

DESIGN, DEVELOPMENT AND PERFORMANCE EVALUATION OF FRUIT AND VEGETABLE GRADER

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Under competitive market conditions of today's agriculture fruit and vegetables quality is of great importance. Grading of agricultural produce especially the fruit and vegetables has become a prerequisite of across the borders trade. In Pakistan grading is mainly done manually that requires significant labor work. Human operations may be inconsistent, less efficient and time consuming. New trends in marketing as specified by World Trade Organization (WTO) demand high quality graded products. Farmers are 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 speed 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 collision 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.

Keywords: Fabricated, produce, grading, prerequisite, optimizing, quality

INTRODUCTION

Agriculture is the back-bone of our economy as over 75 % of its population is directly or indirectly engaged with this profession. Beyond the traditional agriculture, new trends in cropping pattern have been recognized for changing the status of rural community. Importance of horticulture may not be ignored as the horticulture sector contributes about 12 % of agriculture value addition. The production of fruits and vegetables at present is 6.0 million tones and 7.0 million tones respectively and will be enhanced to 9.4 million tones and 10.0 million tones, respectively in 2009-10 (Anonymous 2005).

The horticultural product has inherent variability in size at harvest that differentiates them in value. For the ease of buyer it is necessary to grade them according to some objective standard. Therefore it is need of the time to provide facilities at the doorstep of the farming community so that they may be able to market better quality horticultural products. For most types of fruits and vegetables, bruising is the most common type of post-harvest mechanical injury. Wilson et al. (1999) reported that the moisture loss of a single bruised apple is increased by as much as 400 % compared to that of an intact apple. Dehydration of fruit and vegetable affects their market value, as bruised products are more susceptible to moisture loss. In post-harvest handling, conveying and grading are two

most important operations responsible for mechanical injury. Fresh crop and damage free post-harvest handling of fruits and vegetables were considered basic requirements to increase the farmer's profit margin.

According to a study by international consultants a large number of factors limit Pakistan's production and export potential of fruits and vegetables. The most common among them are poor farm management practices, lack of adequate social and physical infrastructure such as skill development, extension, transportation, and storage facilities, absence of marketing intelligence, improper storage of seeds, irregularities in domestic and international markets and lack of grading. The normal practice in Pakistan is to market the ungraded fruit and vegetables and where it is necessary then it is carried out manually by cullers who consider a number of grading factors and separate fruit and vegetables according to their physical quality which is tedious, labor intensive, time-consuming, slow and non-consistent. In WTO scenario, grading of the horticultural products is basic requirement for national and international marketing system. Therefore, to address this issue, the project was planned with the following objectives.

1. To design and fabricate fruit and vegetables grading machine.
2. To test its performance for grading potatoes and apples based on size of the products.

MATERIAL AND METHODS

To meet the objectives the study was planned to conduct in two phases.

Phase I

Design and Development of a mobile fruit and vegetables grader

Phase II

To evaluate its performance by studying the effects of different machine parameters on crop and to formulate recommendations for its field use.

Phase-I

The fruit and vegetables grader (Figure 1) was designed and its main components were mainframe, take-in conveyor, hopper, space bar conveyor, grading unit, take-away conveyors, and power transmission system. Selected parts were designed using standard formula. The details of design features are as under:

vary the linear speed of the conveyor to change the feed rate.

a. Capacity of the conveyor

The take-in conveyor was designed to operate at a speed of 20 m/min as suggested by Ragni and Berardinelli (2001). The conveyor of 457 mm width was used with the loading capacity of 10-kg/m length of the conveyor. The capacity of the conveyor was determined by the following formula as suggested by Spinvakovsky and Dyachkov (1972).

$$Q = \frac{3600qv}{1000}$$

Where

Q = capacity, tons per hour

Q = weight of the fruit per meter length of conveyor, kg/m

V = linear speed of the conveyor, m/sec

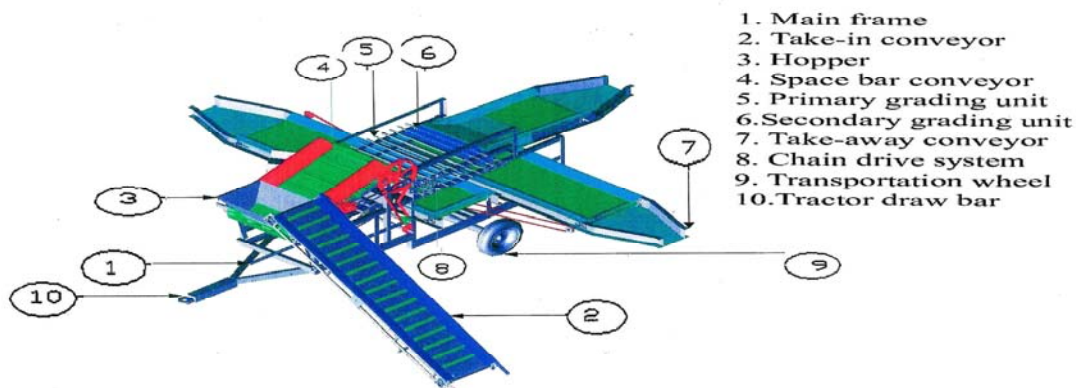


Fig. 1. Fruit and vegetable grader

1. Take-in conveyor

To elevate and convey the crop from ground level to the hopper, a flight type conveyor was designed. The design of take-in conveyor was made keeping in view the function to perform, fabrication facilities and skill, simplicity of the design, social acceptability, know how of the end users, trend of the local industry, local soil and environmental conditions etc. Raising the incoming product to the hopper involved a small drop. Loading capacity, fall height and angle of repose (of the product to be lifted and conveyed) were considered for safe conveying of the produce with out any injury to the crop.

Take-in conveyor consisted of driving shaft, driving drum, flat belt, frame of the conveyor and power transmission system. The conveyor was powered through a gearbox from the main shaft of the machine. Speed reduction arrangement was also developed to



Fig. 2. Take-in conveyor

The product was loaded on the conveyor @ 10 kg per meter length. With the use of speed reduction arrangement it is possible to operate the take-in conveyor at 20, 15 and 10 m/min.

b. Power requirement

Power required to convey the produce from ground surface to the hopper at height of 2 meter, with an inclined conveyor having 3-meter length, was worked out by encountering the frictional resistance during elevating and transporting the produce, with the following formula as suggested by Omre and Saxena (2003).

$$N_{\text{fric}} = (QL\omega)/362 \text{ (kW)}$$

Where

N_{fric} = Power to encounter the frictional resistance (kW)

Q = Capacity of the conveyor (tons /hr)

L = Length of conveyor (m)

ω = Friction factor (0.1 for the fruit conveyor)

The power required to elevate the crop to the height H meters was worked out by the following formula as suggested by Omre and Saxena (2003).

$$N_{\text{eff}} = (QH)/362 \text{ (kW)}$$

Where

N_{eff} = Power required to elevate the crop (kW)

Q = Capacity of the conveyor (tons /hr)

H = Lift height (m)

Since this conveyor performed both functions i.e. conveying and elevating, therefore, total power required (N) for operation of take-in conveyor was determined by the following expression.

$$N = N_{\text{eff}} + N_{\text{fric}}$$

Where

N = Total power required to operate the conveyor (kW)

To operate the take-in conveyor at 20-m/min and load rate of 10 kg/m length of the conveyor, total power worked out was 0.076 kW.

c. Conveyor driving shaft

In order to operate the conveyor, power (0.076 kW) was transmitted through a shaft to its belt through the driving drum. In order to drive the conveyor at recommended linear speed, torque (T) required to rotate the driving drum was worked out by using the following formula as described BAHAL and GOEL, (1982):

$$T = \frac{97303 \times N}{n}$$

Where

T = Torque required to transmit power kg-cm

N = Total power required to operate the conveyor, kW

n = Speed of driving shaft, rpm

Torque (88.3 kg-cm) was transmitted by the driving drum through shaft at speed of 84 rpm to run the conveyor at linear speed of 20 m/min. The diameter of the shaft was worked out by using the following formula as suggested by Khurmi and Gupta (2003).

$$d = \frac{\sqrt[3]{16T}}{S_s \cdot \pi}$$

Where

d = Diameter of conveyor driving shaft (cm)

T = Torque on shaft kg-cm

S_s = Safe shear stress (Kg/cm²) = U_s/F

U_s = 3523 kg/cm² (Ultimate stress)
(Medium Carbon Steel, 0.15 % to 0.4 % Carbon)

F = 8 Factor of safety (Stanton and Winston, 1977)

The design diameter of the shaft was 10.2 mm and the actual shaft of diameter 14.75 mm was used to operate the conveyor. Dia. of the shaft used, was larger than the designed dia. of the shaft, hence the design was safe.

2. Main frame

Mainframe was made with the mild steel angle bar, which was readily available and the most consuming material in farm machinery. To determine the size of mild steel angle bar, dead load and variable loads were considered. For this purpose a section of mild steel angle bar from frame was selected and treated as fixed end beam. This was done because the selected mild steel angle bar was welded at the both ends with the other machine elements. A total weight of 97 kg (dead and variable load) was imposed on the selected machine element to design its features. Maximum deflection 0.14 mm, in selected element of the main frame at 4 factor of safety was observed. This designed load on the angle bar was not enough to produce a mark able deflection in angle iron member that may cause any fatigue on the angle iron member during operation of the machine.

3. Space bar conveyor

This conveyor is inclined at 18° (Angle of repose of most of the fruit is 20°) to avoid the rolling back of the product. A series of mild steel bars having size of 3mm x 25 mm was attached to pair of canvas belt. The conveyor collects the product from the hopper and delivers to the grading unit. Steel bars were cushioned with rubber pipes to cover the exposed hard surface so that the surface may not damage the crop during conveying. Weight of crop on a single bar was worked out as 1 kg. The bending moment 0.650 N-m was determined and thickness of the bar was worked out with the ultimate stress of the material of the bar (4.227×10^8 N/m²) and factor of safety 4 (Stanton and Winston, 1977).

Following formula was used to determine the bending moments:

$$M = S.Z$$

Where

S = Safe shear stress

Z = Section modulus

The bar under load was of rectangular cross section with 25 mm width, hence the thickness of rectangular cross section was determined by using following formula:

$$\text{Section Modulus (Z)} = bh^2/6$$

Where

B = Width of the bar, mm (known)

H = Thickness of the bar, mm (to be calculated)

Thickness of mild steel bar required to bear the load of 1 kg as calculated, was 1.21 mm. But we have used bar having the thickness of 3 mm which was greater, the calculated one and available in local market. Hence the design was safe.



Fig. 3. Space bar conveyor

4. Grading unit

The grading unit comprises a primary grading unit and secondary grading unit to pair of canvas belt. The conveyor collects the product from the hopper and delivers to the grading unit. Steel bars were cushioned with rubber pipes to cover the exposed hard surface so that the surface may not damage the crop during conveying. Weight of crop on a single bar was worked out as 1 kg. The bending moment 0.650 N-m was determined and thickness of the bar was worked out with the ultimate stress of the material of the bar ($4.227 \times 10^8 \text{ N/m}^2$) and factor of safety 4 (Stanton and Winston, 1977).

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H = Thickness of the bar, mm (to be calculated)



Fig. 4. Secondary grading unit

Primary grading unit was used to separate the product having size below 35 mm and the remaining crop was transferred to the tail end of the primary grading for secondary grading. Secondary grading unit further divide the product into three sizes. To register the secondary grading unit for a particular crop and size, provision of adjustment has made it possible to attain a required bank size by changing the spacers in between the diablo discs. Each bank size was provided 3 mm allowance to adjust the shape index of the crop. The grading unit was operated at 25, 50 and 75 rpm to accommodate the different feed rates.

5. Power transmission system

A gearbox was designed to transfer power at right angle with velocity ratio 1:1. Because both the shafts (input & output) were at right angle in gearbox and the miter gears having size (18 teeth), therefore designed power source to operate the grader was 8.79 kW and gearbox transferred the designed power at rated speed 540 rpm. Torque worked out was 1562.75 Kg cm (153306 N mm). Following formula was used to work out tangential load on the gear.

$$W_t = \frac{2T}{mTg}$$

Where

T is torque (N-mm)

m is module (mm)

Tg is teeth on gear

Tangential load on the gear worked out was 2433.43 N.

Maximum load for wear ($W_m = 8944.74$ N) was worked out by using following formula:

$$W_m = \frac{D_p \cdot b \cdot Q \cdot K}{\cos \theta_p}$$

Where θ_p is the pitch angle

D_p is diametral pitch (mm)

b is face width (mm)

Q is Ratio factor

K is Load stress factor

Load stress factor (K) 1.69 was determined by assuming:

Surface endurance limit (σ_{es}) = 630 N/mm²

Young's modulus for material of miter gear was selected 84×10^3 N/mm² and ratio factor 1 was used as miter gears. It was observed that $W_m > W_t$ therefore the design was safe from consideration of wear.

The dia of the gear shaft was determined by using the following expression:

$$T_e = \frac{\pi}{16} \cdot \tau (dg)^3$$

Where

dg is diameter of the gear shaft (mm)

τ is the shear stress of the material of shaft (45 MPa)

T_e is equivalent twisting moment.

Equivalent twisting moment (T_e) was worked out by using the following expression:

$$T_e = \sqrt{(T^2 + M^2)}$$

Where

T is twisting moment and

M is resultant bending moment

Resultant bending moment (M) was calculated as under

$$\text{Resultant bending moment (M)} = \sqrt{(M_1)^2 + (M_2)^2}$$

Where M_1 is bending moment due to axial force (533.92 N) and radial forces (533.92 N) and M_2 is bending moment due to tangential force ($W_t = 2920.11$ N) acting on the mean radius of the gear shaft. Diameter of the gear shaft was worked out as 34 mm that was appropriate to transmit power (8.79 kW) to the system.

6. Take-away conveyor

Graded product was collected and conveyed to the packing point through the take-away conveyors. These were flat belt type horizontal conveyors. A variable

drive system was arranged to drive the conveyors at different speeds (5 m/min, 10 m/min and 15 m/min). All the metal surfaces exposed to the falling crop were cushioned with padding material (Ethafom, 10 mm thick) to avoid the expected damage to the crop.

Phase-II

Performance evaluation

The grader was made of locally available material to keep the cost low. It was designed to grade the crops on size basis. All the workshop facilities were provided by Agricultural Engineering Workshop (AMRI) Faisalabad. The machine has the following components that directly comes in contact with the crop to be graded.

1. Take-in conveyor
2. Space bar conveyor
3. Grading unit
4. Take-away conveyor

Machine parameters

The following machine parameters were selected to study their affects on crop parameters.

Machine Parameters	Level 1	Level 2	Level 3
Take-in conveyor speed	10 m/min	15 m/min	20 m/min
Grading spool speed	25 rpm	50 rpm	75 rpm
Take-away conveyor speed	5 m/min	10 m/min	15 m/min

Above said machine parameters and their interactions were studied on different levels for evaluation of performance of the fruit and vegetables grader. The space bar conveyor was operated at constant speed of 20 m/min throughout the experiment.

Crop parameters

The effects of different machine parameters on crop were investigated to study the following results.

- i. Damage index (DI)
- ii. Grading Error (GE)

Damage index

Damaged products were separated from each fraction and damaged products were separated into following categories

Scuffed Surface abrasion

Peeler Damage upto 3 mm depth

Severe Damage deeper than 3 mm

Then their percentages based on weights of their corresponding fractions were determined by using following formula as suggested by Robertson (1970).

Damage Index = (% Scuffed) + (% Peeler \times 3) + (% Severe \times 7).

Grading error

The grader was tested to study the behavior of its different parameters on grading efficiency. Fraction of lower/over size crop from out coming crop was determined to study the effects of different machine parameters on the grading efficiency of the machine.

Testing procedure

A homogeneous sample of the crop was prepared. For this purpose MINFAL (Ministry of Food, Agriculture and Livestock) and local market size standards were observed. A known weight of each fraction was separated and each tuber falls within the specific size range as specified by MINFAL. Sample prepared comprises all grades and known weight. For each machine parameter combination, the sample was introduced to the take-in conveyor. Crop coming out the take-away conveyor was collected and under size crop from each grade was separated and weighed for determining the grading error on weight basis while damaged crop were also separated from each fraction and damaged products were separated into different categories to determine the damage index. Size of the crop was measured with the help of digital micrometer and depth of the damage was measured after slicing the affected product into slices of 1.5 mm thick. For slicing, a mechanical hand operated slicer was developed and used. The grader was tested for potatoes and apples. The machine was installed by digging a pit in ground and lowering one third of each transportation wheel in that pit to provide stability to the machine during operation. Products were pushed towards the lower end of take-in conveyor with a uniform rate of approximately 10 kg per meter length of conveyor. Time for each combination of variables was recorded to determine the machine capacity.

RESULTS AND DISCUSSION

To evaluate its performance on potato and apple, the effects of different machine parameters were investigated on different crops in terms of damage index (DI) and the grading error (ER). To evaluate the significance of machine parameters and their interactions on crop damage, ANOVA was carried out using PROC / GLM (General Linear Model) procedure of the SAS Institute (1998). In this study two crops namely, potatoes and apples were arranged for grading purposes.

1. Effects of machine parameters on grading efficiency/grading error and damage index for potatoes

To change the feed rate of the grader, three speed levels 10, 15 and 20 m/min of the take- in conveyor were selected. The data regarding grading error and

damage index collected at different levels of machine parameters were recorded in Table 1. Analysis of variance for the effect of machine parameters on grading error and damage index for potato grading has been presented in Table 2. The ANOVA revealed that take in conveyor speed (S_i) and grading spool speed (S_g) significantly effect the grading error and damage index at 5% probability level.

While Take-away conveyor speed (S_o) is non significant. Take-in conveyor speed contributed 47 % to the total damage index and approximately 42.64 % to the total grading error. Statistical analysis (Table-3) revealed that three levels of Take-in conveyor speed were significantly different for producing grading error and damage index at 5% probability level. Minimum grading error (4.56%) was observed at Take-in conveyor speed of 15 m/min and minimum damage index (3.27) was noted at Take in conveyor speed of 20 m/min. Minimum values of grading error and damage index were resulted at grading spool speed of 50 rpm as shown in Table-4. No significant effect of Take-away conveyor speed on grading error and damage index was observed at 5% probability level. Highest value of damage index at lowest speed of conveyor speed (Table-3) might be due to lower feed rate that had not fulfilled the grading unit requirement and thus shared in damaging the crop as occurred repeated jumping rather to move forward to their respective bank during the system operation.

2. Effects of machine parameters on grading efficiency/grading error and damage index for apples

The data regarding grading error and damage index collected at different levels of machine parameters for apple grading were recorded in Table 5.

Analysis of variance (Table-6) indicated the significant effect of take-in conveyor speed and grading spool speed on the both grading error and damage index on apples. Statistical analysis revealed that take in conveyor speed was responsible for 42.64 % of total grading error and 25.35 % of the total damage index while grading spool speed contributed 35.7 % of the total grading error and 49.89 % of the total damage index. The levels of take-in conveyor speed were statistically analyzed and concluded that all the three levels of take-in conveyor speed were significantly different at 5% probability level for the both grading error and damage index. From Table-3 it is clear that minimum value (5.98 %) of grading error was observed at take-in conveyor speed of 10 m/min and 12.87 % increase in grading error was observed at speed of 15 m/min while further 11.56% increase at speed of 20 m/min. At take-in conveyor speed of 20 m/min, minimum damage index of value 6.12 was noted.

Table 1. Average grading error (%) values at different machine parameters for potato grading

Si (m/min)	Sg (rpm)	So ₁ 5 m/min		So ₂ 10 m/min		So ₃ 15 m/min	
		GE	DI	GE	DI	GE	DI
10	25	4.50	3.60	4.50	3.62	4.48	3.58
	50	4.48	3.44	4.72	3.46	4.72	3.5
	75	4.69	4.11	4.86	4.15	4.86	4.17
15	25	4.60	3.52	4.62	3.54	4.60	3.54
	50	4.46	3.14	4.67	3.12	4.68	3.15
	75	4.46	3.60	4.48	3.61	4.47	3.59
20	25	5.28	3.40	5.29	3.39	5.38	3.41
	50	4.32	3.06	4.30	3.134	4.31	3.11
	75	4.65	3.33	4.41	3.29	4.33	3.32

Si = Take in conveyor speed (m/min)

Sg = Grading spool speed (rpm)

So = Take away conveyor speed (m/min)

Table 2. ANOVA for the effect of different machine parameters on grading error and damage index for potatoes

Source	DF	MS GE	Pr > F GE	MS DI	Pr > F DI
Si	2	0.472527	0.0001*	1.51152	0.0001*
Sg	2	0.490980	0.0001*	1.41003	0.0001*
So	2	0.028558	0.4494	0.00198	0.1642
Si*Sg	4	1.057629	0.0001*	0.26910	0.0001*
Si*So	4	0.014372	0.3600	0.00066	0.6489
Sg*So	4	0.004253	0.8517	0.00081	0.5515
Si*Sg*So	8	0.017662	0.2316	0.00208	0.0697
Error	54	0.01291		0.00106	

Si = Take in conveyor speed (m/min)

So = Take away conveyor speed (m/min).

Sg = Grading spool speed (rpm)

Table 3. Effect of take-in conveyor speed on grading error and damage index for potato (P) and Apple (A) grading

Take-in conveyor speed (Si) (m/min)	Grading error (%)		Damage Index (DI)	
	P	A	P	A
10	4.68 ^b	5.98 ^c	3.74 ^a	6.51 ^a
15	4.56 ^c	6.75 ^b	3.43 ^b	6.31 ^b
20	4.82 ^a	7.53 ^a	3.27 ^c	6.12 ^c
Mean	4.69	6.75	3.48	6.31
LSD (0.05)	0.062	0.4671	0.0178	0.1071

^{a, b, c} Means are followed by the same letters are not significantly different at 5 % probability level

Each ER value is a mean of 27 observations

Table 4. Effect of grading spool speed on grading error and damage index for potato (P) and Apple (A) grading

Grading spool speed (Sg) rpm	Grading Error (%)		Damage index	
	P	A	P	A
25	4.81 ^a	6.48 ^b	3.51 ^b	6.38 ^b
50	4.56 ^b	6.21 ^b	3.23 ^c	6.01 ^c
75	4.82 ^a	7.56 ^a	3.69 ^a	6.55 ^a
Mean	4.69	6.75	3.48	6.31
LSD (0.05)	0.062	0.4671	0.0178	0.107

a, b, c Means followed by the same letters are not significant at 5 % probability level
Each ER value is a mean of 27 observations

Table 5. Grading error (%) and damage index at different machine parameters for apple grading

Si (m/min)	Sg (rpm)	So ₁ 5 m/min		So ₂ 10 m/min		So ₃ 15 m/min	
		GE	DI	GE	DI	GE	DI
10	25	5.14	6.55	5.10	6.61	5.12	6.61
	50	6.25	6.43	5.67	5.98	5.78	6.08
	75	6.44	7.35	6.60	6.76	7.73	6.84
15	25	6.2	6.45	6.42	6.44	6.45	6.46
	50	5.45	5.86	5.44	5.82	5.42	5.89
	75	8.40	6.64	8.35	6.61	8.41	6.60
20	25	7.90	6.32	7.93	6.33	7.94	6.29
	50	7.36	5.84	7.29	6.25	7.27	5.91
	75	7.45	6.12	7.40	5.80	7.24	6.20

Si = Take-in conveyor speed (m/min)
Sg = Grading spool speed (rpm)
So = Take-away conveyor speed (m/min)

Table 6. ANOVA for the effect of different machine parameters on damage index and grading error for apples

Source	DF	MS DI_	Pr > F DI	MS GE	Pr > F GE
Si	2	1.058	0.0001*	16.33	0.0001*
Sg	2	2.079	0.0001*	13.65	0.0001*
So	2	0.011	0.747	0.1181	0.852
Si*Sg	4	0.621	0.0001*	7.5561	0.0001*
Si*So	4	0.015	0.809	0.1612	0.926
Sg*So	4	0.185	0.002	0.1946	0.899
Si*Sg*So	8	0.198	0.0001*	0.2464	0.948
Error	54	0.0385		0.7329	
Total	80				

Si = Take in conveyor speed (m/min)
Sg = Grading spool speed (rpm)
So = Take away conveyor speed (m/min)

Grading spool speeds of 25 and 50 rpm were not significantly different at 5% probability level but speed of 50 rpm resulted minimum value of 6.21% and 6.01 of grading error and damage index respectively. From the analysis it was depicted that grading spool speed of 50 rpm was the most appropriate because at this speed minimum damage index was observed. This could be due to proper re-orientation of the product. Other two speeds of 25 and 75 rpm used in this recorded higher values of damage index and thus were treated as unsuitable for grading of apples. At lower speed of 25 rpm the over sized product entered the smaller bank and could not be pulled out to move forward to the proper bank due to low peripheral speed of the grading rollers that caused frictional resistance owing to the relative movement of the diablo shaped discs and the product. Similarly, at grading spool speed of 75 rpm extensive re-orientation of the product caused the increased damage index and this could be due to high circumferential velocity of diablo shaped discs that exerted the impact forces on the product being rotated for grading. Skin puncturing and bruising were major drawbacks at this speed of grading spools. Therefore it is clear that grading spool speed of 50 rpm is appropriate for optimum results.

CONCLUSIONS

The grader was designed keeping in view farmer's requirement, local available material and ease of operation. Performance of the grader was evaluated for grading efficiency and damage occurred during the operation. Following conclusions were drawn from the results of this study.

1. For potato grading, take-in conveyor speed (Si) contributed 47 % of the total damage index while grading spool speed (Sg) shared 44 % of the total damage index. Similarly for grading error, take in conveyor contributed 22.65 % of the total grading error of the system and grading spools speed (Sg) shared 23.54 % of the total grading error. Damage index was increased 4.66 % when the take-in conveyor speed was decreased to 15 m/min and when further decreased to 10 m/min the damage index was increased 8.29 %. Therefore it was concluded that the take-in conveyor speed had an inverse effect on damage index of potatoes. Minimum damage index was observed at grading spool speed 50 rpm while 8.67 and 14.24 % increase in damage index was investigated at 25 and 75 rpm, respectively. Therefore, for potatoes grading take-in conveyor speed of 20 m/min, grading spool speed of 50 rpm and take away

conveyor speed of 10 m/min is the appropriate for optimum results.

2. For apple grading, optimum results were observed at take-in conveyor speed of 10 m/min, grading spool speed of 50 rpm and take away conveyor speed of 10 m/min while statistically same damage index was also observed at take-in conveyor speed 15 m/min, grading spool speed 50 rpm. Grading error at take-in conveyor speed of 20 m/min, grading spool speed 75 rpm and take away conveyor speed of 10 m/min was 7.4% while at take-in conveyor speed of 15 m/min, grading spool speed 50 rpm and take-away conveyor speed of 10 m/min, grading error was 5.44%. Take-in conveyor speed contributed 25.38 % of the total damage index and grading spool speed shared 49.89 % of the total damage index. Similarly take-in conveyor speed and grading spool speed contributed 42.64 % and 35.7 % respectively of the total grading error of the system. Take-in conveyor speeds inversely affected the damage index while linear effects were investigated for grading error. Take-in conveyor, grading spool and take-away conveyor speeds of 15m/min, 50 rpm and 10 m/min respectively were appropriate for apple grading.
3. Optimum results were observed at different speed combinations of the machine parameters and that were probably due to difference in shape index among the crops and within the crops. Grading expenditure for potatoes and apples were Rs 4/- and Rs.5/- per 100 kg respectively.

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