effect of speed and inclination angle on the performance

Table 4 shows the summary of the results on the performance evaluation of the device.

Table-4: Interaction effect of the speed and inclination angle of the grading unit on the performance of the grader

RPM	Angle (degree)	GSE (%)	Capacity (kg/hr)	Damaged Tubers (%)	Power Consumption w-hr/sample
6	3	88.40	280.90	2.22	13.95
	6	82.05	357.37	1.90	10.95
	9	72.81	501.49	1.58	7.80
9	3	82.64	320.65	1.90	12.19
	6	73.67	469.53	1.58	8.37
	9	65.39	620.26	1.58	6.30
12	3	69.08	458.58	1.58	8.52
	6	61.00	587.57	1.58	6.66
	9	52.13	709.93	1.26	6.54

The table 4 shows that the maximum capacity of the grader was found to be 710 kg/hr at 12 rpm and 9^0 of inclination angle. But at the same time the grading efficiency was very low (52.13 %). At the same time the percentages of damaged tubers were low (1.26 %) and power consumption also low (6.54 w-hr/sample). On the other hand, the grading efficiency was high (88.40 %) at 6 rpm and 3^0 inclinations angle with the lowest capacity (280.90 kg/hr). At the same time the percentage of damaged tubers were high (2.22 %) and power consumption also high (13.95 w-hr/sample). It shows from the table that there are variations of grading capacity, efficiency, damaged tubers and power consumption with variations of RPM and angle of inclination.

Grading system efficiency (GSE)

Comparison of means fig-8 showed that the best combination to achieve the highest grading system efficiency was operating the machine at 6 RPM with 3degree inclination. The lowest grading system efficiency was found when operating at 12 RPM with 9 degree inclination. The grading system efficiency gradually decreased with increasing the speed and inclination of the grading unit. This was because with increasing the speed and inclination of the grading unit, the potato tubers moved first through the grading unit. For this reason some of the small size potato tubers moved into the region of hole for medium size classification and some of the medium size move into the large size region which decreased the grading system efficiency.

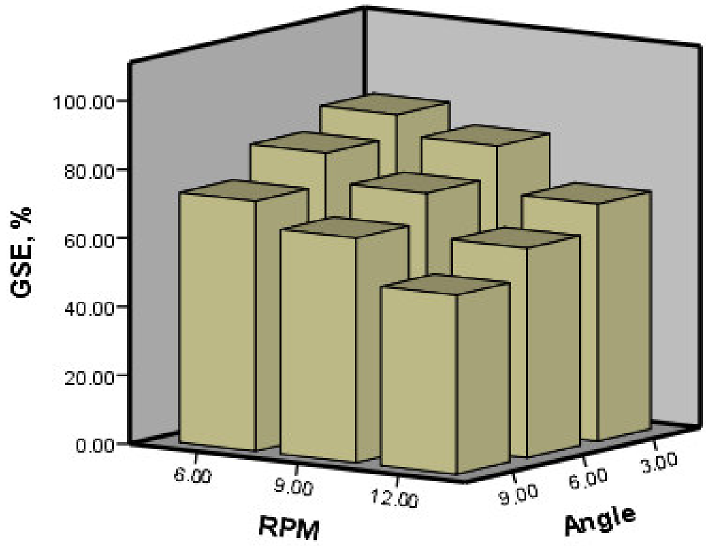

Fig-15: Interaction effect of speed and inclination on grading system efficiency

Capacity

Fig-9 shows that the highest grading capacity achieved when the machine was operated at 9 degree inclination and speed of operation of the machine 12 RPM, with a value of 709.93 kg/hr. The lowest grading capacity was found when the grader was operated at 6 RPM with an angle of 3 degree inclination with a value of 280.90 kg/hr. The results show that grading capacity gradually increased with increasing the speed and inclination of the grading unit and decreased with decreasing the speed and inclination. This is because the potato tubers move first through the grading unit with increasing the speed and inclination of the grading unit. For this reason greater amount of potato was graded with less time hence the capacity was increased. For the grading operation it will therefore important to select suitable combination on the basis of use and grading efficiency requirements.

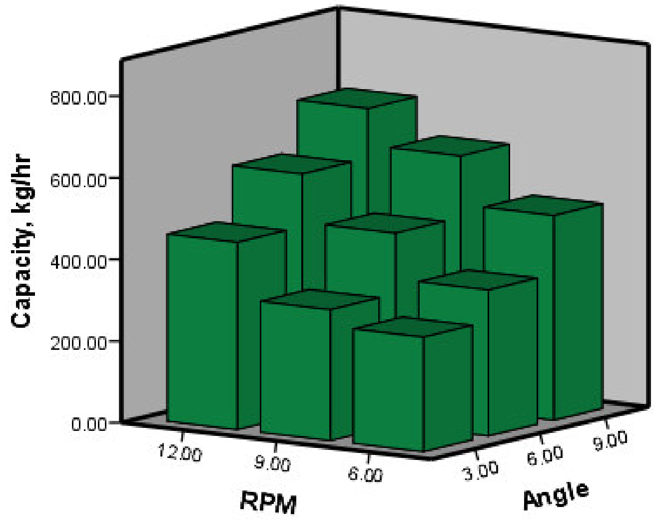

Fig-16: Interaction effect of speed and inclination on capacity of the grader

Damaged tubers

Fig-10 shows that minimal damaged tubers were found when the grader was operated at 12 RPM and 9 degree inclination with a value of 1.26%. Highest damaged tubers were found when grader was operated at 6 RPM and 3 degree inclination. Percentage of tuber damaged increased with decreasing the speed and inclination of the grading unit. Slow speed and small inclination angle caused accumulation of the tuber in the grading unit that induced greater impact as result of their weight which increased the percentages of damaged tubers.

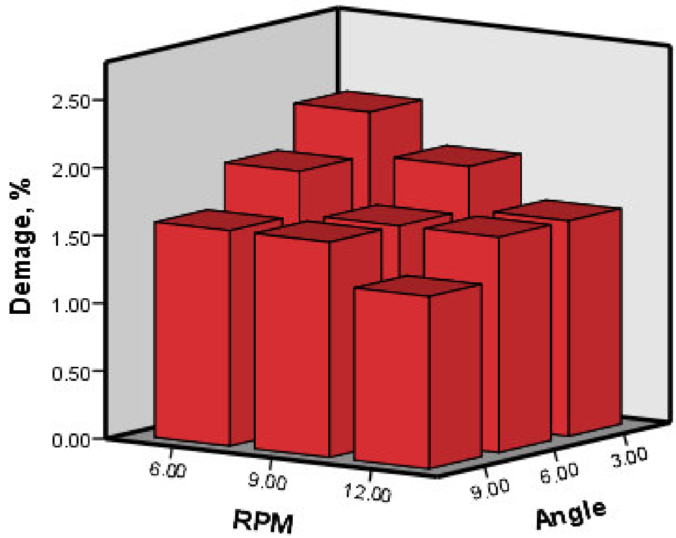

Fig-17: Interaction effect of speed and inclination on percentages of damaged tuber

Power consumption

Fig-11 shows that power consumption was highest when the grader was operated at 3 degree inclination in combination with speed 6 RPM and lowest power consumption was found when operated at 12 RPM and 9 degree inclination. Power consumption was increased with decreasing the speed and inclination of the grading unit. This was because when the grader was operated at a high speed and inclination causing shorter time of operation. Thus the power consumption was less.

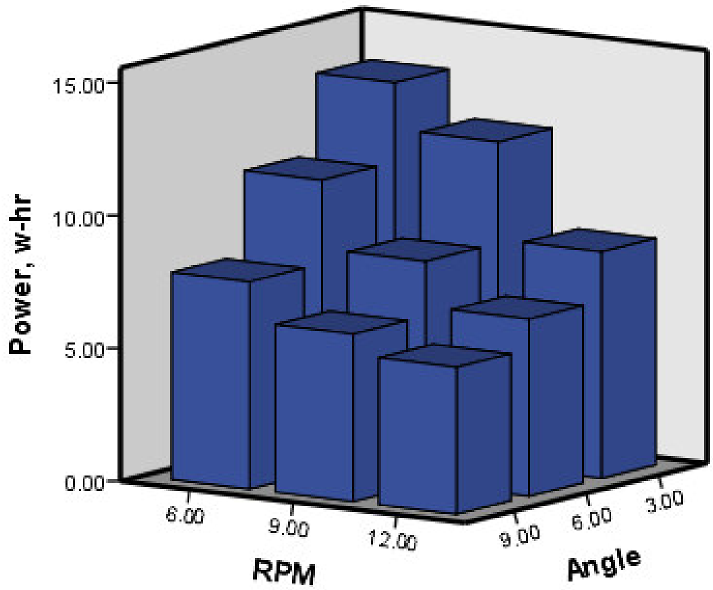

Fig-18: Interaction effect of speed and inclination on power consumption

4.3.2. Influence of Speed

Data in Table-5 shows the performance of the grader at different RPM. It shows that the grader had the highest GSE when operated at 6 RPM. Extremely fast RPM of the grading unit were observed to cause the tubers a fast random movement through the grading unit. This mechanical reaction caused some tubers to move over one region to another to the extent that small-sized tubers even move to the region of the hole for medium-sized classification. This unwanted motion of tubers during extreme rotation significantly affected the grading system efficiency of the device. On the other hand lower RPM of the grading unit were observed to cause the tubers move slowly through the grading unit hence the tubers were get enough time for grading accurately. For this reason grading system efficiency was high in lower RPM than higher RPM of the grading unit. Meanwhile, analysis of variance on the influence of machine parameters to grading system efficiency showed significant effect.

Table-5: Comparison among mean values of the grading system efficiency, capacity, damaged tubers and power consumption as influenced by the speed of the grading unit

Machine Parameters	Speed (RPM)		
	6	9	12
GSE (%)	81.09^{c}	73.90^{b}	60.74^{a}
Capacity (kg/hr)	379.65^{a}	470.15^{b}	585.36^{c}
Damaged Tubers (%)	1.90^{a}	1.69^{a}	1.48^{a}
Power Consumption (W-hr)	10.90^{c}	8.95^{b}	6.90^{a}

*Means separation in raw followed by the same letter(s) are not significantly different at P=0.05

The capacity of the grader using speed of 9 and 12 RPM is significantly higher than using a speed of 6 RPM. High speed (12 RPM) induces more velocity to the tubers causing them to travel along the unit at a faster rate. Conversely, lowest speed (10 RPM) resulted to slow material flow through the grading unit resulting to longer time of operation that caused lower capacity.

Power consumption was lowest at 12 RPM. The grader operated at a faster rate causing shorter time of operation. Lowest speed (6 RPM) resulted to more power consumption. Tubers stayed at a longer time in the unit causing more power inputs. Although power consumption is very minimal, the differences on the mean values are significant.

Damaged tubers were found to be minimal at a speed of 12 RPM. Highest damaged of 1.90% at 6 RPM could be due to large accumulation of tubers in the unit creating significant impacts as a result of weight of the large quantity of tubers. Abrasion of tubers resulted not only with the high RPM of the grader but also due to large quantity of tubers. The combined effect of the speed of the grading unit and the heavy weight of tubers causes greater impact to the tubers.

4.3.3. Influence of Inclination

Table-6 shows the mean values for the machine parameters as affected by the inclination of the grading unit. Highest grading system efficiency of 80.04% was observed at an inclination of 3 degrees whereas; lowest efficiency was obtained at an inclination of 9 degrees. Extremely high inclination caused fast transfer of tubers to the next region as caused by gravity plus the effect of the rotation of the grading unit. This also reduces the time of operation causing significantly high capacity of 610.56 kg/hr and lower power 6.54 W-hr. Tubers in this scenario especially the smaller ones at the first region move to the next selection region without passing to the succeeding region.

Table-6: Comparison among mean values of the grading system efficiency, capacity, damaged tubers and power consumption as influenced by the inclination of the grading unit

Machine Parameters	**Inclination (degrees)**		
	3	6	9
GSE (%)	80.04^{c}	72.24^{b}	63.44^{a}
Capacity (kg/hr)	353.11^{a}	471.50^{b}	610.56^{c}
Damaged Tubers (%)	1.90^{a}	1.69^{a}	1.48^{a}
Power Consumption (W-hr)	11.55^{c}	8.66^{b}	6.54^{a}

*Means separation in raw followed by the same letter(s) are not significantly different at P=0.05

Damaged tubers as influenced by the inclination of the grader were observed to decrease with higher inclination as shown in table-6. As shown earlier in Table-5, damaged tubers were observed to be influenced by the large amount of tubers in the grading unit along with very high RPM. The large number of tubers in the grading unit tends to create a heavier impact among each other during the rotation of the grader. For the inclination of the grader, it was observed that at very low inclination which is 5 degrees, there were more number of tubers damaged which is almost 1.90% of the total samples as shown in Table-6.

4.4. Economics of the Grader

4.4.1. Cost estimation

The present potato grader was designed and fabricated in such a way as to keep its cost low. Table-7 shows the cost factors and items of the potato grader. From the table, it can be seen that the cost of grading with the present grader was only Tk**.** 0.37 per kilogram.

Table-7: Cost factors and items of the potato grader

Cost factors/items	Unit	Amount
A. Cost of the grader	Tk/Unit	
Materials	Tk	22,000
Gear box	Tk	7,000
Electrical motor	Tk	4,000
Construction cost	Tk	12,000
Total Cost	Tk	45,000
B. Life of the grader	Year	10
C. Annual use	Hrs	500
D. Annual fixed cost		
a. Depreciation	Tk/yr	4050
b. Interest (13%)	Tk/yr	3217.5
c. Taxes, Shelter, Insurance (3%)	Tk/yr	1350
Total	Tk/yr	8617.5
Total	Tk/hr	17.23
E. Variable Cost		
a. Repair and maintenance (10%)	Tk/hr	9
b. Labour (two labours, 300tk/day)	Tk/hr	75
c. Electricity	Tk/hr	2.87
Total	Tk/hr	86.87
F. Total cost	Tk/hr	104.10
G. Cost of grading (assuming 280 kg/hr)	Tk/kg	0.37

4.4.2. Break-even point

From table-7 show that the device has an initial cost of Tk. 45, 000.00 with an estimated life span of 10 years. With basic assumptions and current market practice the annual fixed cost of operating the device is Tk.8617.5. Assumptions include: interest, 13%, tax, insurance and shelter, 3%, repair and maintenance, 10%, operation per day, 8 hr, annual use, 500 hr and custom rate Tk 0.5/kg. The grader needs to grade a quantity of 63 tons of potato tubers in one year to break-even the cost of fabrication. Figure-12 shows the cost curve emphasizing the break-even quantity. If available quantity of tubers is greater than the break-even quantity, the use of the grader will result to profit. Otherwise, the machine is expensive to use when available quantity is less than the break-even quantity.

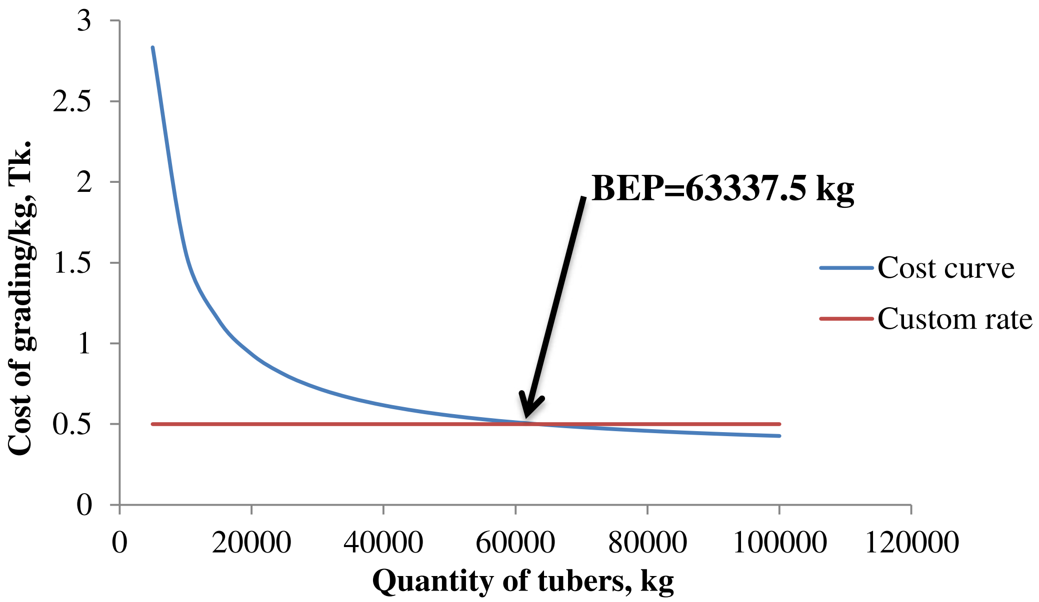

Fig-19: Relationship of the cost of operation of the grader and the quantity of tubers for grading

4.5 Simple comparison between manual and mechanical grading

Using the data for manual grading of potato by hand from the research work of Widodo et al., (2012), a simple comparison between manual and mechanical grading of potato is given below:

Table-8: Simple comparison between manual and mechanical grading

	Manual	Mechanical
Grading capacity, kg/hr/person	75	280
Hours of operation per day	8	8
Average volume that can be graded per day	600	2240
Cost of grading Tk/kg	0.5	0.35

From table-8 it was seen that the mechanical grading cost 30% lower than the manual grading cost.

CHAPTER V

SUMMARY AND CONCLUSIONS

CHAPTER V

CONCLUSIONS

A mechanical potato grader, powered by electric motor, was designed, fabricated and evaluated. The device operates with the principles of rotating drum as grading unit. The grading unit was made up of plastic oil containers. The grading unit was divided into three parts, In the first part, 40 mm diameter holes were made for separating small size potato, in the second part, 55 mm diameter holes were made for separating medium size potato with the help of specially constructed drill bit and in the last part, extra-large holes were made for separating the remaining large size potato. Two M.S. flat bar was connected in the inside wall of the grading unit for uniformly distributing the potato. A 0.75hp, single phase electric motor was used as prime mover with a gear box (30:1) for reducing the rpm of the motor. The power was transmitted from the prime mover to the grading unit using pulley and V-belt.

The performance of the fabricated grader was evaluated on potato tubers. Grading system efficiency, capacity, damaged tubers and power consumption were observed. The optimum operating parameters for the machine was established at a speed of 6 RPM and inclination of 3 degrees giving a system efficiency of 88.40%, capacity of 280.90 kg/hr, less damaged tubers of 2.22% and a power consumption of 13.95 W-hr. The initial cost of the grader was Tk. 45,000 and is expected to last for 10 years. The annual use of the grader in the village is approximately 500 hrs. Cost of operating the machine is affected by several factors such as: depreciation, tax, insurance and shelter, repair and maintenance at a current custom rate of Tk. 0.50/kg, the grader has an annual fixed cost of Tk. 8617.5 and variable operating cost of Tk. 83.13/hr. A quantity of 63,337 kg (63 tons) of tubers is needed to be graded by the device in one year to break-even the cost. Grading by using this machine will cost Tk. 0.37/kg.

Recommendations

1. Further modification of the grading unit should be done for reducing damage and increasing grading system efficiency (GSE)
2. Automatic control system mechanism should be added for changing the speed (RPM) and inclination of the grading unit.

3. Lengthen the regions for small-and medium-sized classifications to reduce multi-layering and crowding of potato tubers at that region.
4. Redesigning the grading unit to have shorter overall length to make the device more portable, accessible and easy to store.

CHAPTER VI

REFERENCES

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REFERENCES

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APPENDICES

APPENDICES

Appendix I

Calculation of power required for rotating the grading unit

We have,

Weight of the drum, M_1= 115 kg (by metal weight calculator)

Weight of the shaft, M_2= 30 kg (by metal weight calculator)

Radius of the drum, R_1= 0.292 m

Radius of the shaft, R_2= 0.025 m

Potato flow rate, F= 12 kg/min

Velocity of potato, V= 0.30 m/s

Therefor

Moment of inertia of the drum, $I_1 = M_1 {R_1}^2$

$= 115 \times 0.292^2$

$= 9.80$ kg-m^2

Moment of inertia of the shaft, $I_2 = M_2 {R_2}^2$

$= 30 \times 0.025^2$

$= 0.0187$ kg-m^2

Total moment of inertia, $I = I_1 + I_2$

$= 9.80 + 0.0187 = 9.82$ kg-m^2

Angular acceleration, $\alpha = \frac{\omega}{t} = \frac{2\pi n}{t} = \frac{2\times\pi\times 20}{60\times 1} = 2.09\ \text{rad/sec}^2$

Torque, $T = I\alpha = 9.82 \times 2.09 = 20.50$ N-m

Power required for rotating of drum $P = \frac{2\pi NT}{60} = \frac{2\times\pi\times 20\times 20.50}{60} = 42.93$ W = 0.057 hp

Power required for potato flow = $\frac{F\times V}{75} = \frac{12\times 0.30}{75} = 0.048\ hp$

Actual power required = 0.057 + 0.048 = 0.11hp

Assume transmission efficiency = 80%

Total power required = $\frac{0.11}{0.80} = 0.14\ hp$

Appendix II

Determination of pulley size

For power transmission motor to gearbox,

Assume, D_1= 1.5 inch

N_1= 1440 rpm

N_2= 540

D_2= ?

Therefor

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

$$\therefore D_2 = \frac{D_1 \times N_1}{N_2}$$

$$= \frac{1.5 \times 1440}{540}$$

= 4 inch

For power transmission gearbox to grading unit,

Assume, D1= ?

D2= 6 inch

N1= $540 \div 30 = 18$

N2= 6, 9, 12 rpm

For 6 rpm

$$\therefore D_1 = \frac{D_2 \times N_2}{N_1}$$

$$= \frac{6 \times 6}{18}$$

= 2 inch

Similarly for 9 and 12 rpm we found 3 and 4 inch pulley.

Appendix III

Determination of type and pitch length of the belt

We have,

Driver machine: Single phase electric motor

Hp= 0.75; N_1= 1440 rpm

Driven Machine: Grader

Hp= 0.57; N_2= 20 rpm

∴ Transmitted horsepower, hp = 0.57

From appendix IV,

N_{sf} = 1.4-0.2 = 1.2 (for machine tools, seasonal use)

∴ Design hp = $N_{sf} \times transmitted\ hp$

$$= 1.2 \times 0.57 = 0.68\ hp$$

For hp = 0.68 and N= 1440 rpm from appendix V,

We get A-type belt

Now, for power transmission from motor to gear box

D= 4 inch; d= 1.5 inch

Center distance between the pulley, C= 14 inch

∴ Now $L = 2C + \frac{\pi(D+d)}{2} + \frac{(D-d)^2}{4C}$

$$= 2 \times 14 + \frac{\pi(4+1.5)}{2} + \frac{(4-1.5)^2}{4\times14}$$

=36.75 inch

From appendix VI,

For L = 36.75 inch & A type we choose A-36 number belt

Again, for power transmission from gearbox to grading unit

For 6 rpm,

D= 6 inch; d= 2 inch

Center distance between the pulley, C= 26.2 inch

$\therefore$ Now $L = 2C + \frac{\pi(D+d)}{2} + \frac{(D-d)^2}{4C}$

$= 2 \times 26.2 + \frac{\pi(6+2)}{2} + \frac{(6-2)^2}{4\times 26.2}$

=65.11 inch

From appendix VI,

For L = 65.11 inch & A type we choose A-64 number belt

Similarly for 9 and 12 rpm we were chosen A-65 & A-66 number belt.

Appendix IV

Service Factor N_{sf}

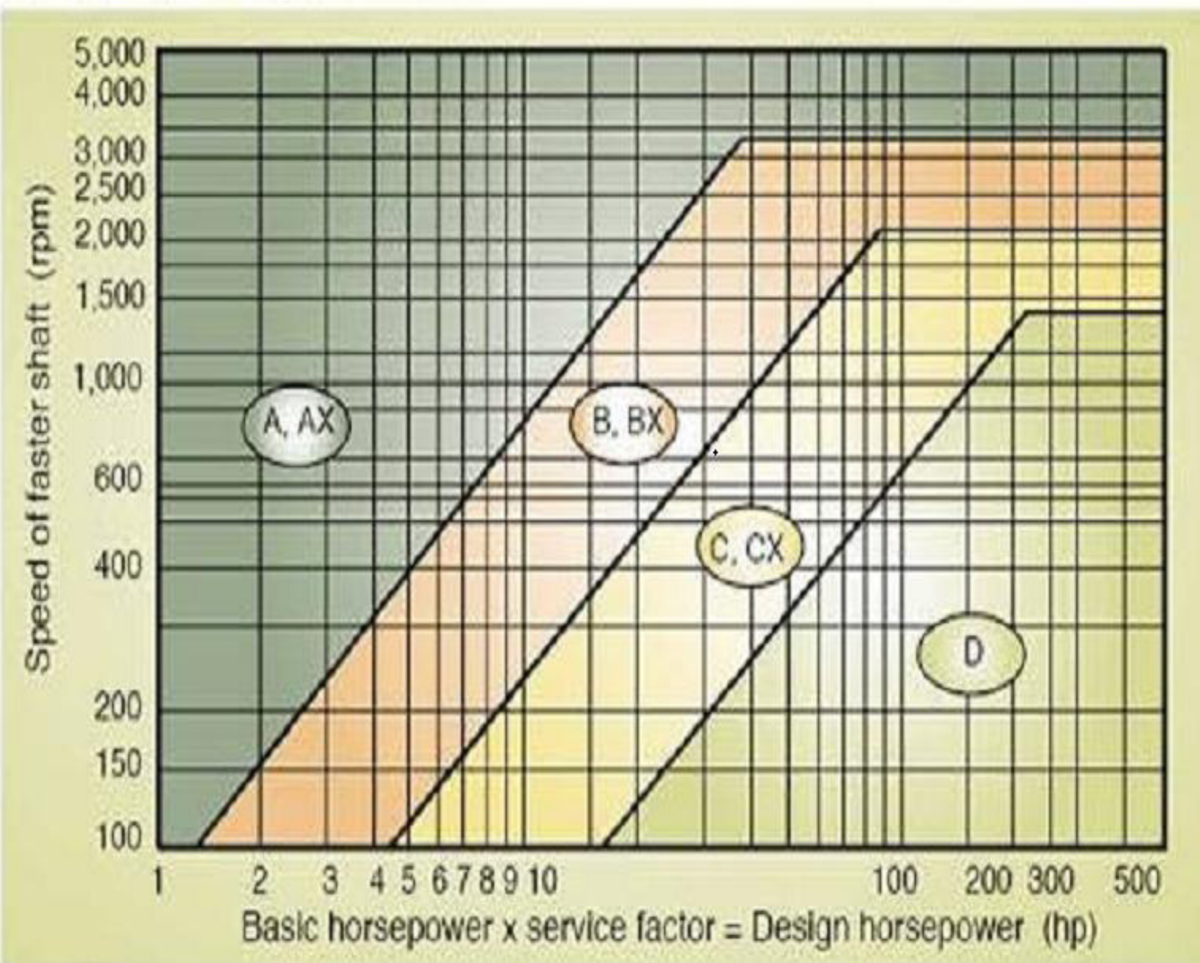
Add 0.2 to the values given for each of the following condition: continuous (over 16 hr/day) service; wet environment; idler in drives. Subtract 0.2 if the operation is quite intermittent or seasonal.

Driven Machines	Driving Machines	
	Electric Motors AC split phase AC Normal Torque Squirrel cage, and Synchronous DC Shunt Wound Water wheels Turbines, Steam and Water Internal Combustion Engines (Hydraulic Drive)	Electric Motors AC Single Phase Series Wound AC High Torque or High Slip AC Slip Ring AC Repulsion Induction AC Capacitor DC Compound wound Steam Engines and Line Shafts Clutch on Driver or Driven Shaft
Agitators, liquid Cam cutters Conveyors, Package Drill presses, Lathes Screw machines Small fans to 10 hp	1.1	1.2
Compressors and blowers, (rotating) Conveyors, ore, sand generators Line shafts Machine Tools (other) Pumps (Rotating)	1.2	1.4
Ball mills Beaters (paper) Circular saws Compressors (reciprocating) Conveyors, bucket, apron, screw, drag Crushers, jaw, etc. Hammer mills Pumps (reciprocating) Propellers Tube mills	1.4	1.6
Hoists Mine fans Positive blowers Spinning frames Tumbling barrels Twisters (textile)	1.6	1.8

(Source: Design of Machine Element, V. M. Faires, Fourth Edition)

Appendix V

Selection of Belt Section from Horsepower and Speed



(Source: Design of Machine Element, V. M. Faires, Fourth Edition)

Appendix VI

Standard V-Belt Lengths; Horsepower Constants

Minimum D_s is the smallest sheave pitch diameter that should be used with that section. A smaller sheave is used, short belt life should be expected; L in inches.

A SECTION		B SECTION		C SECTION		D SECTION	
Min Ds = 3 in		Min Ds = 5.4 in		Min Ds = 9 in		Min Ds = 13 in	
Belt No.	Pitch Length	Belt No.	Pitch Length	Belt No.	Pitch Length	Belt No.	Pitch Length
A 26	27.3	B 35	36.8	C 51	53.9	D 120	123.3
A 31	32.3	B 38	39.8	C 60	62.9	D 128	131.3
A 35	36.3	B 42	43.8	C 68	70.9	D 144	147.3
A 38	39.3	B 46	47.8	C 75	77.9	D 158	161.3
A 42	43.3	B 51	52.8	C 81	83.9	D 173	176.3
A 46	47.3	B 55	56.8	C 85	87.9	D 180	183.3
A 51	52.3	B 60	61.8	C 90	92.9	D 195	198.3
A 55	56.3	B 68	69.8	C 96	98.9	D 210	213.3
A 60	61.3	B 75	76.8	C 105	107.9	D 240	240.8
A 68	69.3	B 81	82.8	C 112	114.9	D 270	270.8
A 75	76.3	B 85	86.8	C 120	122.9	D 300	300.8
A 80	81.3	B 90	91.8	C 128	130.9	D 330	330.8
A 85	86.3	B 97	98.8	C 144	146.9	D 360	360.8
A 90	91.3	B 105	106.8	C 158	160.9	D 390	390.8
A 96	97.3	B 112	113.8	C 173	175.9	D 420	420.8
A 105	106.3	B 120	121.8	C 180	182.9	D 480	480.8
A 112	113.3	B 128	129.8	C 195	197.9	D 540	540.8
A 120	121.3	B 144	145.8	C 210	212.9	D 600	600.8
A 128	129.3	B 158	159.8	C 240	240.9	D 660	660.8
		B 173	174.8	C 270	270.9		
		B 180	181.8	C 300	300.9		
		B 195	196.8	C 330	330.9		
		B 210	211.8	C 360	360.9		
		B 240	240.3	C 390	390.9		
		B 270	270.3	C 420	420.9		
		B 300	300.3				
Rated hp. Constants a = 2.684 c = 5.326 e = 0.0136				Rated hp. Constants a = 8.792 c = 38.819 e = 0.0416		Rated hp. Constants a = 18.788 c = 137.7 e = 0.0848	

(Source: Design of Machine Element, V. M. Faires, Fourth Edition)