DEVELOPMENT, FABRICATION AND PERFORMANCE EVALUATION OF FRUIT AND VEGETABLE GRADER

BY

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To

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# TABLE OF CONTENTS

LIST OF FIGURES vi

LIST OF TABLES ix

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>1.1</td>
<td>OBJECTIVES</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>REVIEW OF LITERATURE</td>
<td>7</td>
</tr>
<tr>
<td>2.1</td>
<td>GRADING</td>
<td>7</td>
</tr>
<tr>
<td>2.1.1</td>
<td>VEGETABLE GRADING</td>
<td>8</td>
</tr>
<tr>
<td>2.1.2</td>
<td>FRUIT GRADING</td>
<td>10</td>
</tr>
<tr>
<td>2.2</td>
<td>SIZE GRADING MECHANISM</td>
<td>11</td>
</tr>
<tr>
<td>2.2.1</td>
<td>SCREEN OR SIEVE TYPE GRADER</td>
<td>13</td>
</tr>
<tr>
<td>2.2.2</td>
<td>BELT TYPE GRADER</td>
<td>14</td>
</tr>
<tr>
<td>2.2.3</td>
<td>ROLLER TYPE GRADER</td>
<td>15</td>
</tr>
<tr>
<td>2.2.4</td>
<td>ROLLER TABLE GRADING MECHANISM</td>
<td>16</td>
</tr>
<tr>
<td>2.2.5</td>
<td>WEIGHT GRADING MECHANISM</td>
<td>16</td>
</tr>
<tr>
<td>2.3</td>
<td>ELECTRONIC GRADING</td>
<td>17</td>
</tr>
<tr>
<td>2.4</td>
<td>MECHANICAL DAMAGE</td>
<td>18</td>
</tr>
<tr>
<td>2.5</td>
<td>CUSHIONING MATERIAL</td>
<td>27</td>
</tr>
</tbody>
</table>
### DESIGN AND FABRICATION

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>DESIGN OF MACHINE ELEMENTS</td>
<td>30</td>
</tr>
<tr>
<td>3.2</td>
<td>MAIN FRAME</td>
<td>32</td>
</tr>
<tr>
<td>3.3</td>
<td>TAKE-IN CONVEYOR</td>
<td>34</td>
</tr>
<tr>
<td>3.3.1</td>
<td>CAPACITY OF THE CONVEYOR</td>
<td>36</td>
</tr>
<tr>
<td>3.3.2</td>
<td>POWER REQUIREMENT</td>
<td>36</td>
</tr>
<tr>
<td>3.3.3</td>
<td>CONVEYOR DRIVING SHAFT</td>
<td>37</td>
</tr>
<tr>
<td>3.3.4</td>
<td>CONVEYOR DRIVING DRUM</td>
<td>39</td>
</tr>
<tr>
<td>3.3.5</td>
<td>CONVEYOR BELT</td>
<td>39</td>
</tr>
<tr>
<td>3.4</td>
<td>HOPER</td>
<td>39</td>
</tr>
<tr>
<td>3.5</td>
<td>SPACE BAR CONVEYOR</td>
<td>42</td>
</tr>
<tr>
<td>3.5.1</td>
<td>BARS</td>
<td>42</td>
</tr>
<tr>
<td>3.5.2</td>
<td>CONVAS BELT</td>
<td>44</td>
</tr>
<tr>
<td>3.5.3</td>
<td>DRIVING ASSEMBLY</td>
<td>44</td>
</tr>
<tr>
<td>3.6</td>
<td>PRIMARY GRADING UNIT</td>
<td>46</td>
</tr>
<tr>
<td>3.7</td>
<td>SECONDARY GRADING UNIT</td>
<td>49</td>
</tr>
<tr>
<td>3.7.1</td>
<td>DIABLO SHAPED RUBBER DISC</td>
<td>51</td>
</tr>
<tr>
<td>3.7.2</td>
<td>SPOOL SHAFT</td>
<td>51</td>
</tr>
<tr>
<td>3.7.3</td>
<td>SPACERS</td>
<td>54</td>
</tr>
<tr>
<td>3.7.4</td>
<td>DRIVING MECHANISM</td>
<td>54</td>
</tr>
<tr>
<td>3.8</td>
<td>TAKE-AWAY CONVEYOR</td>
<td>54</td>
</tr>
<tr>
<td>3.9</td>
<td>POWER TRANSMISSION SYSTEM</td>
<td>56</td>
</tr>
<tr>
<td>3.9.1</td>
<td>DESIGN OF MAIN SHAFT</td>
<td>56</td>
</tr>
<tr>
<td>3.9.2</td>
<td>MAIN GEAR BOX</td>
<td>58</td>
</tr>
<tr>
<td>3.9.3</td>
<td>CHAIN DRIVE SYSTEM</td>
<td>61</td>
</tr>
</tbody>
</table>
4 MATERIALS AND METHODS

4.1 MACHINE PARAMETERS

4.2 CROP PARAMETERS
   4.2.1 DAMAGE INDEX
   4.2.2 GRADING ERROR

4.3 STATISTICAL ANALYSIS

4.4 ECONOMIC ANALYSIS

5 RESULTS AND DISCUSSION

5.1 POTATO GRADING
   5.1.1 Effects of take-in conveyor speed on damage index
   5.1.2 Effects of grading spool speed on damage index
   5.1.3 Effects of take-away conveyor on damage index
   5.1.4 Model of damage index for potato grading
   5.1.5 Effects of treatments on damage index
   5.1.6 Effects of take in conveyor on grading error
   5.1.7 Effects of grading spool speed on grading error
   5.1.8 Effects of take away conveyor speed on grading error
   5.1.9 Model of grading error for potato grading
   5.1.10 Effects of treatments on grading error

5.2 APPLE GRADING
   5.2.1 Effects of take in conveyor speed on damage index
   5.2.2 Effects of grading spool speed on damage index
   5.2.3 Effects of take away conveyor on damage index
   5.2.4 Model of damage index for apple grading
   5.2.5 Effects of treatments on damage index
5.2.6 Effects of take in conveyor on grading error 88
5.2.7 Effects of grading spool speed on grading error 89
5.2.8 Effects of take away conveyor speed on grading error 90
5.2.9 Model of grading error for apple grading 92
5.2.10 Effects of treatments on grading error 93

5.3 ONION GRADING 94
5.3.1 Effects of take in conveyor speed on damage index. 94
5.3.2 Effects of grading spool speed on damage index. 95
5.3.3 Effects of take away conveyor on damage index. 95
5.3.4 Model of damage index for onion grading. 97
5.3.5 Effects of treatments on damage index. 98
5.3.6 Effects of take in conveyor on grading error. 100
5.3.7 Effects of grading spool speed on grading error. 100
5.3.8 Effects of take away conveyor speed on grading error. 101
5.3.9 Model of grading error for onion grading. 102
5.3.10 Effects of treatments on grading error. 104

5.4 MANGO GRADING 105
5.4.1 Effects of take in conveyor speed on damage index. 105
5.4.2 Effects of grading spool speed on damage index. 106
5.4.3 Effects of take away conveyor on damage index. 107
5.4.4 Model of damage index for mango grading. 107
5.4.5 Effects of treatments on damage index. 108
5.4.6 Effects of take in conveyor on grading error. 111
5.4.7 Effects of grading spool speed on grading error. 112
5.4.8 Effects of take away conveyor speed on grading error. 113
5.4.9 Model of grading error for mango grading. 115
5.4.10 Effects of treatments on grading error. 115
5.5 MACHINE ECONOMICS

SUMMARY

CONCLUSIONS AND RECOMMENDATIONS

REFERENCES

APPENDIX – A
APPENDIX – B
APPENDIX – C
APPENDIX – D
APPENDIX – E
APPENDIX – F

116
118
122
124
133
151
164
165
169
178
### LIST OF FIGURES

<table>
<thead>
<tr>
<th>Fig. No.</th>
<th>Title</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Isometric view of fruit and vegetable grader (Final Form)</td>
<td>31</td>
</tr>
<tr>
<td>3.2</td>
<td>Isometric view of main frame of fruit and vegetable grader.</td>
<td>33</td>
</tr>
<tr>
<td>3.3</td>
<td>Isometric view of take-in conveyor.</td>
<td>35</td>
</tr>
<tr>
<td>3.4</td>
<td>Isometric view of hopper.</td>
<td>41</td>
</tr>
<tr>
<td>3.5</td>
<td>Isometric view of space bar conveyor.</td>
<td>43</td>
</tr>
<tr>
<td>3.6</td>
<td>Isometric view of conveyor drive assembly.</td>
<td>45</td>
</tr>
<tr>
<td>3.7</td>
<td>Isometric view of primary grading unit.</td>
<td>47</td>
</tr>
<tr>
<td>3.8</td>
<td>Isometric view of secondary grading unit.</td>
<td>50</td>
</tr>
<tr>
<td>3.9</td>
<td>Isometric view of Diablo shaped rubber disc.</td>
<td>52</td>
</tr>
<tr>
<td>3.10</td>
<td>Isometric view of spool shaft.</td>
<td>53</td>
</tr>
<tr>
<td>3.11</td>
<td>Isometric view of double sprocket.</td>
<td>55</td>
</tr>
<tr>
<td>3.12</td>
<td>Isometric view of take-away conveyor.</td>
<td>57</td>
</tr>
<tr>
<td>3.13</td>
<td>Isometric view of main gear box.</td>
<td>60</td>
</tr>
<tr>
<td>5.1</td>
<td>Damage index (DI) vs Grading spool speed (Sg) at take-away conveyor speed 5m/min for potato grading.</td>
<td>73</td>
</tr>
<tr>
<td>5.2</td>
<td>Damage index (DI) vs Grading spool speed (Sg) at take-away conveyor speed 10m/min for potato grading.</td>
<td>73</td>
</tr>
<tr>
<td>5.3</td>
<td>Damage index (DI) vs Grading spool speed (Sg) at take-away conveyor speed 15m/min for potato grading.</td>
<td>73</td>
</tr>
<tr>
<td>5.4</td>
<td>Grading error (ER) vs Grading spool speed (Sg) at take-away conveyor speed 5m/min for potato grading.</td>
<td>80</td>
</tr>
<tr>
<td>5.5</td>
<td>Grading error (ER) vs Grading spool speed (Sg) at take-away conveyor speed 10m/min for potato grading.</td>
<td>80</td>
</tr>
<tr>
<td>5.6</td>
<td>Grading error (ER) vs Grading spool speed (Sg) at take-away conveyor speed 15m/min for potato grading.</td>
<td>80</td>
</tr>
<tr>
<td>5.7</td>
<td>Damage index (DI) vs Grading spool speed (Sg) at take-away conveyor speed 5m/min for apple grading.</td>
<td>85</td>
</tr>
</tbody>
</table>
5.8 Damage index (DI) vs Grading spool speed(Sg) at take-away conveyor speed 10m/min for apple grading.

5.9 Damage index (DI) vs Grading spool speed(Sg) at take-away conveyor speed 15m/min for apple grading.

5.10 Grading error (ER) vs Grading spool speed(Sg) at take-away conveyor speed 5m/min for apple grading.

5.11 Grading error (ER)) vs Grading spool speed(Sg) at take-away conveyor speed 10m/min for apple grading.

5.12 Grading error (ER) vs Grading spool speed(Sg) at take-away conveyor speed 15m/min for apple grading.

5.13 Damage index (DI) vs Grading spool speed(Sg) at take-away conveyor speed 5m/min for onion grading.

5.14 Damage index (DI) vs Grading spool speed(Sg) at take-away conveyor speed 10m/min for onion grading.

5.15 Damage index (DI) vs Grading spool speed(Sg) at take-away conveyor speed 15m/min for onion grading.

5.16 Grading error (ER) vs Grading spool speed(Sg) at take-away conveyor speed 5m/min for onion grading.

5.17 Grading error (ER)) vs Grading spool speed(Sg) at take-away conveyor speed 10m/min for onion grading.

5.18 Grading error (ER) vs Grading spool speed(Sg) at take-away conveyor speed 15m/min for onion grading.

5.19 Damage index (DI) vs Grading spool speed(Sg) at take-away conveyor speed 5m/min for mango grading.

5.20 Damage index (DI) vs Grading spool speed(Sg) at take-away conveyor speed 10m/min for mango grading.

5.21 Damage index (DI) vs Grading spool speed(Sg) at take-away conveyor speed 15m/min for mango grading.

5.22 Grading error (ER) vs Grading spool speed(Sg) at take-away conveyor speed 5m/min for mango grading.
5.23 Grading error (ER) vs Grading spool speed (Sg) at take-away conveyor speed 10m/min for mango grading.

114

5.24 Grading error (ER) vs Grading spool speed (Sg) at take-away conveyor speed 15m/min for mango grading.

114
# List of Tables

<table>
<thead>
<tr>
<th>Table No.</th>
<th>Title</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>Experimental variables and their interactions</td>
<td>67</td>
</tr>
<tr>
<td>5.1</td>
<td>Effects of take-in conveyor speed (Si) on damage index of potato.</td>
<td>70</td>
</tr>
<tr>
<td>5.2</td>
<td>Effects of grading spool speed (Sg) on damage index of potato.</td>
<td>71</td>
</tr>
<tr>
<td>5.3</td>
<td>Effects of treatments on damage index and grading error for potato</td>
<td>75</td>
</tr>
<tr>
<td>5.4</td>
<td>Effects of take-in conveyor (Si) on grading error of the grader.</td>
<td>76</td>
</tr>
<tr>
<td>5.5</td>
<td>Effects of grading spool speed (Sg) on grading error of the grader.</td>
<td>77</td>
</tr>
<tr>
<td>5.6</td>
<td>Effects of take-in conveyor (Si) on damage index of apples.</td>
<td>82</td>
</tr>
<tr>
<td>5.7</td>
<td>Effects of grading spool speed (Sg) on damage index of apples.</td>
<td>83</td>
</tr>
<tr>
<td>5.8</td>
<td>Effects of treatments on damage index and grading error for apples</td>
<td>87</td>
</tr>
<tr>
<td>5.9</td>
<td>Effects of take-in conveyor (Si) on grading error of grader.</td>
<td>89</td>
</tr>
<tr>
<td>5.10</td>
<td>Effects of grading spool speed on grading error of the grader.</td>
<td>90</td>
</tr>
<tr>
<td>5.11</td>
<td>Effects of take-in conveyor (Si) on damage index of onions.</td>
<td>94</td>
</tr>
<tr>
<td>5.12</td>
<td>Effects of grading spool speed on damage index of onions.</td>
<td>95</td>
</tr>
<tr>
<td>5.13</td>
<td>Effects of treatments on damage index and grading error for onion</td>
<td>99</td>
</tr>
<tr>
<td>5.14</td>
<td>Effects of take-in conveyor (Si) on grading error of the grader.</td>
<td>100</td>
</tr>
<tr>
<td>5.15</td>
<td>Effects of grading spool speed (Sg) on grading error of the grader.</td>
<td>101</td>
</tr>
<tr>
<td>5.16</td>
<td>Effects of take-in conveyor (Si) on damage index of mango.</td>
<td>106</td>
</tr>
<tr>
<td>5.17</td>
<td>Effects of grading spool speed on damage index of mango.</td>
<td>107</td>
</tr>
<tr>
<td>5.18</td>
<td>Effects of treatments on damage index and grading error for mango</td>
<td>110</td>
</tr>
<tr>
<td>5.19</td>
<td>Effects of take-in conveyor speed (Si) on grading error of the grader</td>
<td>112</td>
</tr>
<tr>
<td>5.20</td>
<td>Effects of grading spool speed (Sg) on grading error of the grader.</td>
<td>112</td>
</tr>
</tbody>
</table>
Chapter 1

INTRODUCTION

The country is endowed with a wide range of agro-ecological zones and diverse climatic conditions that make it possible to grow a large variety of tropical, sub-tropical and temperate fruits, vegetables, flowers, medicinal herbs and spices. The horticulture sector contributes about 12% of agriculture value addition. The production of fruits and vegetables will be enhanced from 6.0 million tones and 7.0 million tones in 2004-05 to 9.4 million tones and 10.0 million tones, respectively in 2009-10 (Anonymous, 2005). Pakistan Horticultural Development and Export Board (PHDEB) has been established with a view to promote technological upgradation and human resource development, facilitate and set-up necessary infrastructure for horticulture development including cold chains, promote public-private partnership, design/implement quality standard, diversify overseas markets, enhance horticultural exports and help in formulation and implementation of national horticultural policy. The constraints of the horticulture sector are: poor farming practices, shortage of improved planting/seed materials, low yields, pests/diseases especially fruit fly/viruses, post-harvest losses, sub-standard quality, inadequate facilities for grading, packing, marketing, lack of reefer containers, cold storages and cool chain, limited space/transit time through air/sea ways and poor linkages with potential importing countries.

In a global setting, exchange rates, population and income growth, worldwide market access and market development activities lay an important role in determining the world demand and price levels for goods and services traded between countries. In this regard fruits like apple, mango and citrus, vegetables like potato, tomato and onion are among those horticultural crops that are traded within and across the countries.

Potato (Solanum tuberosum L.) has gained an important commercial position in the crop sector of Pakistan and now ranks 3rd among the major cash crops in order of production. It is grown over an area of approximately 115.8 thousand hectares annually and about 85% of the total area is planted in the lowlands of the Punjab. An estimated
production of potatoes in Pakistan was 1.946 million tones, of which 1.76 million tones were produced in Punjab (Anonymous, 2004).

Mango, Mangifera Indica (Anacardiaceae) is one of the most popular tropical fruits and considered as one of the finest fruit in the world. It has an established export market and poses bright opportunities for export in the international market whether in fresh or processed forms. It is delicate and perishable fruit and requires careful handling during the phase of processing. The world mango production showed an increasing trend averaging to 2.2 million metric tons per year. In 1999, total world production of mango reached to 2.38 million metric tons, which is 0.17 million metric tons higher than the 1995 production (USDA, 2001). Worldwide production is heavily concentrated in Asia, accounting for 77% followed by South and Northern America with 13% share, Africa with 9% share and Oceana at 1% share. Over half of the world mango production is produced by India. The other major mango producers included China, Mexico, Thailand, Indonesia, Pakistan, Nigeria, Brazil and the Philippines. Its production and export in Pakistan has been increased to 1,056 and 354 thousand tones respectively during 2003-2004. Pakistan, Brazil and France have increased their volume of mango traded in the world market posting an export volume growth rate of 26%, 20% and 22%, respectively. In spite of increasing trade no proper mango post harvest handling industry has yet been established in Pakistan and the fruit to be exported is graded and packed manually. Air cargo has made it possible to export this crop to the distant markets in the world.

Apple is a major fruit crop of the Balochistan province and partially of Northern Western Frontier Province (NWFP) of Pakistan. Price and production of this crop provides the highest income per unit area throughout the world. This valuable crop was grown over an area of 47.7 thousand hectares with the production of 334 thousand tones in 2003-2004. Most of this fruit is marketed in the country but due to unique taste and quality its market across boarder is being developed. To improve its shelf life for marketing, processing like grading, washing, waxing and packing before marketing is necessary. In 2003-2004, about 354 thousand tones of worth 5.912 million rupees, fruits were traded abroad. Commercial growers may both grade and pack their apples immediately after they are picked or they may hold them in cold storage until near the
time of sale and then grade and pack them. Although some growers, grade and pack a portion of their crop in the orchard from table, more customarily the apples are hauled to picking shed where they are graded. Usually the machinery is arranged so that the apples are dumped onto a table where they roll onto a sizing belt (often made from heavy pieces of wire joined together to form square links) which separates the under sized apples. Usually the apples are passed on endless belts in front of cullers (usually women) that do the same job on personal judgment.

Technological advancement is gradually finding applications in the agricultural and food industries, in response to one of the greatest challenges i.e. meeting the need of the growing population. In advanced countries efforts are being geared towards the replacement of human operator with automated systems, as human operations are inconsistent and less efficient. Mechanical graders grade the fruit on basis of size while disease affected and damaged fruit is sorted out by hand. Sizing mechanism may be grouped broadly into those which grade by diameter and those which grade by weight. Machines that grade on the basis of diameter vary greatly. Some size in only one or two directions, while others rotate the produce and thereby achieve a more accurate sizing. In general, machines that grade by diameter tend to have higher throughputs, or to be rather less expensive and complex for a given throughput, than those, which grade the produce by weight.

The inherent variability of horticultural products at harvest and their differences in value, make it necessary to grade them according to some objective standard. Grading is the basis of long distance trade. It permits the description of products in terms that are understandable both to buyer and to seller. Without a system of grading, all products would have to be individually inspected. Grading thus adds tangible value to horticultural products.

Grading is important for successful marketing. In Pakistan, the erratic power supply, the low-level of technological know-how are the factors that may hinder the adoption of the emerging technologies in agricultural products handling. Unless these factors are addressed, the application of automated sorting of agricultural materials in Pakistan will remain an illusion. Proper market has not been yet developed in our country
to compete the international market, especially at present when world has been turned into a global village and World Trade Organization (WTO) has specified its standards to meet the international trade contracts. Grading on basis of size and quality is an essential preliminary to marketing of fruit and vegetables grown on commercial holdings. After the awareness of the abroad trade regulations, quality conscious consumers demand the product according to international standards. Therefore farmers are reluctant to sell their raw crop in the market. For this purpose imported graders, to separate the crop into different sizes, are complex and expensive those are beyond the approach of an ordinary farmer as having small land holdings. In such circumstances farmers have to sell their produce in bulk without grading at lower marginal profit to the large enterprises that takes away a big share of income. Among fruits, citrus, mango and apple while among vegetables, particularly potatoes and onions are being marketed abroad. To compete the international market, standards have been decided for each crop because the graded product always commands a premium in the market and should have a better price of the produce.

Good mechanical graders damage little to the produce being graded; however the surface bruising that occurs due to rolling into receiving bin. This is usually negligible compared with damage incurred in harvesting and getting the crop to the grader. However, falling height, rolling speed, conveyor type of the grader, are the main factors that may cause damage if any during the operation.

Throughputs of graders vary widely according to the number and skill of the operators, as well as according to the machines and auxiliary equipment employed. There are innumerable variations and arrangements in the machine, which are used advantageously, and most commercial growers develop the machinery to suit their particular needs. A most important factor to be emphasized regardless of what type of machinery or arrangement of equipment is made, is that the produce being graded, should always be protected from bruising by designing the machine and employing proper materials. At present, the rapid expansion of the other economical sectors has drawn labor forces from agricultural sector, resulting in labor shortages during the crop production activities.
Sorting of agricultural products is accomplished based on appearance, texture, shape and sizes. Manual sorting is based on traditional visual quality inspection performed by human operators, which is tedious, labor intensive, time-consuming, slow and non-consistent. Therefore, farmers are looking forward to have an appropriate crop grading machine in order to alleviate the labor shortage and obtain a better quality of agricultural products. Keeping in view the market requirements as desired by the WTO, quality control by proper grading demands a grading machine that can be used on farm level and within the purchase power of an ordinary farmer. For this purpose, a low cost grader was in dire need for development to grade the horticultural crops on basis of size. To meet the need of time the machine was developed and fabricated with the parameters predetermined for the fruit and vegetable post harvest handling.

The grader was developed to grade the horticultural products on basis of size as per buyers’ requirement. Operational cost and easy operation was focused in development keeping in view the throughput, labor requirement, mobility and future repair and maintenance. Three functional units, Take in conveyor, grading unit and take away conveyor, which are mounted on the main frame. Take in conveyor operates to load the crop on the grading unit. A variable drive system was provided to run the take in conveyor at three different speeds 10 m/min, 15 m/min, and 20 m/min. Grading unit comprises, primary grading unit and secondary grading unit. Provision has been facilitated to attain the required bank size for grading the product into different grades. A drive mechanism to drive the grading unit at three speed levels 25 rpm, 50 rpm and 75 rpm were developed to accommodate the different feed rates. To convey the graded crop to the packing point take away conveyors were developed and operated at three speeds, 5 m/min, 10 m/min and 15 m/min with out causing the mutual collusion of the falling products from grading unit.

Inherent variability in size with in crop and among different crop has made it a little bit complex to accommodate all the products at the same set of conditions. Potato, onion, apple and mango have different characteristics (shape index, maturity level, stiffness and moisture) and the grader behavior with the products was quite different. Take in conveyor speed and grading unit speed were to major parameters that contributed
a lot towards the damage index and grading error while take away conveyor has no significant effect in producing the damage index and grading error.

In order to define the feed rate of the grader, three take in conveyor speed 10 m/min, 15 m/min and 20 m/min were selected to load the crop on the grading unit at 6 t/hr, 9 t/hr and 12 t/hr respectively. High grading speed (75 rpm) was responsible for high damage index while high take in conveyor speed (20 m/min) was responsible for high grading error. Effective supervision was found important for ensuring feeding uninterrupted. At high throughput grading charges @ Rs.4 / 100 kg were recorded.

Keeping in view local market requirements and conditions of WTO for trade abroad, and non availability of a high throughput fruit and vegetable grading machine, for on farm use, need was felt to develop a power operated fruit and vegetable grader to meet the following objectives:-

1.1 OBJECTIVES

Overall Objectives
1. To develop and fabricate a power operated machine for grading fruits and vegetables and evaluate its performance

Specific Objectives
1. To design and fabricate fruit and vegetable grading machine.
2. To test its performance for grading potatoes, onions, apples and mangoes based on size of the products.
Chapter 2

REVIEW OF LITERATURE

The development of graders dates back five decades and the first grader designed was simply a crude slat with a bag attached to the end. Products were inspected on the slat and moved by hand into the bag. These were called slat graders, which led to development of mechanical graders. Grading has been changed very little in the last fifty years. However, the grading process has been fully mechanized. A mechanical grader consisted of a chain conveyor belt, with a bag at the end. Smaller produce used to fall through the chain, making the grading process easier. In Pakistan grading is still being done by hand. Labor shortages and a lack of overall consistency in the process resulted in a search for automated solutions. Research work conducted by different researchers is reviewed as under:

2.1. Grading

For successful marketing, post harvest handling endeavor had very high leverage and had therefore worthy of increased investment by both national and international agencies as described Goletti and Wolff (1999). Among post harvest handling operations, two were of great importance because end users tried to cull the fruit and vegetables mostly on the basis of size and free of visible defects. So sizing and inspection of the product prior to marketing were considered basic requirement to command a premium. The same was discussed by Mc Rae (1985) and he graded the fruit and vegetables on the basis of size and inspection. Inspection involved manual elimination of unwanted material. Shyam et al (1990) described that grading requirements vary with the end use. He further tolled that manual grading by hand picking was very slow, labor intensive and costly. Disposal of product from the fields was many times delayed due to slow grading process, which resulted in qualitative and quantitative losses. To encounter this delayed disposal of product, two grading and packing sheds were established in Punjab. There performances were evaluated by Inayat et al (1995) and they concluded that static grading units were not feasible under the local conditions as farmers were reluctant to
bring their produce to the grading shed. They further recommended the mobile grading unit for on-farm use.

2.1.1 Vegetable grading

The need to be responsive to market demands 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. Anonymous (1967) designated five grades for export potatoes i.e. Pak extra large (>70 mm), Pak large (55-70 mm), Pak medium (40-55 mm), Pak small (28-40 mm) and Pak mids (17-28 mm) where as 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. Rana and Chauhan (1985) described four grades and these grades were designated on weight basis. Mostly the researchers designated grades to potatoes on basis of size as per demand of the market as described by K.C. Roy et al (2005). He designated four grades to potatoes (< 28 mm, 28-40 mm, 40-55 mm and >55 mm. He further described that recognized official standards grade of potatoes enabled producers and buyers to fix reasonable price for both. Consumers got a benefit whenever the packages carry the official grade marking (Schoenemann, 1977).

Srivastava et al., (1995) described that a fruit and vegetable (Apple & potato) grader was developed by the Govind Ballabh Pant University of Agriculture and Technology, Pant Nagar, India. That grader was diverging belt type and able to grade the produce into three different grades with throughput of 1.5 ton/hr. Shyam et al., (1979) working on potato sorting, found that with a decrease in feed rate from 50 q/hr to 25 q/hr resulted in better efficiency of the grader. An other power operated oscillating sieve type potato grader was developed by Shyam et al., (1990) and found that grader yielded the throughput of 37 q/hr with 462 strokes/min, stroke length of 31.5 mm and 14.5° of sieve
Similar type of grader was developed by K.C. Roy at Bangladesh Agricultural Research Institute (BARI) Joydebpur, Gazipur. That potato grader was able to grade the potatoes into four sizes at 167 strokes /min and sieve slope of 15°. He further studied the economics of the grader and concluded that the operational cost of the grader was 73% lower than manual grading at throughput of 1.5 ton /hr. A common problem of trapping potatoes on the sieve in sieve type grader was observed and re-orientation of the tubers was recommended for trouble free operation. Similarly different researchers studied onion grading and revealed that the size of the crop varied widely from country to country, however, average size of onion bulbs were almost the same (20 mm to above 90 mm) and grades were designated as per buyer requirement. Suppavit Chawpo et al., (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 capacity of this machine was determined by the velocity of the belt. 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 found the optimum velocity 0.13m/s of the belt for maximum grading capacity of 3150 kg/h with an error of 2.46%. Anonymous, (2004) designated three grades on 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, above 65 mm. Maw et al. (1989) stated that "Sweet onion varieties do not have the internal pesticidal properties of the more pungent varieties" and therefore have a much shorter shelf life than dry onions. The sugar content increases and pungency decreases as onions mature near harvest. They pointed out that damaged areas on the onions might become infected with pathogens like black mold; this fungus will often infect an entire ring within an onion. Damage can occur in the form of surface abrasion, impact bruising, or a separation of the layers for any reason. Inayat Ali et al., (1995) described that onions after curing were graded manually before storage and thus losses in storage were reduced. They studied diverging and screen type graders and recommended
slope. Similar type of grader was developed by K.C. Roy at Bangladesh Agricultural Research Institute (BARI) Joydebpur, Gazipur. That potato grader was able to grade the potatoes into four sizes at 167 strokes /min and sieve slope of 15°. He further studied the economics of the grader and concluded that the operational cost of the grader was 73% lower than manual grading at throughput of 1.5 ton/hr. A common problem of trapping potatoes on the sieve in sieve type grader was observed and re-orientation of the tubers was recommended for trouble free operation. Similarly different researchers studied onion grading and revealed that the size of the crop varied widely from country to country, however, average size of onion bulbs were almost the same (20 mm to above 90 mm) and grades were designated as per buyer requirement. Suppavit Chawpo et al., (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 capacity of this machine was determined by the velocity of the belt. 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 found the optimum velocity 0.13m/s of the belt for maximum grading capacity of 3150 kg/h with an error of 2.46%. Anonymous, (2004) designated three grades on 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, above 65 mm. Maw et al. (1989) stated that "Sweet onion varieties do not have the internal pesticidal properties of the more pungent varieties" and therefore have a much shorter shelf life than dry onions. The sugar content increases and pungency decreases as onions mature near harvest. They pointed out that damaged areas on the onions might become infected with pathogens like black mold; this fungus will often infect an entire ring within an onion. Damage can occur in the form of surface abrasion, impact bruising, or a separation of the layers for any reason. Inayat Ali, et al., (1995) described that onions after curing were graded manually before storage and thus losses in storage were reduced. They studied diverging and screen type graders and recommended
that mechanical graders were suitable for grading potato and onion as grading before marketing paid back much more and economical. The average size of onion specified in Canada varied from 44 to 76 mm and the grades designated to onion by MINFAL (Pakistan) were almost have the same range as per local requirement and for abroad marketing (http://www.gov.on.ca/OMAF/english/food/inspection/index.html).

2.1.2 Fruit grading

Grading of fruits is very important operation as it fetches high price to the grower and improves packaging, handling and causes an overall improvement in marketing system. The fruits are generally graded on basis of size and graded fruits have better export market and reduce handling losses during transportation. In Pakistan 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. It has also been reported that the weight of spherical fruits like apples, pears and citrus is proportional to the cube of its characteristics dimensions (Royal and Lipton, 1972).

Apple growers grade apples in the orchard from moveable table by manual process while some commercial growers used other grading equipments. Mack, W B. (1956) designated three grades with size range 50 – 57 mm, 57-64 mm, and 64-71 mm. To grade the apples, they developed a sizing belt type grader built from heavy pieces of wire joined together to form square links. These square links separated the under sized apples while passed over fruit were useable and feeded to brushing section for washing purpose. The washed apples were passed through another grading unit that separated the apples into three grades. They further recommended foam padding of 25.4 mm thickness to protect the apples from bruising. Where as DAVENEL., (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. They designated the grade with 5 mm increment while Mack, W B. (1956) assigned the grades with 6 mm increment. Similarly MINFAL developed four
grades of apples and these grade standards were designated as per market requirements throughout the world.

Raw mango grader was developed by Zameer et al., (2005) that was expanding roller type, worked on the principle of rolling the mango around the axis of minimum mass inertia. They designated grade I, grade II, grade III and grade IV with the size range of 50-57 mm, 57 - 64 mm, 64 – 70 mm and >70 mm respectively. The grader was tested for different varieties at slopes 8 degree, 12 degree and 16 degrees at 720 kg/hr, 1800 kg/hr and 2400 kg/hr. They found that 12-degree slope was the best and the fruit grading efficiency decreased with an increased feed rate. They described the reason for such decreased efficiency that increased feed rate resulted in increased blocking of the grader openings or faster rolling of fruits which resulted in smaller fruits getting dropped into a larger category. Similar results were obtained by Goodman and Hamann (1971) in sizing sweet potato where increased feed rate resulted in decreasing efficiency from 95.6% to 89.9% and that of canning grade from 100 % to 96.6 %. Beriage and Langmo (1982) studied the mechanical apple harvester with sorting capabilities and revealed that it was difficult to recognize and retrieve obvious culls. Observation of the sorters at work suggested that their lower output was due to work-place restraints and vibration of the conveyor. They recommended to use a variable speed cross conveyor drive so that the flow of the fruit could be adjusted to match the fruit density. Belt speed slower than 18.3m/min (60 ft/min) and improved inspection could easily be achieved by the variable speed drive.

2.2 Size grading mechanism

To categorize the agricultural produce into different grades, researchers used different methods. Malcolm et al. (1953) carried out extensive tests on fruits and potatoes using roller tables with the facility to alter translation speed, roller rotation speed, lighting, scanning and operating position. They set out a number of practical guidelines to enable optimum throughput and quality to be achieved. They suggested that potatoes should rotate so that their top surface travels in the direction of translation and if possible should be presented directly to the operator at regular intervals. Translation speed should
be 6-9 m/min and rotation speed 6-12 revolution per meter of translation. 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-rev/meter 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. In the test they correlated the feed rate, translation of crop and rotation of the rollers to remove the maximum defective tubers.

Carlow (1980) designed a roller conveyor and fitted an electronic aid, when unwanted potatoes were touched by hand held wand 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 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 finger 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. Nelson et al., (1980) compared a conventional roller table with the one fitted with a wand unit and concluded that whilst the operation of either system could not be regarded as stressful, the wand was much preferred to the manual removal system.

A high throughput variable aperture grader with parallel rollers was developed and tested by Hutchison and McRae (1980). That was the simplest sizing machine developed for agricultural produce. These had been popular for some time for crops such as carrots and parsnips, which were of cylindrical or tapered profile and would tend to be damaged
and poorly sized through a square-mesh screen. Its efficiency when grading the variety Maris Piper compared with a hand operated parallel bar riddle was 96.8 % at 12 t/h throughput, but in comparison with a standard square-mesh riddle an efficiency of only 85 % was achieved at the same output. Further McRae (1985) described that the both throughput and efficiency found by Hunter and Yaeger (1970) were higher than figures from comparable studies in the U.K. Potato Marketing Board tests at Sutton. Experimental Station in U.K. showed that efficiency at a low throughput of 0.72 ton/h was 57% and fell to 33% at 2.16 t/hr. A higher efficiency of 67-72 % for the three output levels selected was achieved by having two inspectors stationed opposite each other, so that end defects could be observed. He further described that there is a scope for improvements to roller tables, which might result in more efficient operation and better throughput. It was also reported that lighting on some U.K. grading lines were inadequate. There was no rotational speed control for the rollers. Rollers became clogged with sticky soil and required scraping; if the soil was allowed to harden, damaged tubers were resulted. The use of high speed brushes with a 3.3 m/s peripheral speed mounted under the return run of the rollers could be effective. There was still an unresolved problem of varying effective tuber diameters, leading to excessive rotational speed variations between potatoes. This could be diminished if closer size grading were carried out prior to inspection.

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 – 25 q/h 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 problem and a little bit higher skin bruising was observed.

### 2.2.1 Screen or sieve type grader

Balls (1986) described the perforated and mesh screen, 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 can easily be changed to obtain a wide range of grading capability of the grader. Shyam et al., (1990) developed a power operated oscillating sieve type potato grader capable of sorting potatoes into 4 or 5 different sizes or grades and tried different combinations of sieve speed, stroke length and sieve slope for satisfactory operation and high screen efficiency. Sieves of size 60 cm × 120 cm with round perforations of 50.4, 44, and 35 mm diameter were used. The machine yielded the throughput of 37 q/hr with speed of 462 stroke/min, stroke length of 31.5 mm and sieve slope of 14.5 %. They further described that grading of potato tubers had been an important operation in potato production. A similar type low cost potato grader was developed by K. C. Roy et al (2005). There were three sieves at an angle of 150° with the horizontal and sieves were made of rubber impregnated G.I wires. The grader was capable to size the potatoes into four sizes with the capacity of 2,030 kg/hr. Trapping of potatoes in the sieves was observed and to eliminate the potato trapping, a mechanism for re-orientation of potato tubers was recommended.

Doraiswamy (2000) developed a sieve type grader for grading groundnuts into three different sizes. The output capacity was 600 kg/hr and was powered by a one horsepower 3-phase electric motor. Re-orientation of pods in sieve holes was observed that required modification in shaking system. After reviewing the literature it was concluded that sieve type graders faced a same problem of sieve hole blocking.

2.2.2 Belt type grader

A combined apple and potato grader was developed by the Govind Ballabh Pant University of Agriculture and Technology, Pant Nagar, India. It consisted of six v-belts and was able to grade the produce into three grades. It was powered by an electric motor of two-horse power with grading capacity of 1,500 kg/hr. The Punjab Agriculture University, Ludhiana, India, developed an other 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 (Srivastava et al., 1995).

2.2.3 Roller type grader

The simplest sizing machines developed for agricultural produce used parallel rotating rollers. These had been popular for some time for crops such as carrots and parsnips which are of cylindrical or tapered profile and would tend to be damaged and poorly sized through a square-mesh screen. A high throughput variable aperture grader with parallel rollers was developed and tested by Hutchison and McRae (1980). Its efficiency when grading the variety Maris Piper compared with a hand operated parallel bar riddle was 96.8% at 12 t/h throughput, but in comparison with a standard square-mesh riddle an efficiency of only 85% was achieved at the same output. A self-propelled sizing machine was developed by Liu (1989) that was consisting of three layers of inclined rotating parallel rollers supported at each end. The spaces between the rollers were such that the undersized fruit passed through to the second layer and the larger fruit was retained and rolled to the end of the unit for collection. The second and the third layer of rollers functioned exactly the same as the first layer. Four different size classes of fruit could be separated with this unit. Each layer of rollers was constructed as a module and could be replaced easily. Therefore, the same machine could be used for sizing different tree fruit by changing the roller module. The capacity for this sizing unit was about 300 kg (660lb)/hr.

An other sizing unit was discussed by O’ Brien (1968) that was consisted of parallel rollers supported at each end by roller chains making a continuous conveyor. This unit can separate larger fruit from undersized fruit. For fruits such as gherkins that need to be separated into several different sizes. Similarly O’ Brien and Gaffney (1983) used an expanding chain roller sizer with sizing cams which determined the opening between rollers. A spiral-roller conveyor for sorting purpose was used by Allshouse and Stephenson (1969). They used a multiple and adjustable v-belt arrangement for grading sweet potatoes.
Peleg (1985) also reviewed extensive discussions on the sizing machines, their construction, operation, adjustment, and suitability for sizing different produce varieties.

2.2.4 Roller table grading mechanism

Malcolm and DeGarmo (1953) tested a roller table to grade fruits and potatoes. The roller table grader was provided with the facility to alter translation speed, roller rotation speed, lighting, scanning and operating position. They recommended several practical guidelines for optimum throughput and quality to be achieved. They suggested that potatoes should rotate so that their top surface travels in the direction of translation and if possible should be presented directly to the operator at regular intervals. They further recommended 6-9 m/min translation speed and 6-12 revolutions per meter of translation speed. Surprisingly, the percentage of defects appeared to have little adverse effects on inspection efficiency, but for each type of defect sought in the sample, a drop of 3% in efficiency occurred.

McRae (1985) developed a roller table grader and described the scope for improvements to roller tables, which might result in more efficient operation and better throughput. It was also reported that lighting on grading lines should be adequate. Rollers required scraping because they were clogged with sticky soil and hardened soil damaged the tubers. To wash out the sticky soil high speed brushes with a 3.3 m/s peripheral speed were mounted under the return run of the rollers. An other problem was observed that was the crop having a wide range of effective diameter and their variable rotational speed. To solve this problem closer size grading was recommended.

2.2.5 Weight grading mechanism

Jager et al. (1958) developed an early type of weight grader, which consisted of a rotating hub carrying a number of radially disposed cups on single leaf spring arms. The leaf springs responded according to the weight of potato, which was released into the appropriate outlet by a cam rail tipping arrangement. Jager plotted a graph of weight against diameter, pointing out that weight increases as the cube of the diameter.

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 basis of weight. Grade A
(> 200 gms), Grade B (150 – 200 gms), Grade C (100 – 150 gms) and Grade D (< 100 gms). Grader performance of the grader was evaluated at different speeds (5, 10, 15, 20, 25 and 30 rpm) and was found satisfactory at carrier speed 12 and 15 rpm with overall grading efficiency about 96 %. Royal and Lipton (1972) reported that the weight of spherical fruits like apples, pears and citrus was proportional to the cube of its characteristics dimensions. Brennan (1976) described that weight grading was capable of more precise separation than dimensional grading as it reduced labor cost, damage, time and power consumption and improved efficiency and accuracy.

Shyam et al., (1990) developed a potato grader capable of grading the potatoes into four grades on basis of weight and these grades were designated by Central Potato Research Institute (CPRI), Shimla, India. i.e. small, medium, large and extra large with the weight of < 25 g, 25 to 50 g, 50 to 75 g and > 75 grams respectively. The average throughput of that grader was 20-25 q/hr and efficiency of grader was 90 %.

2.3 Electronic grading

McRae (1985) described that following consideration may be taken into account in the design of a singulation system for potatoes which are to be graded by electronic methods.

1. Throughput should be high enough to enable the full potential of the sizing head to be realized. In the case of potatoes for the ware market this could be 2-10t/hr or 20,000-1,00,000 potatoes/hr depending on the sizing equipment.

2. Doubles (potatoes side by side or contiguous on the presentation belt) should be virtually eliminated; otherwise, for example, a sample of bakers with a high standard of uniformity could be spoiled by the inclusion of a few quite small potatoes.

3. The device should be capable of handling all the leading varieties in a wide size band and be prone to breakdown through build-up soil, straw and other debris.
Lawton and Gale (1974) described two methods of instructing machines for quality grading apples. One of them used a floor-mounted lever moving in two axes to define the position of a cup on a moving belt containing a sub-grade apple. The other used a system in which a glove fitted with electrical contacts was used to define the location of the sub-grade apple by touching a conductor pin adjacent to the cup.

Ikeda et al., (1982) described a system for evaluating the shape of farm products using an image-processing technique. In the equipment used, the shadow of an apple was projected on a matrix of 96 cadmium sulphide cells and their output analyzed by a Mitsubishi Melcom 70-30 computer. The object was rotated at a controlled rate, through 10 increments of 36°, to evaluate its shape. They concluded that an improved version of the device using stereo image processing through two cameras could be made. Webster (1970) developed following shape index:

\[
TuberShapeIndex = \frac{Tuberlength}{Tuberbreadth} \times 100
\]

They further described that the efficiency of any sizing system, which depends on estimating the volume by optical means, was likely to be affected by the shape of the tubers and by the method of presentation.

2.4 Mechanical damage

External qualities i.e. sizes, shapes and colors are considered of paramount importance in the marketing of fruits. Presence of blemishes influences consumer perceptions and therefore determines the level of acceptability prior to purchase. The economic implications of bruising are extraordinary. Impact damage in horticultural crops is costly and it was estimated that 30% to 40% of fruits and vegetables undergo mechanical damage from harvesting to market delivery (Peleg and Hinga, 1986).

Peters, 1996 described that mechanical damage to potato tubers is one of the most important causes of quality loss throughout the world, costing $2 billion annually in the USA alone; and, although he tolled that avoidance of mechanical forces is the most
promising means of preventing tuber damage, he further pointed out that the extent of
damage was dependent on the condition of the tubers and their history. Brook, 1996 also
supported the view of Peter and estimated that a one-percent reduction in the number of
impact-related defects in potato tubers (Solanum tuberosum) was worth approximately
$7.5 million in an average year in the USA. One large processor estimated that each
percentage point of total defects costs over $4 million annually. The cost of bruising in
apples and several other commodities was also significant.

A distinction has to be made between pre-harvest and post harvest mechanical
damage. In case of pre-harvest damage, fruits can be injured in several ways while still
on the plant. During growth they may come into contact with other fruits or other parts of
the plant such as branches causing abrasion, puncture and bruising. Herbivorous animals,
slugs, insects, birds and mammals, can puncture the skin and consume a proportion of the
tissue. Weather is another important cause of damage: wind can aggravate damage
caused by contact with other parts; hail causes impacts bruises that can be locally
devastating for fruit production.

Apart from predation, pre-harvest mechanical damage is infrequent or sporadic
and not easily controlled. Affected fruit will be culled either on the field or in the packing
house (Knee and Miller, 2002). While during post harvest handling, there are two major
causes of mechanical damage for fruit and vegetables; excessive impacts during
harvesting, grading, handling, and transportation, and excessive compressive forces
during bulk bin and package handling. Managing tuber condition, handling system
design, handling system operation, or all three can control impact damage. Commercial
production of fruits requires different mechanical attributes so that the soft tissues survive
their journey through the marketing chain in a state suitable for human consumption.
Similarily Bajema, 1995 described two categories of damage for potato tubers: external
and internal. External damage includes skinning, cracks, shatter, cuts and scrapes (Hesen
and Krosenberg, 1960; Witz, 1954) while internal damage includes cracking, shatter and
black spot (Noble, 1985; Baritelle, 1997). Internal and external damage often both occur
during the harvesting and subsequent handling of tubers.
The skin of potato tuber is its shield against damage and so any action, which weakens or breaks the skin, can potentially cause a loss of quality. In particular, the number of times a tuber is dropped during handling, and the heights of the drops, will largely determine the final product quality. It is therefore important that all handling processes must be taken responsible for final product. One misconception is that potatoes are solid and tough and can withstand rough treatment. In fact potatoes are highly sensitive, susceptible to both mechanical damage (cuts and bruises) and attack by pathogens. Often the two are associated, with a cut or bruise enabling the entry of a fungal or bacterial infection; this reinforces the need to minimize mechanical damage.

In most grading and handling installations efforts are made to minimize the effects of drops which may be fixed, or may vary. Fall breaking devices have been developed to reduce the falling velocity. O'Brien et al. (1980) detailed a number of filling mechanisms for fruit and vegetable crops to reduce damage and he recommended that a swinging flighted type conveyor with a height sensor as it was most effective. Similarly McRae (1974) described an automatic height control for a potato harvester delivery conveyor, which was also applied to filling boxes. One unit was used in East Lothian that filled over 5000 1-t boxes without breakdown.

Koning and Lerink (1981) conducted experiments with a simple commercially available fall breaker consisting of a number of 12 mm diameter strings 35 mm apart, spanning a trailer and connected in the middle in groups of three. They found that 32% of the incoming material passing through the strings was slowed down to an acceptable impact velocity. Haan and Zwol (1974) carried out tests on a check-way and a chute system, each with a vertical height of 4.3 m. Throughputs of 10, 25 and 40 ton/h were used. A third test was arranged in which potatoes fell from a horizontal conveyor set at three heights above a hard surface. Results showed that in case of chute, a vertical fall height of 4.3 m was ameliorated by the chute to an equivalent clear drop of 1.0 m, whilst in case of a check-way the equivalent was a 0.5 m drop. Apart from the potentially serious damage, which could occur with drops of 0.5m, chutes and check-ways promote considerable rolling and mutual collisions as potatoes move to the exit point. There is a considerable scope for developing new conveying and handling devices, particularly to
eliminate or reduce drops at transfer points from one conveyer to another, from conveyer to grading machine or from machine to conveyer and to the packing point.

Umaerus (1978) collated methods for measurement of damage and U.K. signed an agreement on terminology for external damage in 1979. Though internal damage has not yet been clearly defined. In U.K. damage is classified into following categories:
- Scuffing – Surface abrasion damage to the skin.
- Peeler – Damage removed by two strokes of a potato peeler, maximum depth 3 mm.
- Severe Damage – Damage deeper than 3 mm.

Robertson (1970) developed a damage index that express the weight of tissue lost when tissues in above categories of damage are removed by peeling. It is determined by first classifying the damage, then weighing the peeler.

Damage Index = (% Scuffed) + (% Peeler × 3) + (% Severe × 7)

IMAG, Wageningen and Bull (1979) described that damage index based on following formula was used for machinery testing in Holland and Germany.

\[
\text{Damage Index} = \frac{(% \text{Light}) + (2×% \text{Medium}) + (3×% \text{Severe})}{6}
\]

Where Light denotes < 2%, Medium denotes 2 - 10 % and Severe denotes >10% surface damage.

Shimada (1980) conducted a comprehensive range of drop tests including dropping tubers on steel plates and cushioned rods. A drop of 1m on to a steel plate produced splitting and a maximum deceleration of 638 g. When potatoes dropped on a 10 mm diameter bar their deceleration peaked at a drop of 515 mm. The ratio of deceleration with cushioning to that without cushioning was 0.697 for 1mm thick foam rubber and this became 0.34 with 3mm thick material. Vinyl foam proved a poor alternative. When large sized tubers fell 1m on to a layer of small tubers the smaller ones were damaged by the impact. Several studies have discussed the influence of characteristics of vegetal material and of the stresses on the damage of fruits flesh, firmness maturity, time and quality of
storage, cultivar and color of skin in the impact point (Hyde and Ingle, 1968; Nelson and Mohsenin, 1968; Hung and Prussia 1988; Brusewitz and Bartsch, 1989; Sober et al., 1989). Rangi and Berardinelli (2001) studied the response of apples considering the shocks registered by means of an instrumented sphere (Techmark, Type IS 100) in a plant to sort and pack fruits, having a working capacity of 3.5-4.5 t/h and concluded that mechanical impacts caused by the equipment for sorting and packing fruits could involve in damage the flesh of apples. Flesh deterioration could reach a depth of 5 mm and a diameter of 15 mm, which were not eliminated by peeling. The deterioration shows marked fractures and darkening of the flesh. They further concluded that the first impact was critical to overcome breaking load of the vegetable material and the loss of its initial elastic characteristics.

Shyam et al., (1990) developed a power operated sieve type potato grader and studied different parameters. Scuffed tubers (with surface abrasion damage to skin) and those with flesh damage were separated manually from each fraction and their percentages based on the weights of the corresponding fractions were taken as tuber damage. It was observed that tuber damage depends upon the crop maturity and curing period. Average tuber damage for K. Chandramukhi, K. Jyoti and K. Sindhuri varieties at full maturity and after curing for a minimum period of 25 days was found to be about 3% in large tubers, 1% in seed-size tubers. Longer curing period was suggested for immature crop and shorter for late harvested crop.

Mohsenin (1986) defined bruising as damage to plant tissue by external forces causing physical change in texture and/or eventual alteration of color, flavor, and texture. Note that there are both physical (texture) and chemical (color, flavor) aspects in potato bruising. The physical aspects involve physical damage to cell walls, cell membranes, or both; the chemical aspects involve chemical reactions that occur as a result of that damage. The blue-black or gray-black discoloration associated with black spot bruise is results of oxidation of tyrosine by polyphenol oxidize (Mohsenin, 1986; Dean et al., 1993; Dean, 1996). This reaction occurs when cell membranes are disrupted due to impact damage, and may or may not be associated with cell wall damage (Reeve, 1968). Thus, discoloration can occur without obvious tissue damage. On the other hand, there can be cell wall failure
without discoloration if the particular tuber or cultivar does not have the chemical potential to discolor or if membranes are not disrupted. Such tissue damage is important even without discoloration, because damaged tissue absorbs more oil during frying than does sound tissue.

Bruise indexing methods were used in the mid 1980's for evaluating the impact sensitivity of potato tubers. Pavek et al., (1985) used the falling mass approach to bruise tubers that were then hand-peeled and subjectively scored into one of six categories based on the intensity of discoloration; 0 (no bruise) to 5 (darkest). The composite scores were the mean discoloration index for each sample group. Other researchers have used similar systems (Skrobacki et al. 1989 and Turczyn et al., 1986). The limitation of this type of system is that it emphasizes the chemical aspects of bruising because the impacts are not consistent with the impacts encountered in normal handling (Bajema, 1995). Also, by nature, these subjective quantifications of damage make results from different researchers difficult to compare and reproduce. Lack of discoloration in damaged tissue may be important in evaluating impact sensitivity of new cultivars.

Baritelle and Hyde (1997) found that the tissue of a new tuber cultivar exhibited particularly poor failure properties but did not have the chemical potential to discolor. Use of discoloration only as an indicator of impact sensitivity or “bruise susceptibility” may result in mistakenly accepting a cultivar as useful only to find in production that it is highly prone to bruising. The classification system described here deals primarily with the physical rather than the chemical aspects of bruising, both because tissue strength is the more important aspect, and because that strength gives an indication of tuber condition.

Baheri (1997) developed a pendulum device for his study of potato mechanical damage. Three different sensors were used: accelerometer, force transducer and an analog angle sensor to measure impact and rebound angle of the pendulum rod. To quantify bruise damage, bruise volume was selected, as it was mostly applied bruise quantification method in scientific publications. Nevertheless some critics have been made by Pang et al. (1996) that the bruise surface should be used to measure bruise damage. The argument therefore was that only the bruise surface is noticed by consumers
when purchasing the apples. The bruise volume was measured (single impact) 24 hours later utilizing the equation by Henand Sun (1981):

\[ BV = \frac{\pi}{6} dD^2 \]

Where \( BV \) bruise volume (m\(^3\))
\( d \) bruised depth (m)
\( D \) bruised diameter (m)

To calculate the bruise surface the following equation was used (Barreiro, 2004):

\[ BS = \pi \frac{D}{2} d \]

Where \( BS \) bruise surface (mm\(^2\))
\( D \) bruise diameter (mm)
\( d \) bruise depth (mm)

Baritelle et al., (1997) developed bruise classification system. He described that once the experiments were performed the tubers were stored at room temperature (\( \approx 23^\circ C \)) for a period of 72 hours before measurements were made. The tubers were cut into one mm slices through the bruise and the diameter of the bruise was measured to the closest millimeter in each of three directions (length, width and depth). Treating the bruise as an ellipsoidal shape the three diameters were compiled to determine the total bruise volume. Only bruises 0.048 cm\(^3\) or greater in volume were scored, this is equivalent to a 4.5 mm diameter sphere (the size of a standard BB, 0.177 in). This bruise size was chosen to make the classification of the data more practical and to represent that which has practical meaning to the commercial potato industry.

Brook (1996) reviewed the history of potato bruising research dating back to 1912, and discussed both mechanical and physiological aspects of potato bruising. However, a concise definition or classification system for potato bruises was omitted. Many of the bruise classification systems reported in the literature are bruise indexing systems utilizing subjective judgments of the amount of discoloration associated with bruises. Further, methods of creating the bruises often involve falling masses with hemispherical impact surfaces that create tissue stresses rarely if ever encountered in real
handling systems (Bajema, 1995). Relating bruise type resulting from standardized impacts to tuber condition provides a tool for managing easily modifiable factors. Such factors include tuber hydration level (Thornton et al., 1974; Bajema, 1995), tuber temperature (Peterson and Hall 1974 & 1975) and impact velocity during handling (Mathew and Hyde, 1997).

Impact bruise threshold was defined as the drop height at which bruising just begins to occur for a specimen of given mass and radius of curvature, falling onto a given impact surface (Zhang, 1994). This definition was slightly different from that of Schulte et al. (1992), which applied specifically to the statistical threshold technique. Bruise threshold in fruits and vegetables varied considerably due to a number of variables, many of which were not well understood (Baritelle, 1997a). Three of the variables that may be controlled are temperature, relative turgor, and impact velocity or strain rate. Temperature and relative turgor (hydration) can be controlled within limits by conditioning the commodity; strain rate is primarily related to handling system design and operation. Another factor for bruise damage was discussed by Johnson and Dover (1990) and Garcia (1995) they found an increase in bruise damage with harvest date. They further identified that large apples have larger cells and thinner cell walls and this is the reason they contract more bruise damage.

Other authors, like Diener et al., (1979) found the opposite effect. Garcia (1995) gave an explanation for the contradicting results found in literature. Two processes are associated with ripening: decrease in turgor and decrease in apple firmness. Decrease in turgor leads to less bruise damage. But in contrary, decrease in apple firmness leads to more bruise damage (Garcia et al., 1995).

Mathew and Hyde (1992) demonstrated that the impact damage continuum in potatoes begins with black spot bruises at low drop heights and changes to tissue shatter and cracking as drop height increases. Their results were obtained by dropping whole tubers onto different surface materials from different realistic handling system drop heights. Drop heights above 400 mm onto steel caused cracking without tissue discoloration in some tubers. The lack of tissue discoloration can be interpreted as evidence that the fracture was between the cells, and did not damage the cell structure in
a way that allowed the mixing of polyphenol oxidize with tyrosine, which would result in the blue-black melanin discoloration associated with black spot bruising. Later Mathew and Hyde (1997) found that drop height (in which impact energy and velocity are combined but not distinguished from one another) influenced not only the amount but the type of bruise damage in whole potato tubers. As drop height increased, the percentage of 250±30 g (8-10 oz.) tubers damaged increased, but above 200 mm (8"'), the amount of black spot bruise decreased and was replaced by more brittle types of tissue failure until, at 450 mm (18"'), the black spot dropped to zero.

Mohsenin (1986) discussed work done by Tabachuk (1953) who found that potato tuber damage began at absorbed kinetic energies of as small as 1.5 inch-pounds when the tuber was striking a flat metal surface. Maximum allowable drop height was 10-20 inches on a flat surface, but only 4-6 inches on steel rods like those used in potato harvesters. The absorbed energy was found from the principle of conservation of momentum. Mohsenin (1986) stated that plant tissue damage results from external forces that result in a change in the tissue's texture or color. Chen and Yazdani (1991) successfully predicted apple bruise volume (related to bruise resistance, but not to bruise threshold) using impacting acceleration and mass. Further, they found the strongest bruise volume correlations with maximum rate of change of acceleration, maximum total deformation of fruit and cushioning together, and maximum energy absorbed by fruit and cushioning together. Of course, impact energy depends upon both mass and drop height, while impact approach velocity depends only on drop height and gravity.

Consumer’s demand for high quality products, especially in the Western world, has increased last decades and is still increasing. However, not only the visual aspect of mechanical damage can affect the demand, but also a higher risk of bacterial and fungal invasion, leading to a lower shelf-life of the fruits. In addition, 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. For most fruit types, including apples and tomatoes, bruising is the most common type of post harvest mechanical injury. A survey for 12 years on the New York market indicated that 6% of apples and 1% of tomatoes were affected by bruising. However, most likely these percentages are underestimated.
According to New York market studies, mechanical injury was never the most common defect for most fruits (including apples and tomatoes). It is likely that minor mechanical injuries were not counted by the market inspectors and were only seen through their consequences in fungal infections. So, mechanical injury could be the most important cause of defects and disease. If mechanical injury could be avoided there would be less need for fungicides to prevent disease and there would be much less loss of fruit (Knee and Miller, 2002).

Studman (1997) indicated that apple bruising could result in product losses up to 50%, although typically loss levels were in the 10 to 25% range, depending on consumer's awareness.

Agricultural commodities are known to be viscoelastic materials meaning that loading velocity and temperature influence their mechanical properties (Pitt, 1982). Hydration level (turgor) also influences the tissue mechanical properties (Mohsenin, 1986). Altering the condition of the commodity by raising its temperature or dehydrating it slightly (up to 3% mass loss) can have a dramatic effect on impact sensitivity (Thornton et al., 1974, Bajema, 1995). There are cases, especially with potatoes, where too much dehydration can have the opposite effect (Thornton et al., 1974). With potatoes and other commodities a loss of consumer appeal occurs if they become too dehydrated. There was also a weight loss associated with dehydration, which resulted in financial losses; so an optimum hydration level needs to be found to minimize damage with little or no effect on consumer appeal which could optimizes profits. Siyama et al., (1988) demonstrated the superiority of multiple linear statistical models above theoretical models in predicting the bruise damage.

2.5 Cushioning material

Fresh fruits and vegetables suffer impacts as they are mechanically handled in commercial packing lines. Impacts commonly occur when the product crosses transfer points along the line. Bruising occurs when product tissue failure stress is exceeded. Bruise onset and size depend on a range of factors: height of the transfer points, fruit velocity at impact, hardness of the impact surfaces, curvature of the surfaces, and fruit
characteristics (mass, curvature, temperature, hydration, firmness). The choice of a padding material must be such that the most bruise sensitive products may be handled without damage. Damage can be reduced or avoided by locating padding materials on the surfaces of the machines (Burkner et al., 1972). A good padding material must satisfy three requirements (Bollen et al., 1995): (1) it must absorb the impact energy without damaging the product; (2) it should not apply a high rebound energy to the produce and it should avoid fruit–fruit impacts; and (3) it must be durable and compatible with packing line specifications (non-toxic, no absorption of dirt, etc.). In addition to the three requirements from Bollen et al., (1995), the combination of padding thickness and elastic modulus must be such that the fruit neither “bottoms out” (i.e., pushes through the padding to be stopped by the hard surface beneath) nor is bruised by padding that is too stiff (rigid).

Bittner et al., (1967) developed a method for analyzing padding materials based on the absorbed energy, calculating the dropping height and the rebound height of a wooden ball anchored to an impacting pendulum. They used balls of different diameters to evaluate the effect of the contact area (radius of curvature of fruit). Hemmat et al., (1980) developed a mathematical model to estimate the thickness of the padding materials based on cushioning properties obtained with static methods, physical properties of the fruit, and impact energy.

Bollen et al., (1995) proposed a method based on the measurement of three parameters of the padding material: (1) cushioning properties measured with an instrumented sphere, (2) restitution coefficient, and (3) durability of the padding material (6 out of the 8 materials tested showed fatigue signs after receiving 4400 impacts with a rubber ball of 170 g). There are many locations in potato handling and grading installations where drops are difficult to eliminate, or where the drop height fluctuates according to the level of the accumulated potatoes in hoppers or on chutes. Few experimental data are available on the efficacy of cushioning material in reducing damage to potatoes, although some work has been done on protecting fruit from impact damage. Fluck & Ahmed, 1973; Zapp et al., 1990 described two approaches to damage reduction:
1) Improve the design and operation of the equipment.

2) Reduce the impact sensitivity of the commodity of interest.

Bajema, 1995 described that reducing the amount of bruising can also increase food safety by decreasing the potential for microbial infestation. In addition the aesthetic, trimming and disposal problems associated with these defects will also be reduced Some work has been done to improve mechanical handling systems, but more information is still needed to quantify commodity condition at the time of handling so that the commodities can be conditioned to minimize damage.

Burkner et al., (1972) dropped oranges on a range of padding materials and measured damage by comparing respiration rates and sound of dropped fruit. They found that oranges could be dropped 3 meter, to a Neoprene sponge rubber covered frame with no more damage than from a drop of 150 mm on to a plywood frame. For proper selection of cushioning material, Hammerle and Mohsenin (1966) investigated the problems involved in the evaluation of dynamic mechanical properties of cushioning materials. A vertical drop tester was constructed from a heavy steel table and vertical track guides for the drop head. A high-speed optical oscillograph (Visicorder), an accelerometer, and an analog computer provided data on velocity of impact, specimen deformation, and specimen rebound height. The apparatus was used by dropping a metal, spherical drop head on cushion materials or inversely by dropping mounted cushions on various fruits.

McRae (1985) described that foamed plastics sold under brand names such as Ethafoam and Plastazote were used quite widely to line hopper walls and areas where potatoes may suffer impact damage.
Chapter 3

DESIGN AND FABRICATION

This study was carried out to develop and test an appropriate grading machine to provide a practical mean of separating fruits and vegetables into sizes. Grading of size and quality is an essential preliminary to marketing of fruits and vegetables grown on commercial holdings. Proper marketing system is being developed in our country to compete the international market, especially at present when world has turned into a global village and World Trade Organization (WTO) has specified its standards to meet the international trade contracts. To achieve the access to the markets abroad, traded commodity must be according to standards specified by WTO and that is only possible by the direct linkage between consumer demand in the importing countries and producers in the exporting countries. In our country grading and sizing of agricultural products has not been introduced on farm level. It is a labor-intensive task but is obviously one of the major operations to obtain a better selling price. At present, majority of farmers have to sell their produce in bulk without grading, at lower marginal profit to the large enterprises that take away a big share of profit. Thus a fruit and vegetable grading machine was developed, fabricated and its performance was also evaluated taking into account different machine and crop parameters in order to grade different horticultural crops on the basis of size, at farm level. In WTO snario, this will definitely set a new trend of quality and trade abroad for net high return for farming community.

This chapter solely deals with design and fabrication of fruit and vegetable grader. Detailed features of design and development of the grader are given in the following paragraphs.

3.1 Design of machine elements

Keeping in view grading principle, rotation and translation of the product, a spool type, power operated and mobile grading machine was developed. The isometric view of
1. Main frame
2. Take-in conveyor
3. Hopper
4. Space bar conveyor
5. Primary grading unit
6. Secondary grading unit
7. Take-away conveyor
8. Chain drive system
9. Transportation wheel
10. Tractor draw bar

Fig. 3.1 Isometric view of fruit and vegetable grader
the grader is shown in Fig 3.1; Variability in size of the products was focused to grade different horticultural crops. Machine was developed with the locally available material to bear all the static and dynamic loads due to machine weight (765 Kg) and crop load respectively during operation and transportation. The detailed drawings of complete machine and parts are shown in Appendix-B. The effects of different machine parameters and their interaction on damage index and grading error were studied. Its performance was evaluated for potato onion, apple and mango grading. The details of development of the machine are discussed in the following sections.

3.2 Main frame

In order to assemble all the components of the machine, main frame was developed which is shown in Fig. 3.2. It was fabricated with mild steel angle bar (51mm×6.4mm) and design was flexible to fit all the other working units rigidly. Main frame was mounted with transportation wheels and designed to bear static and dynamic loads during operation and transportation. During operation different parts were subjected to a load that varied in direction and in magnitude. Main frame was developed keeping in view the static and dynamic loads, in order to avoid frequent failures during operation. In order to combat the mechanical fatigue failure machine elements were designed with appropriate factor of safety. The fatigue stress was the result of a variable loading which may cause the failure of the part. Although the nature of fatigue failure is now reasonably well understood, but the complexity of the problem is such that rational methods of design for fatigue are difficult to develop with the reason that fatigue strength of the parts is not only the function of the material but also of the design features, fabrication method and service condition. Further fatigue strength of the material is influenced by small cracks and other flaws. Main frame was made with the mild steel angle, which was readily available and the most commonly consumed material in the fabrication of farm machinery. In machine, components manufactured with such type of materials, fatigue failure is produced by progressive fracture starting from a point in the form of a minute crack that spreads generally under the action of fatigue loads until the resisting area becomes so small that complete fracture occurs suddenly. To determine the size of
mild steel angle, 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 considered on the selected machine element to determine its thickness and width. Maximum deflection was determined in the center of the mild steel angle bar that was 0.14 mm when the spool was loaded with four times greater than the actual load. This designed load on the angle bar was not enough to produce mark able deflection in angle iron member that may cause any fatigue on the angle iron member during operation of the machine. Hence the design was safe. A detailed design feature of mild steel angle bar is given in Appendix A-1.

3.3 Take-in conveyor

The design, fabrication and selection of different components for a machine are very important factors for its better performance. 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. As the grader had to work at the farmer’s field under different climatic conditions, efforts were made to design it as simple as possible so that its future repair could be carried out without any problem.

Endless flight type conveyor was developed to convey the produce from ground to hopper (Fig. 3.3). Raising the incoming product to the hopper caused a small drop. Loading capacity, fall height and angle of repose of the product to be lifted were considered for safe conveying of the produce without 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 designed to convey 12 tons (maximum throughputs) of bulk at a conveyor linear speed of 20 meter/min (Rangi and Berardinelli, 2001). It was powered through a gearbox from the main shaft of the machine. Speed reduction arrangement was also developed to vary the linear speed of the conveyor.
3.3.1 Capacity of the conveyor

The system was designed to operate the take in conveyor at a speed of 20 m/min as suggested by Rangi 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 expression (Spivakovsky and Dyachkov 1972).

\[ Q = \frac{3600qv}{1000} \]

Where

\[ Q = \text{capacity, tons per hour} \]
\[ q = \text{weight of the fruit per meter of the conveyor length, kg/m} \]
\[ v = \text{linear speed of the conveyor, m/sec} \]

The product was loaded on the conveyor at the rate of 10 kg per meter length of conveyor and the conveyor was operated at a speed of 20 meter per minute. Thus the capacity of conveyor under test was worked out as 12 t/hr.

3.3.2 Power requirement

Power required to convey the produce from ground surface to the height of two meter, employing an inclined conveyor having three meter length, was worked out taking into account frictional resistance of the system and lifted height. To encounter the frictional resistance during elevating and transporting the produce, following formula was used as suggested by Omre and Saxena (2003).

\[ N_{\text{fric}} = \frac{(QL\omega)}{362} \quad (kW) \]

Where

\[ N_{\text{fric}} = \text{Power required to overcome the frictional resistance (kW)} \]
\[ Q = \text{Capacity of the conveyor (tons /hr)} \]
\[ L = \text{Length of conveyor (m)} \]
\[ \omega = \text{Friction factor (0.1 for the fruit conveyor)} \]
The conveyor was designed to convey the produce to a height of two meters with carrying capacity of 12 ton/hr and the power calculated 0.009945 kW was necessary to overcome the frictional resistance during the conveying the product.

The power required to elevate the crop to a height of two meters was determined by the following formula as suggested by Opare and Saxena (2003).

\[ N_{\text{eff}} = \frac{(QH)}{362} \quad \text{(kW)} \]

Where

\( Q = \) Capacity of the conveyor (tons/hr)
\( H = \) Lift height (m)

Thus for a designed rate of 12 ton/hr from the ground surface to hopper at a height of 2 meter, the power worked out was 0.0663 kW for the required lift height.

Since this conveyor performed both functions i.e. conveying and elevating, therefore, total power was worked out as follows.

\[ N = N_{\text{eff}} + N_{\text{fric}} \]

Where

\( N = \) Total power required to operate the conveyor (kW)
\( N_{\text{eff}} = \) Power required to elevate the produce (kW)
\( N_{\text{fric}} = \) Power required to overcome frictional resistance (kW)

Hence in order to operate the conveyor for conveying of produce to the hopper, the total power required was 0.07625 kW.

3.3.3 **Conveyor driving shaft**

In order to operate the conveyor, power was transmitted through a shaft to its driving drum. A mild steel power transmission shaft was employed. The torque (T) required to rotate the driving drum was worked out as suggested by Bahl and Goel (1982).
\[ T = \frac{97303 \times N}{n} \]

Where

- \( T \) = Torque required to transmit power \( N \), kg-cm
- \( N \) = Total power required to operate the conveyor, kW
- \( n \) = Speed of driving shaft, rpm

Torque (\( T \)) worked out to transmit the total power (0.07625 kW) to driving the drum at speed 84 rpm to run the conveyor at linear speed of 20 meter/min, was 88.325 kg-cm. In order to transmit required torque of 88.325 kg-cm, the diameter of the shaft worked out was 10.224 mm, which was calculated by the following equation.

\[ d = 3 \sqrt[3]{\frac{16T}{Ss \pi}} \]

Where

- \( d \) = Diameter of conveyor driving shaft (cm)
- \( n \) = Speed of driving shaft of conveyor (rpm)
- \( T \) = Torque on shaft (kg-cm)
- \( Ss \) = Safe shear stress (Kg/cm\(^2\))

The safe shear stress was worked out by dividing ultimate safe stress (\( U_s \)) of 3523 Kg/cm\(^2\) by factor of safety eight as recommended by Stanton Winston (1977).

The actual diameter of the shaft used to drive the conveyor-driving drum had 14.75 mm diameter as compared to 10.224 mm diameter calculated theoretically to transmit a torque of 88.325 kg-cm. Therefore the shaft employed had greater diameter (14.75 mm) than the worked out diameter (10.224 mm), thus the design of the shaft was considered safe. The shaft was designed to transmit the torque produced by the maximum load on conveyor belt while lifting and conveying the product, which was applied by the conveyor through the driving drum to the conveyor-driving shaft. The driving shaft was attached to the conveyor-driving drum to transfer the torque for operation of the conveyor belt at 20-meter/min linear speed.
3.3.4  **Conveyor driving drum**

The conveyor-driving drum was made of mild steel pipe of 76 mm diameter. The driving drum operated the conveyor belt at a linear speed of 20 meter per minute as recommended by Rangi and Berardinelli, (2001). Mild steel round plate of 3 mm thickness and 90 mm diameter was attached to each end of the drum to mount the driving shaft to the driving drum. The collar of the round plate was extended from the pipe diameter to keep the conveyor belt at the proper location.

3.3.5  **Conveyor belt**

General type horizontal belt of width 457 mm was used as transportation conveyor. The lugs, 25 mm high, were fixed on the conveyor belt at 30 cm interval, to stop the rolling back of the products. These types of conveyors are ideally used to convey items with irregular surfaces having small size items that would fall in between rollers. This conveyor was made of sheet metal frame with rollers at either end. One roller was provided at the mid point of the conveyor to encounter the sag. The Globe Ultimate 140 BOS -Nitrile, impregnated belt was used that slid across the metal frame. The steel structure had made it an inexpensive, quiet conveyor and easy to install. This type of conveyor was considered quite suitable for light to medium loads. Sealed, pre-lubricated, self-aligning, ball bearings on drive and tail pulleys were provided to support the drums having 76 mm diameter.

3.4  **Hopper**

The hopper was designed to contain the products to be graded (Fig. 3.4). It was constructed using mild steel sheet 16 SWG and mild steel angle iron 51 × 51 × 6.35 mm. The produce coming from the take-in conveyor was delivered to hopper and this hopper was so designed to load the crop on the space bar conveyor. Load rate was controlled with opening of the hopper that was designed to accommodate various products like potato, onion, apple and mango, and corresponding angle of repose of 20° . Following equation was used to determine the size of opening of the hopper as described Spinvakovsky and Dyachkov, (1972).
\[ b = k \left( 80 + a_{\text{max}} \right) \tan \varphi, \text{ mm} \]

Where

\[ k = \text{empirical factor (2.4 for un-sorted fruits)} \]

\[ a_{\text{max}} = \text{size of the largest fruit} \]

\[ \varphi = \text{angle of repose (20° for selected fruits)} \]

\[ b = \text{size of opening (Shutter height)} \]

Shutter height 140 mm was worked out to pass through the biggest size of the product being graded. Capacity of hopper was calculated based on the quantity of the products to be retained in the hopper. Bulk density of the product and volume of the hopper defined the quantity of the product to fill the hopper. Capacity of the hopper was determined as under:-

\[ Q = V \cdot \rho \]

Where

\[ Q = \text{Hopper capacity, kg.} \]

\[ V = \text{Volume of hopper, m}^3 \]

\[ \rho = \text{Bulk density of product to be graded, kg/m}^3. \]

Average bulk density of the potato, onion, apple and mango was determined with the help of a cubical box, which was 400 Kg/m\(^3\). Volume of the hopper was measured as 0.13915 m\(^3\) with a worked out capacity of 55.66 kg.
3.5 Space bar conveyor

The conveyor was developed to convey, elevate and screen the produce (Fig. 3.5). Produce coming out from hopper was received by the lower end of the space bar conveyor that was conveyed to the seed-grading unit. It was oriented at an inclination angle of 18° to raise the product to the primary grading unit. The inclination angle of space bar conveyor was within the angle of repose of selected fruits and vegetables (20°) in order to stop the rolling back of the produce. The space bar conveyor consisted of steel bars, canvas belt and drive assembly, which are discussed, in the following sections.

3.5.1 Bars

A series of mild steel bars were arranged with 15 mm gap in between two consecutive bars. The bar had 3 mm thickness, 25 mm width and 520 mm length. These bars were fixed on a pair of canvas belt with temporary fasteners i.e. nut and bolts. These steel bars were cushioned with plastic pipe to avoid bruising of the product. To convey the produce, the conveyor was loaded with 10 kg per meter length of conveyor. The conveyor had 15 bars per meter length and thus a load of 0.7 kg was supported by a single bar. The bar was considered a simply supported beam with a span of 52 cm in between two supports. Bending moment due to the load on the bar was determined as follows:

\[ M = \frac{QL}{8} \]

Where

\[ Q = \text{Total load on a single bar (Kg)} \]
\[ L = \text{Bar length (cm)} \]

Average load of the product on the single bar was one-kilogram. The bar was 52 cm long and 2.5 cm wide. The bending moment 4.55 Kg-cm was determined and thickness of the bar was worked out with the ultimate stress of the material of the bar \( 4.227 \times 10^3 \) kg/cm².
Following formula was used to work out the thickness of the bar.

\[ M = S \times Z \]

Where

\( S = \) Safe shear stress

\( Z = \) Section modulus

And

\[ Z = \frac{bh^2}{6} \]

Where

\( b = \) Width of the bar, cm (known)

\( h = \) Thickness of the bar, cm (to be calculated)

The bar under load was of rectangular cross section with 2.5 cm width and the thickness of rectangular cross section was worked out as 1 mm to bear the load of 0.70 kg. While a bar having the thickness of 3 mm was used in fabrication of the space bar conveyor which was greater than the calculated thickness and the nearest available size in local market. Hence the design was safe. Detailed design has been given in Appendix A-3.

3.5.2 Canvas belts

A pair of canvas belt three ply (8 mm thickness and 76 mm width) was used in loop form for continuous run. Distance between two belts were so arranged to avoid the deflection in the mild steel bars. These canvas belts provided continuous motion to the space bar conveyor by making a contact between the flat pulleys and belt.

3.5.3 Driving assembly

Driving assembly comprised two cast iron flat pulleys having diameter 160 mm and 100 mm width that were mounted on a mild steel shaft of 45 mm diameter (Fig. 3.6). This shaft was powered through a v-belt driving system to run at 40 rpm, which in turn operated the space bar conveyor at a linear speed of 20 m/min.
Fig. 3.6 Isometric view of conveyor drive assembly
3.6 Primary grading unit

Three rollers were developed and arranged in series to receive the falling crop from the space bar conveyor (Fig. 3.7). The rollers were made of mild steel pipe having 60 mm diameter with the plain surface. Each roller was provided an axel at both ends to mount the ball bearing for its free movement. These rollers were attached to the main frame and powered through the chain drive mechanism for rotation. Space bar conveyor delivered the crop to the primary grading unit. Roller-spacing and angular velocity were the factors considered responsible for grading according to size and move the product. The distance between two adjacent rollers of 60 mm diameter determined the slot or space to accommodate the required size. A provision was also made to change the space or slot in order to accommodate various products having different sizes. The seed-conveying chute received the crop separated by this unit. The product having larger size passed over these rollers, to the secondary grading unit for further sizing. This unit performed three functions i.e. transport, rotation and grading. Thus transportation and rotation of discrete items of irregular shape was accomplished with powered rollers without translation. In this case transport of the product along the roller bed (perpendicular to roller axes) depended on product size relative to roller diameter and spacing, and/or the density of the product on the conveyor. Non- translating rollers were found useful in design of machine elements where the space was limited (Humphries 2001). A variable drive system was provided to drive the primary grading rollers at 25, 50 and 75 rpm. Grading roller speed was selected in accordance with the feed rate and speed of the take-in conveyor. Powered roller conveyor with these features were used to translate and rotate (for inspection and grading) fruits and vegetables in packing house operations (Rohrbach and Harris, 1998., Tennes, 1981., and Webb et al., 1970). Slot width corresponding to the size grades of products was utilized as a mechanism for size grading. Non-homogenous product was introduced on to the primary grading unit and the product larger than 35 mm (in case of potato grading) diameter was transported over the rollers and subsequently discharged from the discharge end to the secondary grading unit.
The product of smaller size passed through the slots and collected below. Better results were ensured with uniform feeding of single layer of the product to the rollers and large variations were observed when multilayer product was allowed to overload the roller bed area. Uniform feeding of roller was achieved by controlling the loading rate onto space bar conveyor through a variable opening of hopper at bottom. Adjustable hopper opening and inclined space bar conveyor effectively delivered a uniform flow of the product to the discharge end for proper sizing in primary grading unit.

The movement of the product relative to the rollers was due to the friction between the product and the roller surfaces. The rate of progression of the products across the roller was directly related to the angular velocity of the roller. When two adjacent rollers supported a single product and the rollers kept rotating. It was observed that the friction forces between rollers and product rotated the product without causing it to advance relative to the rollers. In order to advance the product relative to the rollers, a support on the upstream side of the product was provided. Continuous flow of the product caused the product to move on rollers by the action of pushing each other in forward direction. That was due to the reason that three mutually contacting bodies (Two rollers and the common product) could not all rotate in the same direction. When an additional product was provided at the upstream then one slipped relative to the other. Due to the rotation of the rollers, instability of the product caused the forward movement of the product and this behavior agreed with the results reported by Liang (1988). Continuous loading of product to the intake end of a primary grading roller provided increased the number of contacts between the rollers and products and hence caused movement of the material. Product was fed until the population of the products on the roller bed was sufficient to cover the roller bed. Under these circumstances the product motion became, more or less uniform.
3.7 Secondary grading unit

This grading unit was designed to grade largest, medium and smallest ranges of sizes of the product. The unit consisted of two sections i.e. upper section containing nine spools and the lower section comprising 11 spools. Both sections were similar in construction. Fig. 3.8 shows the isometric view of the grading section. The secondary grading unit consisted of diablo shaped rubber discs, spool shaft, spacer and driving mechanism. Upper section comprised nine spools of diablo shaped rubber discs and was capable of separating the largest size. The other entire product was passed through the banks, to the lower grading section having 11 spools. Function of lower grading section was same as of the upper section. Lower grading unit divided the product into two sizes, i.e. medium and smallest. For example potato was graded ranging in sizes from 35 to 55 mm and 55 to 70 mm as a smallest and medium size product respectively. The crop was sized by the banks formed by inter disc distance on two consecutive spool. Diablo shaped discs were so designed to rotate and pull out the crop that entered into bank but did not pass through the bank opening because of a bit greater size. Due to the grooved form of the discs, crop was re-oriented repeatedly to attain proper bank. Spacers were provided in between diablo discs to attain the bank of required size. The rate of progression of the product across the spools was directly related to the angular velocity of the rubber sections and continuous supply of the products to the grading section. When two adjacent spools supported a single product and were rotated, the friction forces between spool sections and product rotated the product without causing it to advance relative to the spools. In order to advance the product relative to the spool, one contact point on the upstream side of the product was provided. That contact point was attained by a continuous flow of the product over the grading spools. Rotation of the spools and pushing force behind the product caused instability of the product and forward movement of the product was resulted. A chain drive mechanism was developed to rotate the spools.
Fig. 3.8 Isometric view of secondary grading unit
3.7.1 Diablo shaped rubber disc

Diablo section of 100 mm diameter and 10 mm thickness were molded of rubber having low stiffness and pulled over the spool shaft with the rubber spacers in between them in order to attain the required size bank (Fig 3.9). Spool offered two types of motion to the crop i.e. translatory and rotary. The diablo section has grooves at periphery and due to its rotary motion, the crop having a little bit higher size, was pulled out of the gap. At spool speed of 25, 50 and 75 rpm, diablo section yielded terminal velocity of 7.86, 15.71, 23.57 m/min respectively and re-orientated the products properly to pass through the exact size bank. Rubber stiffness was also important and the selected material has desired flexibility to accommodate the crop within the tolerance of the grade size, without any damage to the crop.

3.7.2 Spool shaft

Rubber sections were pulled over the mild steel shaft having square cross section of size 25.4 mm x 25.4 mm. A series of rubber discs and spacers were arranged on the spool shaft to attain bank of required size in between two consecutive discs and two consecutive spools (Fig. 3.10). Spool shaft was mounted on bearings (6204 zz) at the ends and powered by a chain drive system to run the spool at required rpm. A variable drive mechanism was arranged to run the spools at 25, 50 and 75 rpm. The shaft was subjected to bear a load of 5 kg/spool and was designed to operate at designed load of 20 kg/spool with a factor of safety of 4.00. The shaft was considered to act as simply supported beam with uniformly distributed load of 22.5 kg per meter length. Following formula was used to determine maximum deflection.

\[ y_{\text{max}} = \frac{5WL^4}{384EI} \]

Where

- \( W \) = weight per unit length, kg/m length
- \( L \) = Length of spool shaft, m.
Maximum deflection at the centre of the spool shaft was worked out as 0.246 mm, which was within safe limit of design even at designed load of four times greater than actual load. Detailed design of the spool shaft has been given in Appendix A-2 while detailed drawing of the shaft has been shown in Annexure-B.

3.7.3 Spacers

Rubber ring of 45 mm diameter and five millimeter thickness were sandwiched in between two consecutive diablo discs to attain required bank size. These spacers were made of the same material as the diablo shaped discs.

3.7.4 Driving mechanism

A chain drive system was designed to operate the grading spools. A double sprocket was provided at the end of each spool shaft (Fig. 3.11). Sprockets of hardened steel having 15 teeth were powered through a roller type chain No. 0.8 B. The chain drive instead of belt drive was selected because of their rigidity, strength, and no slippage. The selection of chain was also done due to its low wear and elongation.

3.8 Take-away conveyor

Three flat belt conveyors were developed to take the graded crop away from the machine to the packing point (Fig 3.12). These conveyors were arranged horizontally and all the metal surfaces were cushioned with padding material to avoid product damage. Main frame of take-away conveyor was made of mild steel sheet (16 SWG) and a variable drive system was provided to run all the take-away conveyors at linear speed of 5, 10, and 15 meter/min. The variable speed of the take-away conveyor was selected to study mutual collision of the falling products. Conveyor belt was made of Globe Ultimate 140 BOS-Nitrile impregnated and powered with the conveyor-driving drum that was made of pipe having size of 76 mm diameter. The driving drum operated the conveyor belt at selected speed. These conveyors were used to take away the homogeneous product that was falling from the lower secondary grading table. Mild steel round plate 3 mm
Fig. 3.11 Isometric view of double sprocket.
thickness and 90 mm diameter was attached to each end of the drum to mount the driving shaft to the driving drum. The first and second take-away conveyors were operated by the gearbox attached beneath the conveyors while the third one was driven directly by the shaft that was also responsible to drive the rear gearbox. Thus the speeds of all the three conveyors were changed by changing the speed of the shaft. All the metal surfaces of the conveyor, exposed to the falling crop, were cushioned with padding material "Ethafom" 10 mm thick to avoid product damage due to falling.

3.9 Power transmission system

A power transmission system was developed to transmit required power from tractor or any other prime mover to the gearbox or other parts of the grader. Power transmission in the grading machine was accomplished by shafts, v-belts, pulleys, chain and sprockets and gearbox.

3.9.1 Design of main shaft

A shaft is a rotating machine element, which is used to transmit power from one place to another. The power is delivered to the shaft by some tangential force and the resultant torque or torsional moment set up within the shaft permits the power to be transferred to various members linked to the shaft. The desirable properties of the materials for shafts are sufficient high strength, a low sensitivity to stress concentration, ability to withstand heat and case hardening treatment and good machinability. Power transmission shaft was required to transmit power from tractor PTO to main gearbox of the machine. For this purpose a power transmission shaft was designed keeping in view the load type, power to be transmitted and the material to be used. The material C45 steel (C=0.45%, Mn=0.7%) was selected for shaft.

On the basis of designed power and speed of main drive shaft of power transmission system, torque transmitted through the shaft was determined as described by GOEL and BAHL, (1982).

\[ T = \frac{97303 \times N}{n} \]
Fig. 3.12 Isometric view of take away conveyor
Where

\[ T = \text{Torque required to transmit power, kg-cm} \]
\[ N = \text{Total power required to operate the conveyor, kW} \]
\[ n = \text{Speed of driving shaft, rpm} \]

Main shaft was operated at 540 rpm by the tractor PTO. The transmitted torque worked out was 7207 kg-cm. To transmit the torque at 540 rpm following torsion equation was used to determine the diameter of the shaft.

\[ T = \frac{Ss.\pi d^3}{16} \]

Assuming safe shear stress of 400kg/cm² the diameter of the shaft was found to be 45mm. It was the standard size of the shaft available in local market so the same size was employed to serve the purpose.

3.9.2 Main gear box

The tractor power was transmitted to the main gearbox with the help of a shaft that was fitted inside the main frame. The gearbox was developed to transmit the designed power (8.79 kW) through two output shafts (Fig 3.13). Input shaft of the gearbox was directly attached to tractor PTO and output shafts were attached to sprockets having 18 teeth each to transmit designed power through chain drive system. The equation described in section 3.2.8.1 was used to determine the torque transmitted to the input shaft of gear and was found as 1583.88 kg-cm and the tangential load of 219.98 kg on gear tooth was worked out by using following equation:

\[ W_t = \frac{2T}{mT_G} \]

Where

\[ T = \text{Torque transmitted (kg-cm)} \]
\[ W_t = \text{Tangential load in kg} \]
\[ m = \text{Module in mm} \]
\[ T_G = \text{Numbers of gear tooth} \]
Because velocity ratio of the gearbox was 1 (As miter gear), therefore, gears have 18 teeth each. In order to determine the module following equation was used.

\[ m^3 - 20.3m - 238.83 = 0 \]

The detail of development of the equation has been discussed in Appendix A-5.

By using hit and trial method module (m) was calculated as 8 mm. Using above equation the value of \( W_t \) was determined as 219.98 kg and detail of the calculation is given in Appendix.

In order to find out that whether the worked out tangential load of 219.98 kg was safe, the value of load needed to wear out the teeth was determined using the following equation as suggested by Khurmi and Gupta (2003).

\[ W_w = \frac{D_p b Q K}{Cos \theta_{cf}} \]

Where

- \( W_w \) = Maximum load for wear, kg
- \( D_p \) = Diametral Pitch mm
- \( b \) = Face width, mm
- \( Q \) = Ratio factor
- \( K \) = Load stress factor, kg/mm²
- \( \theta \) = Pitch angle

Load stress factor, k was calculated employing the following equation as described Khurmi and Gupta (2003)

\[ K = \frac{(\sigma_{es})^2 Sin\phi}{1.4} \left[ \frac{2}{E_g} \right] \]

Where

- \( \sigma_{es} \) = Surface endurance limit (6.3 \times 10^3 kg/cm² as material of the gear was selected gray cast iron)
\[ E_G = \text{Young's modulus for material of gear } \ (8.4 \times 10^2 \text{ kg/cm}^2) \]

\[ \phi = \text{pressure angle} \]

To determine the value of maximum load for wear the values of diametral pitch, face width, ratio factor, load stress factor were found as 144 mm, 33.94 mm, 1, 0.169 kg/mm² respectively. The details of calculations are given in Appendix A-5. However the value of k, load stress factor, was calculated as 0.169 kg/mm². Using above mentioned values the maximum load for wear was determined. Thus the values worked out for wear and tangential loads were 219.98 kg and 1168.27 kg respectively. It is clear that wear load is greater than tangential load and hence the design was considered safe as regards wear and tear aspect of the gears materials.

All the necessary specifications for design were worked out as follows:-

- Pitch circle diameter \( (D_G) = mT_G = 144 \text{ mm} \)
- Pitch line velocity \( (v) = \pi D_G N_G/60 = 4.08 \text{ m/sec} \)
- Face width = 33.94 mm
- Formative number of teeth = 25.46
- Form factor = .097
- Length of pitch cone element = 102 mm

### 3.9.3 Chain drive system

Power was transmitted from gearbox to shaft through chain drive system. For this purpose one sprocket of 18 teeth on each output shaft of gearbox was mounted. For chain power transmission system, designed power was determined by multiplying the rated power (3 kW) with service factor (2.93) of the chain (Bahl and Goel, 1982). Designed power of 8.79 kW was transmitted by the prime mover through the gear box, to the chain drive system on the both output shafts. Hence half of designed power was transmitted through one output shaft of the gearbox. The driving load of 212.47 kg on one output shaft of the gearbox was calculated as follows;

\[ F = \left\{(8.79/2) \times 1000/10\right\}/\text{pitch line velocity (m/s)} \]
Pitch line velocity of sprocket having 18 teeth was worked out as 2.068 m/sec.
Pitch of the sprocket was 12.7 mm and pitch circle diameter of the sprocket as calculated was 73.136 mm. Pitch line velocity (v) of the sprocket was 2.068 m/sec and total driving load 212.47 kg load was exerted on each output shaft of the gear box. This driving load was transferred through sprocket. Hence on the basis of driving load on shaft and actual breaking load of chain, the factor of safety was 9.41 which when compared with the range as described by Bahl and Goel (1982) was found safe because the calculated value was greater than the table value. Detailed design has been given in Appendix A-4.
Chapter 4

MATERIALS AND METHODS

Field performance of a machine reflects suitability, economic viability of the design adaptability and skill in fabrication of a machine. In accordance with the objectives of the study, the fruit and vegetable grader was designed, fabricated and successfully tested in Agricultural Mechanization Research Institute, at Faisalabad. In order to evaluate the field performance of the prototype designed and fabricated in this study, various machine and crop parameters were chosen. The following sections discuss in detail the machine and crop parameters selected for testing of fruit and vegetable grader.

4.1 Machine parameters.

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

4.1.1 Take-in conveyor speed (Si)

Three levels of conveyor speed (Si) of 10, 15, and 20 m/min were selected to change the feed rates. The effects of different feed rates on damage index and grading error of the grader were studied. Optimum speed of take-in conveyor was also selected that delivered the required feed rate to the grading unit.

4.1.2 Grading unit speed (Sg)

Three levels of grading spool speed (Sg) of 25, 50 and 75 rpm were selected to operate the grading spools. Optimum circumferential speed was determined that facilitated the crop to pass through the opening in between the two spools and diblo sections.

4.1.3 Take-away conveyor speed (So)

Three levels of conveyor speed (So) of 5, 10 and 15 m/min were selected to carry out the graded crop from machine to the packing point. Optimum speed of the
conveyor was selected for operation in order to avoid collision. Above said machine parameters and their interactions were studied on different levels to for evaluation of performance of the fruit and vegetable grader. Table 4.1 depicts the major variables, their interactions at various levels.

4.2 Crop parameter

Crop parameters play an important role in evaluation of field performance of the machine. The various size ranges of potato, onion, apple and mango were arranged for grading purpose. The size ranges used for testing of machine for potato, onion, apple and mango were 15 to 98 mm, 35 to 85 mm, 32 to 72 mm and 40 to 90 mm respectively. Selected crop were arranged to grade in their respective grades as tabulated below.

For grade designation of potatoes following size range were provided as described by Tariq et al., (1995).

<table>
<thead>
<tr>
<th>S.No</th>
<th>Grade Designation</th>
<th>Size (mm)</th>
<th>Tolerances</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pak Extra Large</td>
<td>&gt; 70</td>
<td>± 5 % by weight</td>
</tr>
<tr>
<td>2</td>
<td>Pak Large</td>
<td>55 – 70</td>
<td>-do-</td>
</tr>
<tr>
<td>3</td>
<td>Pak Medium</td>
<td>35 – 55</td>
<td>-do-</td>
</tr>
<tr>
<td>4</td>
<td>Pak Small (Seed)</td>
<td>&lt; 35</td>
<td>-do-</td>
</tr>
</tbody>
</table>

For grade designation of onions following size range were designated as described

<table>
<thead>
<tr>
<th>S. No</th>
<th>Grade Designation</th>
<th>Size (mm)</th>
<th>Tolerances</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pak Bold</td>
<td>&gt; 64</td>
<td>± 5 mm</td>
</tr>
<tr>
<td>2</td>
<td>Pak Medium</td>
<td>51 – 64</td>
<td>± 7 mm</td>
</tr>
<tr>
<td>3</td>
<td>Pak Small</td>
<td>38 – 51</td>
<td>± 8 mm</td>
</tr>
</tbody>
</table>
For grade designation of apples, following size range were provided.

<table>
<thead>
<tr>
<th>S. No</th>
<th>Grade Designation</th>
<th>Size (mm)</th>
<th>Tolerances</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Extra</td>
<td>&gt; 65</td>
<td>5% of grade 1</td>
</tr>
<tr>
<td>2</td>
<td>No.1</td>
<td>&gt; 60</td>
<td>10% of grade 2</td>
</tr>
<tr>
<td>3</td>
<td>No.2</td>
<td>&gt; 55</td>
<td>10% of grade 3</td>
</tr>
</tbody>
</table>

For grade designation of mangoes, following size range were separated as described by Zameer, H. (2005).

<table>
<thead>
<tr>
<th>S. No</th>
<th>Grade Designation</th>
<th>Size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Grade I</td>
<td>50-57 mm</td>
</tr>
<tr>
<td>2</td>
<td>Grade II</td>
<td>57-64 mm</td>
</tr>
<tr>
<td>3</td>
<td>Grade III</td>
<td>64-70 mm</td>
</tr>
<tr>
<td>4</td>
<td>Grade IV</td>
<td>&gt; 70 mm</td>
</tr>
</tbody>
</table>

4.2.1 Damage index

A lot of crop was divided into their respective grade sizes. Population and weight of tubers in each grade were determined manually. Again all the grades were mixed to form a homogeneous sample for feeding the grader to evaluate its performance at different machine parameters. Loading at rate of 10 kg was ensured for all the crops. Time was noted for each treatment and graded crop was placed at room temperature for 24 hours. After grading the crop was examined carefully and damaged products were separated and categorized as follows:-

1. Scuffed   Skin puncture or bruised
2. Peeler    Damage depth up to 3 mm
3. Severe    Damage depth more than 3 mm
For this purpose a mechanical slicer was designed to slice the damaged product into 1.5 mm thick slices. After identifying the category of damage, following formula was employed to determine the damage index as described by Robertson (1970).

$$\text{Damage Index} = (\% \text{ Scuffed}) + (\% \text{ Peeler} \times 3) + (\% \text{ Sever} \times 7) \text{ (On weight basis)}$$

### 4.2.2 Grading Error

At the tail end of the grader, graded products were collected and digital micrometer was used to measure the size range as specified for the particular crop. Under size products in each grade were separated and weighed to determine the grading error (%) for each treatment.

To evaluate its performance on selected crops, the effect of take-in conveyor speed (Si), grading spool speed (Sg) and take-away conveyor speed (So) on the crop damage index and the grading error were investigated. The data were recorded in Appendix D.

### 4.3 Statistical Analysis

To evaluate the significance of machine parameters and their interactions on crop damage and grading error, ANOVA was carried out using PROC / GLM (General Linear Model) procedure of the SAS Institute (1998). Covariate analysis was performed using Minitab (Statistical Package). When the F-test indicated statistical significance, treatment means were separated by the LSD test. The behavior of different machine parameters on damage index and grading error were investigated through the fitted models. Detailed statistical analysis were shown in Appendix-E.

### 4.4 Economic Analysis

The ultimate purpose of grading is to meet the buyer’s requirement for net high return. The cost of grading of each crop was calculated by the procedure described by Kepner et al. (1987). The life of the grader in terms of number of hours of operations was assumed as 2500 hours. Cost benefit ratio of different crop grading were also calculated.
Table 4.1 Variables and their interactions

<table>
<thead>
<tr>
<th>Variables</th>
<th>Si</th>
<th>Sg</th>
<th>So</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interactions</td>
<td>$Si \times Sg$</td>
<td>$Si \times So$</td>
<td>$Sg \times Sg$</td>
</tr>
</tbody>
</table>

Where:-

Si, Sg and So are machine parameters (three levels each)

$Si = \text{Take-in conveyor speed in meter/min}$

$Si_1 = 10 \text{ m/min}$
$Si_2 = 15 \text{ m/min}$
$Si_3 = 20 \text{ m/min}$

$Sg = \text{Grading spool speed in rpm}$

$Sg_1 = 25 \text{ rpm}$
$Sg_2 = 50 \text{ rpm}$
$Sg_3 = 75 \text{ rpm}$

$So = \text{Take-away conveyor speed in m/min}$

$So_1 = 5 \text{ m/min}$
$So_2 = 10 \text{ m/min}$
$So_3 = 15 \text{ m/min}$
Chapter 5

RESULTS AND DISCUSSION

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. To compete the international market, standards have been decided for each crop because the graded product always commands a premium in the market and should have a better price of the produce. Horticultural mechanization, being realized as trade abroad, has scope of greater profit margin and fresh fruit and vegetables require a rapid post harvest handling process prior to market. Proper marketing system is being developed in our country to compete the international market, especially at present when world has turned into a global village and World Trade Organization (WTO) has specified its standards to meet the international trade contracts. To achieve the access to the markets abroad, traded commodity must be according to standards specified by WTO and that is only possible by the direct linkage between consumer demand in the importing countries and producers supply in the exporting countries. Quality conscious consumers demand the fruits and vegetables that appeal at first look. 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. Commercial production of fruits and vegetables requires different mechanical attributes so that the soft tissues survives their journey through the marketing chain in and away the country. Consumer's demand for high quality products, especially in the western world has been increased in the last decade and is still increasing. 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 postharvest handling of fruits and vegetables were
considered basic requirements to increase the farmer's profit margin. For this purpose a low cost fruit and vegetable grading machine was developed to grade agricultural products into recommended sizes. To evaluate its performance on potato, onion, apple and mango, the effect of different machine parameters i.e. take-in conveyor speed (Si), grading spool speed (Sg) and take-away conveyor speed (So) 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). Covariate analysis was performed using Minitab (Statistical Package). In this study four crops namely, potato, onion, apple and mango were arranged for grading purposes. Since the shape and size of each crop varied very widely from the other respective crop used in the study. As a result the data recorded for retrieving useful information regarding machine and crop parameters varied widely from crop to crop. Thus it was imperative to discuss the grading phenomenon for each crop separately. The following sections there discuss the results obtained in this study crop wise selected for grading.
5.1 Potato grading

5.1.1 Effect of take-in conveyor speed on damage index

To change the feed rate of the grader, three speed levels 10, 15 and 20 m/min were selected. The data regarding damage index at different speed combinations are presented in Appendix D-1. The ANOVA and computer program are presented in Appendix E-1. Effects of different take-in conveyor speed (Si) were statistically analyzed and results are shown in Table 5.1.

Table 5.1 Effect of take-in conveyor speed on damage index

<table>
<thead>
<tr>
<th>Take-in conveyor speed (Si) (m/min)</th>
<th>Damage Index (DI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>3.74(^a)</td>
</tr>
<tr>
<td>15</td>
<td>3.43(^b)</td>
</tr>
<tr>
<td>20</td>
<td>3.27(^c)</td>
</tr>
<tr>
<td>Mean</td>
<td>3.48</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.0178</td>
</tr>
</tbody>
</table>

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

* Each DI value is a mean of 27 observations.

The effects of take-in conveyor speed on damage index at three different speed levels were significantly different and overall effect of take-in conveyor speed on damage index were also significant at 5% probability level as shown in ANOVA (Appendix E-1). At take-in conveyor speed of 10 m/min, the damage index was 3.74. As the speed increased from 10 to 15 m/min a reduction of 8.29 % in damage index was recorded as shown in Table 5.1. Similar trend was observed when the speed further increased to 20 m/min showing a decrease of 4.66 % in damage index giving a value of 3.27. The ANOVA (Appendix E-1) indicated that the take-in conveyor contributed approximately 47 % to the total damage index of the crop. Decrease in damage index at linear increase in
conveyor speed might be due to lower feed rate that had not fulfilled the grading unit requirement and thus shared in damaging the crop during the system operation.

5.1.2 Effect of grading spool speed on damage index

The effects of three levels of grading spool speeds (Sg) 25, 50 and 75 rpm on damage index for potato grading were studied. The data were statistically analyzed and results are shown in Table 5.2

Table 5.2. Effect of grading spool speed on damage index.

<table>
<thead>
<tr>
<th>Grading spool speed (Sg)</th>
<th>Damage index</th>
</tr>
</thead>
<tbody>
<tr>
<td>rpm</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>3.51b</td>
</tr>
<tr>
<td>50</td>
<td>3.23c</td>
</tr>
<tr>
<td>75</td>
<td>3.69a</td>
</tr>
<tr>
<td>Mean</td>
<td>3.48</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.0178</td>
</tr>
</tbody>
</table>

\(^{a,b,c}\text{Means followed by the same letters are not significant at 5 \% probability level.}\)

The analyzed results indicated that all the grading spool speeds (25, 50 and 75 rpm) were statistically different in producing damage index. Lowest damage index of 3.23 was observed at grading spool speed of 50 rpm and 8.67 \% increase at 25 rpm and 14.24 \% increase in damage index at 75 rpm was observed. The ANOVA (Appendix E-1) also indicated that the effect of grading spool speed at 5 \% probability level was significant. It is clear from the ANOVA that grading spool speeds contributed approximately 44 \% to the total damage of the crop during grading. Higher damage index at 25 rpm might be due to poor re-orientation of the potato tubers and had less chance to vacate the banks of marginal lower size. At higher speed (75 rpm) aggressive re-orientation might be responsible for higher damage index due to high peripheral impact velocity of diablo sections.
5.1.3 **Effect of take-away conveyor speed on damage index**

The data of take-away speed of conveyor on damage index were recorded and presented in Appendix D-1. The data were statistically analyzed using statistical package, MINITAB. Appendix E-1 shows analysis of variance for the effect of different machine parameters on damage index of potato. The ANOVA (Appendix E-1) indicated that the effects of take-away conveyor speed (So) on damage index was non significant and shared only 0.062 % to the total damage index of the system.

The interaction of Si x Sg was observed significant at 5 % probability level and contributed 8.42 % to the total damage index of the system as indicated in ANOVA (Appendix E-1). The interaction of Si and Sg at different take-away conveyor speeds is presented graphically in Figure 5.1 through 5.3. For all the take-away conveyor speeds, take-in conveyor speed of 20 m/min produced the lower values of damage index at all the three grading spool speeds while the lowest take-in conveyor speed yielded the highest values of damage index at 75 rpm grading spool speed. Same trend of curves of all three figures showed the similar behavior of all the three take-away conveyor speeds. Therefore it is evident clear that the only interaction Si x Sg had a significant role in producing the damage index.

5.1.4 **Model of damage index for potato grading.**

A co-variate analysis (Regression analysis) using statistical package, PROC GLM (General Linear Model) procedures of the SAS Institute (1998) was employed to study the effects of different machine parameters on crop parameters. The co-variate analysis yielded the following model for the damage index in terms of take-in conveyor speed, grading spool speed and take-away conveyor speed having a coefficient of correlation of 0.99. The equation 5.1 indicated that Si, Sg, So and the interaction Si x Sg contributed 47.29, 44.12, 0.062 and 8.42 % respectively to the total damage index. It was confirmed that take-in conveyor and grading unit were important machine parameters towards producing the damage index while their
Fig. 5.1 Damage index vs grading spool speed at take away conveyor speed of 5 m/min for potato grading.

Fig. 5.2 Damage index vs grading spool speed at take away conveyor speed of 10 m/min for potato grading.

Fig. 5.3 Damage index vs grading spool speed at take away conveyor speed of 15 m/min for potato grading.
interaction had played a moderate role in damaging the potato tubers. The high value of $R^2$ (0.99) indicated that the fitted model was appropriate to explain the relationship between dependent and independent variable.

$$DI = 4.643 - 0.66Si - 1.797Sg + 0.27Si^2 + 0.637Sg^2 + 1.1SiSg - 0.417SiSg^2 - 0.408Si^2Sg^2$$

5.1.5 Effect of treatments on damage index for potato grading.

The data of damage index for potato grading at various combinations of machine parameters i.e. take-in conveyor speed (Si), grading spool speed (Sg) and take-away conveyor speed (So) were recorded and presented in Table D-1. Effects of different combinations of machine parameters on damage index were studied and their statistically analyzed results are presented in Table 5.3 and ANOVA in Appendix E-1 (Table - 2). Table 5.3 indicated that treatment Nos. 7 and 8 yielded statistically same results recording values of 4.11 and 4.15 for damage index respectively. Similarly treatment Nos. 8 and 9 also produced statistically the same damage index values i.e. 4.15 and 4.17 respectively. However treatment No. 9 yielded the highest damage index value of 4.17 amongst all the treatments. Reason of highest damage index was that, at this treatment, feed rate was minimum and required population of the product at grading unit might not be achieved. Thus the tubers probably began to rotate at the same location rather to move forward. This may be further attributed to the fact that grading spool speed was also maximum thus low feed rate and high grading spool speed imposed repeated impacts on the tubers during aggressive re-orientation rather to move forward. Treatment Nos. 1, 2, 3, 16, 17 and 18 were non significant in producing the damage index but yielded significantly different and lower values than that of treatment No 7, 8 and 9. Similarly treatment Nos. 13, 14, 15, 23 and 24 produced the statistically same damage index values that were significantly different but lower than that of treatment Nos. 25, 26 and 27. This behavior might be due to lower grading spool speed at treatment No 13, 14, 15, 23 and 24 than that of treatment No 25, 26 and 27. Lowest damage index of 3.063 was observed at treatment No 22 and treatment No 24 had also statistically same results. Treatment Nos.
Table 5.3 Effect of treatments on damage index and grading error of potatoes

<table>
<thead>
<tr>
<th>TRT</th>
<th>Treatment combinations</th>
<th>Damage index</th>
<th>Grading error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$S_{i1}S_{g1}S_{o1}$</td>
<td>3.60&lt;sup&gt;c&lt;/sup&gt;</td>
<td>4.5&lt;sup&gt;fhi&lt;/sup&gt;</td>
</tr>
<tr>
<td>2</td>
<td>$S_{i1}S_{g1}S_{o2}$</td>
<td>3.62&lt;sup&gt;c&lt;/sup&gt;</td>
<td>4.5&lt;sup&gt;fhi&lt;/sup&gt;</td>
</tr>
<tr>
<td>3</td>
<td>$S_{i1}S_{g2}S_{o1}$</td>
<td>3.58&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>4.48&lt;sup&gt;hi&lt;/sup&gt;</td>
</tr>
<tr>
<td>4</td>
<td>$S_{i1}S_{g2}S_{o2}$</td>
<td>3.44&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>4.72&lt;sup&gt;cde&lt;/sup&gt;</td>
</tr>
<tr>
<td>5</td>
<td>$S_{i1}S_{g2}S_{o1}$</td>
<td>3.46&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.72&lt;sup&gt;cde&lt;/sup&gt;</td>
</tr>
<tr>
<td>6</td>
<td>$S_{i1}S_{g2}S_{o2}$</td>
<td>3.50&lt;sup&gt;d&lt;/sup&gt;</td>
<td>4.69&lt;sup&gt;cde&lt;/sup&gt;</td>
</tr>
<tr>
<td>7</td>
<td>$S_{i1}S_{g3}S_{o1}$</td>
<td>4.11&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.86&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>8</td>
<td>$S_{i1}S_{g3}S_{o2}$</td>
<td>4.15&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>4.86&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>9</td>
<td>$S_{i1}S_{g3}S_{o3}$</td>
<td>4.17&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.82&lt;sup&gt;bcd&lt;/sup&gt;</td>
</tr>
<tr>
<td>10</td>
<td>$S_{i2}S_{g1}S_{o1}$</td>
<td>3.52&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.60&lt;sup&gt;ghi&lt;/sup&gt;</td>
</tr>
<tr>
<td>11</td>
<td>$S_{i2}S_{g1}S_{o2}$</td>
<td>3.54&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>4.60&lt;sup&gt;ghi&lt;/sup&gt;</td>
</tr>
<tr>
<td>12</td>
<td>$S_{i2}S_{g1}S_{o3}$</td>
<td>3.54&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>4.61&lt;sup&gt;ghi&lt;/sup&gt;</td>
</tr>
<tr>
<td>13</td>
<td>$S_{i2}S_{g2}S_{o1}$</td>
<td>3.14&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.46&lt;sup&gt;bij&lt;/sup&gt;</td>
</tr>
<tr>
<td>14</td>
<td>$S_{i2}S_{g2}S_{o2}$</td>
<td>3.12&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.67&lt;sup&gt;def&lt;/sup&gt;</td>
</tr>
<tr>
<td>15</td>
<td>$S_{i2}S_{g2}S_{o3}$</td>
<td>3.15&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.66&lt;sup&gt;def&lt;/sup&gt;</td>
</tr>
<tr>
<td>16</td>
<td>$S_{i2}S_{g3}S_{o1}$</td>
<td>3.60&lt;sup&gt;c&lt;/sup&gt;</td>
<td>4.46&lt;sup&gt;bij&lt;/sup&gt;</td>
</tr>
<tr>
<td>17</td>
<td>$S_{i2}S_{g3}S_{o2}$</td>
<td>3.61&lt;sup&gt;c&lt;/sup&gt;</td>
<td>4.48&lt;sup&gt;bij&lt;/sup&gt;</td>
</tr>
<tr>
<td>18</td>
<td>$S_{i2}S_{g3}S_{o3}$</td>
<td>3.59&lt;sup&gt;c&lt;/sup&gt;</td>
<td>4.47&lt;sup&gt;bhi&lt;/sup&gt;</td>
</tr>
<tr>
<td>19</td>
<td>$S_{i3}S_{g1}S_{o1}$</td>
<td>3.40&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>5.28&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>20</td>
<td>$S_{i3}S_{g1}S_{o2}$</td>
<td>3.39&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.29&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>21</td>
<td>$S_{i3}S_{g1}S_{o3}$</td>
<td>3.41&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>5.38&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>22</td>
<td>$S_{i3}S_{g2}S_{o1}$</td>
<td>3.06&lt;sup&gt;d&lt;/sup&gt;</td>
<td>4.33&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>23</td>
<td>$S_{i3}S_{g2}S_{o2}$</td>
<td>3.13&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.30&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>24</td>
<td>$S_{i3}S_{g2}S_{o3}$</td>
<td>3.11&lt;sup&gt;d&lt;/sup&gt;</td>
<td>4.31&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>25</td>
<td>$S_{i3}S_{g3}S_{o1}$</td>
<td>3.33&lt;sup&gt;f&lt;/sup&gt;</td>
<td>4.65&lt;sup&gt;dfg&lt;/sup&gt;</td>
</tr>
<tr>
<td>26</td>
<td>$S_{i3}S_{g3}S_{o2}$</td>
<td>3.29&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.92&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>27</td>
<td>$S_{i3}S_{g3}S_{o3}$</td>
<td>3.32&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>4.94&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

$S_{i1} = 10$ m/min  $S_{g1} = 25$ rpm  $S_{o1} = 5$ m/min  
$S_{i2} = 15$ m/min  $S_{g2} = 50$ rpm  $S_{o2} = 10$ m/min  
$S_{i3} = 20$ m/min  $S_{g3} = 75$ rpm  $S_{o3} = 15$ m/min

LSD (DI potato) = 0.0533  
LSD (ER potato) = 0.186

<sup>a, b, c</sup> Mean followed by the same letters are not significant at 5% probability level.
19, 20 and 21 were statistically non-significant but significantly different from treatment Nos. 25, 26 and 27. Higher values of damage index at treatment Nos. 19, 20 and 21 were due to higher feed rate (12t/hr) and lower grading spool speed of 25 rpm. At lower grading spool speed the tubers were not pulled out that were plugged in the banks of relatively lower size and the relative movement of the tubers and diablo sections caused higher damage index due to severe bruising and skin puncturing. Lower damage index at treatment Nos. 25, 26 and 27 was probably due to high speeds of take in conveyor and grading spools. At these treatments continuous flow of the product due to high feed rate and proper re-orientation due to high spool speed supported the proper progression of the products across the grading unit. It was also crystal clear from the treatment analysis that treatments having grading spool speed of 75 rpm and take-in conveyor speed (Si) of 10 m/min had yielded higher values of damage index as compared to those treatments having grading spool speed of 50 rpm and take-in conveyor speed 20 m/min while take-away conveyor had no significant effect on the damage index as shown in ANOVA Appendix E-1.

5.1.6 Effect of take-in conveyor speed on grading error

In order to change the feed rate of the grader, three speed levels 10, 15 and 20 m/min were selected. The data regarding grading error at different speed combinations are presented in Appendix D-1.

Table 5.4 Effect of take-in conveyor speed on grading error

<table>
<thead>
<tr>
<th>Take in conveyor speed (Si) (m/min)</th>
<th>Grading error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>4.68&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>15</td>
<td>4.56&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>20</td>
<td>4.82&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mean</td>
<td>4.69</td>
</tr>
<tr>
<td>LSD(0.05)</td>
<td>0.062</td>
</tr>
</tbody>
</table>

<sup>a, b, c</sup> Means are followed by the same letters are not significantly different at 5% probability level. Each ER value is a mean of 27 observations.
The ANOVA and computer program are presented in Appendix E-1. Effects of different take-in conveyor speed (Si) were statistically analyzed and results are shown in Table 5.4. The effects of take-in conveyor speed (Si) on grading error (ER) at three different speed levels were significantly different as shown in Table 5.4. The overall effect of take-in conveyor speed on grading error was also significant at 5% probability level. The detailed analysis is shown in Appendix E-2. At take-in conveyor speed of 15 m/min, grading error was 4.56% and 2.64 % increase in grading error was observed when the speed was 10 m/min. As speed (Si) increased from 15 to 20 m/min, the grading error also increased by 5.70 % and yielded the value of 4.82. The ANOVA (Appendix E-2) indicated that the take-in conveyor contributed approximately 22.65 % to the total grading error of the crop. Increase in grading error at 10 m/min was due to lower feed rate at higher speed of grading spool that had not fulfilled the grading unit requirement. Thus excessive jumping of tubers due to high peripheral speed of diablo sections contributed significantly in grading error during the system operation.

5.1.7 Effect of grading spool speed on grading error

The effects of three levels of grading spool speeds of 25, 50 and 75 rpm on grading error for potato were studied. The data had been recorded in Appendix D-1 (Table-2) which were statistically analyzed and results are shown in Table 5.5.

Table 5.5 Effect of grading spool speed on grading error

<table>
<thead>
<tr>
<th>Grading spool speed (Sg)</th>
<th>Grading Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>rpm</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>4.81&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>50</td>
<td>4.56&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>75</td>
<td>4.82&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mean</td>
<td>4.69</td>
</tr>
<tr>
<td>LSD(0.05)</td>
<td>0.062</td>
</tr>
</tbody>
</table>

<sup>a, b, c</sup> Means followed by the same letters are not significant at 5 % probability level.

Each ER value is a mean of 27 observations.
The analyzed results indicated that the grading spool speeds 25 and 50 rpm were statistically different and the grading spool speeds 25 and 75 rpm were not statistically different in producing error during grading of potato. Lowest grading error of 4.56% was observed at grading spool speed of 50 rpm and 5.48 % and 5.7 % increase in grading error were recorded at 25 and 75 rpm respectively. The complete analysis of variance (ANOVA is shown in Appendix E-2). Higher grading error at 25 rpm was attributed to poor re-orientation of the potato tubers which had greater chance to overflow of crop at higher take-in conveyor speed. Nevertheless higher speed of 75 rpm produced aggressive re-orientation which was responsible for high grading error. Thus due to the fact that high peripheral impact velocity of diablo sections caused excessive jumping of the tubers when the feed rate was the minimum.

5.1.8 Effect of take-away conveyor speed on grading error

In order to study the effect of take-away conveyor speed on grading error, data were recorded and presented in Appendix D-1 (Table-2). The data were statistically analyzed using PROC GLM (General Linear Model) procedures of the SAS Institute (1998) and results are shown in Appendix E-2. The results indicated that the effect of take-away conveyor speed (So) on grading error was non significant at 5% probability level and shared only 1.37 % to the total grading error of the system.

The interaction of Si x Sg was observed significant at 5 % probability level and shared 50.7 % to the total grading error of the system as indicated in ANOVA (Appendix E-2). The interaction of Si x Sg at different take-away conveyor speeds (So) are presented graphically in Figure 5.4 through 5.6. For all the values of take-away conveyor speeds, take in conveyor speed 20 m/min produced the higher grading error at grading spool speed 25 rpm and lower error values at grading spool speed 50 rpm and 75 rpm than the two other take in conveyor speeds. Same trend of the curves of all three figures showed the similar behavior of all the three take-away conveyor speeds. So it was evident that the only interaction Si x Sg had a significant and major role in producing the grading error of the system.
5.1.9 Model of grading error for potato grading.

A co-variate analysis (Regression analysis) using statistical package, MINITAB, was employed to study the effects of different machine parameters on crop parameters.

The co-variate analysis yielded the following model having a coefficient of correlation of 0.90, for the grading error in terms of take in conveyor speed (Si), grading spool speed (Sg), take away conveyor speed (So).

\[ ER = 1.963 + 2.486S_i + 4.268S_g - 0.262S_i^2 - 1.047S_g^2 - 4.82S_iS_g + 1.27S_i^2S_g^2 - 0.268S_i^2S_g^2 \]

The equation 5.2 indicated that Si, Sg, So and the interaction Si x Sg contributed 22.65, 23.54, 1.37 and 50.7 % respectively to the total system error. It was concluded that speeds of take in conveyor and grading unit were important machine parameters to wards producing the grading error while their interaction had played a major role in producing the error. The R² value of 0.90 as mentioned above indicated that the fitted model was appropriate to explain the relationship between dependent and independent variables that were fitted well to their respective data sets.

5.1.10 Effect of treatments on grading error for potato grading.

The data of grading error at various speed combinations used in the study of take-in conveyor, grading spool and take-away conveyor were recorded and shown in Appendix D-1 (Table -2). The effects of different combinations of machine parameters were studied and their statistically analyzed results are presented in Table 5.3. The detailed analysis is provided in Appendix D-2 (Table -2). Table 5.3 indicated that treatment Nos. 19, 20 and 21 yielded statistically same grading error values that were higher than all the other treatments. Reason was that at these treatments take-in conveyor speed was maximum i.e. 20 m/min and grading spool speed was minimum (25rpm). High feed rate were not properly entertained by the lower speed of the grading spool that resulted over loading of grading unit and tubers were shifted to the next banks rather to pass through their respective route. The lowest grading error of4.3 % was observed at treatment No 23 and treatment Nos. 3, 13, 16, 17, 18, 22, and 24 also produced statistically the same and higher error values than that of treatment No 23. Similarly,
Fig. 5.4 Grading error (%) vs grading spool speed ($S_g$) at take-away conveyor speed 5 m/min for potato grading.

Fig. 5.5 Grading error (%) vs grading spool speed ($S_g$) at take-away conveyor speed 10 m/min for potato grading.

Fig. 5.6 Grading error (%) vs grading spool speed ($S_g$) at take-away conveyor speed 15 m/min for potato grading.
treatment Nos. 1, 2, 3, 10, 11, 12, 16, 17 and 18 were found non significant among themselves and significantly different from treatment No 4, 5, 6, 14, 15. Lower grading error was probably due to the highest speed of take in conveyor (Si = 20 m/min) and moderate speed of grading spools (Sg = 50 rpm). Maximum grading spool speed of 75 rpm and moderate take-in conveyor speed of 15 m/min also produced the same values of grading error. It can easily be concluded from the treatment comparison that lower take in conveyor speed with high grading spool speed or high take in conveyor speed with lower grading spool speed were responsible for high values of grading error. Similarly, treatment Nos. 4, 5, 6, 10, 11, 12 were statistically non significant and produced lower grading error than that of treatment No 7, 8 and 9 i.e. at lowest take-in conveyor speed of 10 m/min and moderate speed of grading spool of 50 rpm, the grading error was recorded as 4.72%. It is worthwhile to point out that higher grading error at treatment Nos. 7, 8 and 9 was probably due to lowest take-in conveyor speed of 10 m/min and highest grading spool speed of 75 rpm. However treatment Nos. 4, 5, 6, 10, 11 and 12 were non significant and produced lower grading error than that of treatment Nos. 7, 8 and 9. This section concluded that treatment combination of take-in conveyor speed of 20 m/min, grading spool speed of 50 rpm and take-away conveyor speed of 10 m/min, was found appropriate in order to reduce grading error significantly.

5.2 Apple grading

5.2.1 Effect of take-in conveyor speed on damage index

The data regarding damage index have been presented in Appendix D-2. Take-in conveyor speed (Si) controlled the feed rate of the grader. Accordingly three speed levels of 10, 15 m/min and 20 m/min were selected to load the crop on the grading unit. The analysis of data collected is presented in Appendix E-3. Statistically analyzed results are shown in Table 5.8. It was revealed that damage index (DI) decreased significantly with the increase in take-in conveyor speed (Si) i.e. damage index values were 6.51, 6.31 and 6.12 at take-in conveyor speeds of 10, 15 and 20 m/min respectively. With a uniform
increase in take-in conveyor speed i.e. 10 to 15 m/min, the damage index decreased 3.07% and further decreased 3.07 % with the increase of take-in conveyor speed from 15 to 20 m/min. This indicated that linear increase in take-in conveyor speed resulted in 

Table 5.6 Effect of take-in conveyor speed on damage index

<table>
<thead>
<tr>
<th>Take-in conveyor speed (Si) (m/min)</th>
<th>Damage Index (DI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>6.51^a</td>
</tr>
<tr>
<td>15</td>
<td>6.31^b</td>
</tr>
<tr>
<td>20</td>
<td>6.12^c</td>
</tr>
<tr>
<td>Mean</td>
<td>6.31</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.1071</td>
</tr>
</tbody>
</table>

^a,^b,^c Means are followed by the same letters are not significantly different at 5 % probability level. Each DI value is a mean of 27 observations.

linear decrease in damage index. It can be safely concluded that the lower speed of take in conveyor could not meet the required capacity of the grading unit. Therefore, more damage index was observed at low speed due to repeated re-orientation of the product without moving forward to the proper bank.

5.2.3 Effects of grading spool speed on damage index

In order to study the effects of grading spool speed on damage index data were recorded at grading spool speed of 25, 50 and 75 rpm and presented in Appendix D-2 (Table-1). The data were analyzed statistically and shown in Appendix E-3. Statistically analyzed results of the mean values have been presented in Table 5.7 that indicates the significant effect of grading spool speed (Sg) on damage index. Grading spool speed contributed about 50 % of total damage index that showed the importance of this parameter in grading system. At grading spool speed of 75 rpm there was maximum damage index that was 6.55. Minimum damage index of 6.01 was observed at 50 rpm
Table 5.7 Effect of grading spool speed on damage index.

<table>
<thead>
<tr>
<th>Grading spool speed (Sg) rpm</th>
<th>Damage index</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>6.38(^b)</td>
</tr>
<tr>
<td>50</td>
<td>6.01(^c)</td>
</tr>
<tr>
<td>75</td>
<td>6.55(^a)</td>
</tr>
<tr>
<td>Mean</td>
<td>6.31</td>
</tr>
<tr>
<td>LSD(0.05)</td>
<td>0.107</td>
</tr>
</tbody>
</table>

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

Each DI value is a mean of 27 observations.

while 5.9 and 9 % increase in damage index were observed at 25 and 75 rpm respectively. Table 5.7 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.

5.2.3 Effect of take-away conveyor speed on damage index

In order to study the effects of take-away conveyor speed (So) on damage index data were recorded at take-away conveyor speed 5, 10 and 15 m/min and presented in Appendix D-3 (Table-2). Statistically analyzed results indicated that the effect of take-
away conveyor speed (So) on damage index were non significant. However, take-away conveyor speed (So₂) 10 m/min produced damage index 6.29 that was lower than at the other two speeds 5 and 15 m/min. The ANOVA (Appendix E-3) indicated that take-away conveyor speed contributed damage index only 0.27% which was so small that it could be assumed as silent partner of the other two parameters Si and Sg.

The interaction of the conveyor speed (Si) and the grading spool speed (Sg) at different take-away conveyor speeds has been presented in Figure 5.7 through 5.9. The interaction of Si x Sg x So were found highly significant at 5% probability level (Appendix E-3). At all the selected take-away conveyor speeds of 5, 10 and 15 m/min damage index values were greater for take in conveyor speed of 10 m/min than its other two speeds. Take-in conveyor speed of 20 m/min offered the lower damage index at all the take away conveyor speeds for grading spool speeds of 75 rpm. Also it was clear from all the three Fig. 5.7, 5.8 and 5.9 that minimum damage index of 5.80 at α = 0.05 was produced by the grader at take-in conveyor speed of 20 m/min, grading spool speed of 75 rpm and take away conveyor speed of 10 m/min. While damage index 5.82 was observed at take in conveyor speed of 15 m/min and grading spool speed of 50 rpm and take away conveyor speed of 10 m/min. Despite the fact that speed combination of 20 m/min, 75 rpm and 10 m/min for take-in conveyor, grading spool and take-away conveyor speed registered quite high value of grading error, but this combination was found suitable for causing minimum damage index of 5.80.

5.2.4 Model of damage index for apple grading

In order to determine the extent to which machine parameters affect the total damage index, a co-variate analysis (Regression analysis) using statistical package MINITAB was employed. The co-variate analysis yielded the following model for the damage index in terms of take-in conveyor speed (Si), grading spool speed (Sg) and take-away conveyor speed (So), with a coefficient of correlation as 0.84.
Fig 5.7 Damage index vs grading spool speed at $S_{i1}$, $S_{i2}$ and $S_{i3}$ for take-away conveyor speed 5 m/min for apple.

Fig 5.8 Damage index vs grading spool speed at $S_{i1}$, $S_{i2}$ and $S_{i3}$ for take-away conveyor speed 10 m/min for apple.

Fig 5.9 Damage index vs grading spool speed at $S_{i1}$, $S_{i2}$ and $S_{i3}$ for take-away conveyor speed 15 m/min for apple.
\[ DI = -28.55 + 3.729 S_i + 1.06 S_g - 5.6 \times 10^{-3} S_g^2 - 0.102 S_i S_g + \\
4.2 \times 10^{-4} S_i S_g^2 + 1 \times 10^{-6} S_i S_g^2 \]  

The Equation 5.3 indicated that Si, Sg, So and the interactions Si × Sg, Si × So, Sg × So and Si × Sg × So contributed 25.38, 49.89, 0.27, 14.8, 0.369, 4.43 and 4.76 % respectively. Therefore, it is evident that Si and Sg contributed approximately 75 % of the total damage index and played major role while take away conveyor speed caused negligible damaging to the apples which was 0.27 % only. The interaction played a moderate role in producing damage in comparison with Si and Sg. The high values of R^2 (0.84) indicated that the fitted modes were appropriate to explain the relation ship between the dependent and independent variables.

### 5.2.5 Effect of treatments on damage index

In order to study the effects of machine parameters on damage index data were recorded and presented in D-2 (Table -1). Table 5.8 indicated that treatments significantly affected the damage index at 5% probability level and revealed that treatment No. 7 (Si = 10 m/min, Sg = 75 rpm and So = 5 m/min) resulted in greatest mean damage index value, which was 7.35. Treatment No. 26 (Si = 20 m/min, Sg = 75 rpm and So = 10 m/min) gave the lowest mean value of damage index of 5.8. Highest damage index at treatment No. 7 was due to lower feed rate of the product at take-in conveyor speed of 10 m/min. At lower take-in conveyor speed the grading unit requirement was not fully met with and the movement of the product relative to the rollers was not attained. Repeated re-orientation without forward movement caused increased impacts and resulted greater damage index because the rate of progression of the products across the roller was directly related to the angular velocity of the grading spools. The two adjacent spools might have supported a single product while rotating. It was observed that the friction forces between spools and product rotated the product without causing it to advance relative to the spools. In order to advance the product relative to the spools, at least one contact point on the upstream side of the product was required. When an additional product was fed to the upstream that contact point was achieved, which caused the
Table 5.8 Effect of treatments on damage index and grading error of apples.

<table>
<thead>
<tr>
<th>TRT</th>
<th>Treatment combinations</th>
<th>Damage index</th>
<th>Grading error</th>
</tr>
</thead>
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<td>6.20&lt;sup&gt;ijkl&lt;/sup&gt;</td>
<td>7.24&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Si<sub>1</sub> = 10 m/min  
Si<sub>2</sub> = 15 m/min  
Si<sub>3</sub> = 20 m/min  
S<sub>g1</sub> = 25 rpm  
S<sub>g2</sub> = 50 rpm  
S<sub>g3</sub> = 75 rpm  
S<sub>O1</sub> = 5 m/min  
S<sub>O2</sub> = 10 m/min  
S<sub>O3</sub> = 15 m/min

LSD (DI apple) = 0.3213  
LSD (ER apple) = 1.4014

<sup>a,b,c</sup> Mean followed by the same letters are not significant at 5% probability level.
product to move across the spools. Due to the rotation of the spools, instability of the product caused the forward movement of the object and this behavior agreed with the results reported by Liang (1988). Lower speed of take-in conveyor (Si) did not provide enough products on the grading unit to push forward the crop on the grading table. On the other hand higher speed of take-in conveyor (20 m/min) loaded sufficient product on the grading unit and resulted in positive progression across the grading table. This also caused less impact on the product that produced lower damage of the crop. Treatment Nos. 8 and 9 were statistically non significant, however were significantly different from treatment Nos. 2, 3, 16 and 18. Treatment Nos. 2, 3, 16, 17, and 18 resulted in almost same value of mean damage index value but were found significantly lower than those recorded in treatment Nos. 8 and 9. Treatment Nos. 4, 10, 11 and 12 produced almost the same values of mean damage index but were significantly greater than those at treatment Nos. 19 and 20. Treatment Nos. 6, 25 and 27 were non significant but produced significantly lower values of mean damage index than those at treatment No 21 & 23 i.e. 6.07, 6.12 and 6.19 respectively. However, these treatments (6, 25 and 27) gave larger mean index values than those at treatment No 1 & 5. Treatment Nos. 13, 14, 22 & 26 were also non significant but produced statistically lowest mean damage index values of 5.86, 5.82, 5.83 and 5.8 respectively, than those at all the other treatment combinations of the experiment. Even though treatment No 13, 14, 22 and 26 were statistically non significant but treatment No 26 produced the lowest mean damage index value of 5.8. Thus it was revealed that speeds, take-in conveyor of 20 m/min, grading spool of 75 rpm and take-away of 10 m/min were optimum to cause minimum damage to apples with damage index of 5.8 and suitable for grading.

5.2.6 Effect of take-in conveyor speed on grading error

The data regarding grading error have been presented in Appendix D-2 (Table-2). Take-in conveyor was operated at three speeds of 10, 15 and 20 m/min to change the feed rate of 6, 9 and 12 t/hr to study the effect machine and crop parameters on grading error. Statistically analyzed results are shown in the Table 5.9.
Table 5.9 Effect of take-in conveyor speed on grading error.

<table>
<thead>
<tr>
<th>Take-in conveyor speed (Si) (m/min)</th>
<th>Grading error (ER) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>5.98&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>15</td>
<td>6.75&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>20</td>
<td>7.53&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>Mean</td>
<td>6.75</td>
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<tr>
<td>LSD (0.05)</td>
<td>0.4671</td>
</tr>
</tbody>
</table>

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

Table 5.9 indicates that grading error increased with the increase in take-in conveyor speed (Si). Grading error was 5.98, 6.75, and 7.5% at take-in conveyor speed of 10, 15 and 20 m/min respectively. The results indicated that take-in conveyor speeds significantly affected the grading error at 5% probability level and contributed 42.64% to the total grading error of the system.

### 5.2.7 Effect of grading spool speed on grading error.

To study the effect of grading spool speed on grading error, data were recorded at grading spool speeds of 25, 50 and 75 rpm and presented in Appendix D-2 (Table-2). The data were analyzed statistical and shown in Table 5.10 and analysis of variance is presented in Appendix E-4. During the experiment it was observed that the grading spool speeds have significant effect on the grading error and contributed about 35.7% to the total grading error of the system. At grading spool speed of 25, 50 and 75 rpm, grading error was 6.48, 6.21 and 7.56% respectively. It was found that grading spool speeds of 25 and 50 rpm have statistically the same effects on the grading error while grading error at 75 rpm was significantly different from the other speeds. Even though the grading error at 25 and 50 rpm was statistically the same but at the grading spool speed of 50 rpm
Table 5.10 Effect of grading spool speed on grading error

<table>
<thead>
<tr>
<th>Grading spool speed (Sg) (rpm)</th>
<th>Grading error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>6.48&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
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<td>0.4671</td>
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</table>

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

Grading error was minimum that was 6.21%. The reason was that at 25 rpm speed of grading spool with higher feed rate of 12 t/hr over loading of the grading unit was observed that caused the multilayer product to pass over to the next higher size bank due to poor re-orientation. On the other hand maximum grading error at 75 rpm might be due to extensive re-orientation of the product that caused it to jump due to high peripheral velocity of the diabolo rubber discs. Since the grading error was minimum at grading spool speed of 50 rpm, therefore, it was regarded as the appropriate speed for grading of apples.

5.2.8 Effect of take-away conveyor speed on grading error

Data regarding the effect of take-away conveyor speed (So) on grading error were recorded and statistically analyzed results are shown in ANOVA (Appendix E-4). The results indicated that the effects of take-away conveyor speed (So) on grading error were non significant at 5% probability level. The ANOVA indicates that take-away conveyor speed shared only 0.31% of the total grading error of the system that was so small that could be neglected towards the system grading error.

The interaction of the take-in conveyor speed (Si) and the grading spool speed (Sg) on grading error has been presented in fig 5.10 through 5.12. The interaction of Si x Sg was found significant (α = 0.05). At all the selected take-away conveyor speeds of 5,
Fig 5.10 Grading error vs grading spool speed at take-away conveyor speed of 5 m/min for apple.

Fig 5.11 Grading error vs grading spool speed at take-away conveyor speed of 10 m/min for apples.

Fig 5.12 Grading error vs grading spool speed at take-away conveyor speed of 15 m/min for apple.
10, and 15 m/min grading error values were greater for take-in conveyor speed (Si) of 20 m/min than its other two speeds. Take-in conveyor speed of 10 m/min offered the lower grading error at each take-away conveyor speeds and grading spool speed of 25 rpm as shown in Fig. 5.14, 5.15 and 5.16. However, maximum grading error of 8.41% was observed at take-in conveyor, grading spool and take-away conveyor speed combination of 15 m/min, 75 rpm and 15 m/min respectively. This occurred due to massive re-orientation of product because of high velocity of diablo discs. It was observed that at lower take-in conveyor speed (Si = 10 m/min), as the grading spool speed increased, the grading error also increased but for higher speed of take-in conveyor (Si = 20 m/min) the grading error decreased as the grading spool speed (Sg) increased (Figs. 5.10, 5.11 and 5.12). This contradictory behavior supported the strong correlation between take-in conveyor speeds and grading spool speeds.

### 5.2.9 Model of grading error for apple grading

A mathematical model was developed using regression analysis in order to determine the contribution of each variable in the estimation of total grading error. The co-variate analysis gave the following model for the grading error in terms of take-in conveyor speed (Si), grading spool speed (Sg) and take-away conveyor speed (So) having correlation of 0.703. The Equation 5.4 indicated that Si, Sg, and the interaction Si x Sg, contributed 42.64, 35.7, 19.77 %, respectively. Therefore it is evident that Si and Sg contributed approximately 78 % of the total grading error of the system and played major role while take-away conveyor speed was not effective in producing the error for apple grading. The interaction Si x Sg played a moderate role in producing grading error in comparison with their independent variables (Si and Sg).
5.2.10 Effect of treatments on grading error

The effects of various combinations of machine parameters on grading error were studies and data were recorded as shown in Appendix D-2 (Table-2). Statistically analyzed results of grading error (ER) for apple are presented in Table 5.8 and ANOVA (Appendix E-4., Table -2) indicated that treatments significantly affect the grading error at 5% probability level. Treatment No 18 (Si = 15 m/min, Sg = 75 rpm and So = 15 m/min) resulted in maximum grading error of 8.41. Treatment No 2 (Si = 10 m/min, Sg = 25 rpm and So = 10 m/min) resulted in lowest mean value of grading error of 5.08. Highest grading error at treatment No. 18 was probably due to high speed of grading unit (Sg). Treatment Nos. 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26 and 27 produced statistically the same results but significantly different from treatment No. 8. Similarly treatment Nos. 8, 9, 19, 20, 21, 22, 23, 24, 25, 26 and 27 do not differ statistically but have greater values than treatment No.1, 2, 3, 4, 5, 6, 7, 10, 11, 12, 13, 14 and 15. From Table 5.4, it is clear that the treatments 1, 2, 3, 13, 14 and 15 having lower grading error, were statistically non significant at 5% probability level. Table 5.4 indicated that treatment Nos. 1, 2, 3, 13, 14 and 15 were statistically non significant for grading error and have the lower values of grading error than the other treatments. Similarly treatment No. 1, 5, 13, 14, 15, 22, 24 and 26 were not significantly different for damage index and had lower values of damage index than all the other treatments. At treatment No 26, the damage index was minimum (5.8) and grading error at this treatment was high (7.4%) and significantly different from treatment No. 1, 2, 3, 13, 14, and 15. Similarly treatment Nos. 22 and 24 yielded high values of grading error that were significantly different from grading error of treatment Nos.1, 2, 3, 13, 14 and 15. On the basis of these results, treatment Nos. 22, 24, and 26 can be neglected. Treatment No. 2 and 3 cannot be selected due to high damage index and these were significantly different from treatment 13, 14, and 15 for damage index. It was found that treatment Nos. 13, 14 and 15 had lower values of damage index and grading error, i.e 5.86, 5.82, 5.89 and .5.45, 5.44, 5.42% respectively. These treatments were statistically non significant for damage index and grading error. However, treatment No. 14 resulted lower value of damage index were
regarded as proper for selection of machine and crop parameters values for efficient and effective operation of grader.

5.3 **Onion Grading**

5.3.1 **Effect of take-in conveyor speed on damage index**

Three levels of take-in conveyor speed (Si) 10, 15 and 20 m/min were selected to load the crop on the machine at 6, 9 and 12 t/hr respectively. Data regarding damage index have been presented in Appendix D-3. Analysis of variance is presented in Appendix E-5. Statistically analyzed results are shown in Table 5.11.

**Table 5.11 Effect of take-in conveyor speed on damage index**

<table>
<thead>
<tr>
<th>Take-in conveyor speed (Si) (m/min)</th>
<th>Damage Index (DI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1.38^a</td>
</tr>
<tr>
<td>15</td>
<td>1.26^b</td>
</tr>
<tr>
<td>20</td>
<td>1.21^c</td>
</tr>
<tr>
<td>Mean</td>
<td>1.28</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.0067</td>
</tr>
</tbody>
</table>

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

Each DI value is a mean of 27 observations.

Table 5.11 elaborated the effects of take-in conveyor speed (Si) on damage index. Results at all the three take-in conveyor speeds were statistically significant at 5% probability level. Damage index (DI) values were 1.38, 1.26 and 1.21 at 10, 15 and 20 m/min respectively. Damage index decreased linearly with the linear increase in take-in conveyor speed and take in conveyor speed contributed approximately 47.24 % to the total damage index.
5.3.2 Effect of grading spool speed on damage index

In order to study the effects of grading spool speed on damage index, data were recorded at grading spool speed of 25, 50 and 75 rpm and presented in Appendix D-3 (Table -1). The ANOVA (Appendix E-4) revealed that the effect of grading spool speeds (Sg) on damage index is significantly different at 5 % probability level and contributed about 44.14% to the total damage index of the system. Statistically analyzed results are shown in Table 5.12.

Table 5.12. Effect of grading spool speed on damage index.

<table>
<thead>
<tr>
<th>Grading spool speed (Sg) rpm</th>
<th>Damage index (DI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>1.30a</td>
</tr>
<tr>
<td>50</td>
<td>1.19c</td>
</tr>
<tr>
<td>75</td>
<td>1.36a</td>
</tr>
<tr>
<td>Mean</td>
<td>1.28</td>
</tr>
<tr>
<td>LSD(0.05)</td>
<td>0.0067</td>
</tr>
</tbody>
</table>

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

The results indicated that minimum damage index of 1.19 was observed at grading spool speed of 50 rpm, while 14.29 and 9.24% increase in damage index was observed at 75 and 25 rpm respectively. It is clear from the table that grading spool speed 50 rpm was suitable for proper grading. Relatively higher DI at 25 rpm might be due to improper re-orientation of the product at grading table. Similarly at 75 rpm, higher peripheral speed of diablo shaped discs was responsible for excessive damage of the crop.

5.3.3 Effect of take-away conveyor speed on damage index

Effect of take-away conveyor speed on damage index was studied and data were recorded and statistically analyzed. The ANOVA (Appendix E-5) indicates that the
Fig 5.13 Damage index vs. grading spool speed at take away conveyor speed of 5 m/min for onion.

Fig 5.14 Damage index vs grading spool speed at take-away conveyor speed of 10 m/min for onion.

Fig 5.15 Damage index vs grading spool speed at take-away conveyor speed of 15 m/min for onion.
effects of different take-away conveyor speeds (So) on damage index were non significant and contributed only 0.07 % to the total damage index of the system.

The interaction of the conveyor speed (Si) and the grading spool speed (Sg) has been presented in Figure 5.13 through 5.15. The interaction of Si x Sg was found highly significant at 5% probability level (Appendix D-5) and contributed 8.44% to the total damage index. At all the selected take away conveyor speeds (5, 10 and 15 m/min) damage index values were greater for take-in conveyor speed of 10 m/min than the other two speeds. Take in conveyor speed of 20 m/min caused the lower damage index at all the take away conveyor speeds for grading spool speeds of 75 rpm. Also it is clear from all the three figures that minimum damage index of 1.13 (α = 0.05) was produced by the grader at take-in conveyor speed of 20 m/min, at grading spool speed of 50 rpm and take-away conveyor speed of 5 m/min. While maximum damage index of 1.54 was observed at take- in conveyor speed of 10 m/min, grading spool speed of 75 rpm and take-away conveyor speed of 15 m/min.

5.3.4 Model of damage index for onion grading

The data on damage index for onion were used to develop a model for explaining the contribution of each variable in calculation of damage index. The co-variate analysis generated the following model for damage index in terms of machine parameters Si, Sg, So with a high value of coefficient of correlation of 0.99.

\[
DI = 1.69 - 0.2233Si - 0.6183Sg + 0.0967Si^2 + 0.2217Sg^2 + 0.3667SiSg - 0.1417SiSg^2 - 0.1433Sg^3 + 0.045Si^2Sg^2
\]

The equation 5.5 indicated that Si, Sg, So and the interaction Si x Sg contributed 47.24, 44.14, 0.07 and 8.44% respectively, to the total damage index. Therefore it was clear that take-in conveyor speed and grading spool speed contributed approximately 91% of the total damage index while take away conveyor has not played a significant role in damaging the crop. The only interaction Si x Sg significantly affected the results in comparison with the other interactions. The high value of R^2 (0.991) indicated that the
fitted model was appropriate to explain the relationship between machine and crop parameters and were fitted well to their respective data sets.

5.3.5 Effect of treatments on damage index

The data of damage index at various speed combinations used in the study Take-in conveyor, grading spool and take-away conveyor were recorded and shown in Appendix D-3 (Table-1). Statistically analyzed results of damage index for onion has been presented in Table 5.13 and ANOVA in Appendix E-5 (Table-2). The ANOVA indicated that treatments were highly significant towards the damage index at 5% probability level. It is clear from the Table 5.13 that treatment No. 22 (Si = 20 m/min, Sg = 50 rpm and So = 5 m/min) yielded lowest damage index of 1.3 and treatment No 9 (Si = 10 m/min, Sg = 75 rpm and So = 15 m/min) resulted highest damage index value of 1.54 that was probably due to low feed rate and highest grading spool speed which resulted repeated impacts on the onion bulbs due to high peripheral speed of diablo shaped rubber discs of the grading spools. Treatment Nos. 22 and 24 were statistically non significant, however were significantly different from treatment Nos. 13, 14, 15 and 23 whereas treatment No 23 and 24 also produced non significant damage index values. Treatment Nos. 1, 2, 3, 16, 17 and 18 were also statistically non significant but had the higher damage index values than those of treatment No 10, 11, 12. Treatment analysis also indicated that the treatments having same values of Si and Sg had the same effects on damage index at different levels of So (5, 10 and 15 m/min). The same results were graphically discussed in Figure 5.17 through 5.19. Table 5.13 indicated that treatments having grading spool speed of 50 rpm caused lower damage index as compared to 25 and 75 rpm. For example at take-in conveyor speed of 20 m/min and grading spool speed of 50 rpm damage index was 1.15 while at 25 and 75 rpm, the damage index was 1.25 and 1.21 for the same take-in conveyor speed.
Table 5.13 Effect of treatments on damage index and grading error of onions

<table>
<thead>
<tr>
<th>TRT</th>
<th>Treatment combinations</th>
<th>Damage index</th>
<th>Grading error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$Si_1Sg_1S0_1$</td>
<td>1.33&lt;sup&gt;de&lt;/sup&gt;</td>
<td>4.40&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>2</td>
<td>$Si_1Sg_2S0_2$</td>
<td>1.34&lt;sup&gt;e&lt;/sup&gt;</td>
<td>4.43&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>3</td>
<td>$Si_1Sg_1S0_2$</td>
<td>1.32&lt;sup&gt;cde&lt;/sup&gt;</td>
<td>4.40&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>4</td>
<td>$Si_1Sg_2S0_1$</td>
<td>1.27&lt;sup&gt;ghi&lt;/sup&gt;</td>
<td>4.63&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>5</td>
<td>$Si_1Sg_2S0_2$</td>
<td>1.28&lt;sup&gt;gh&lt;/sup&gt;</td>
<td>4.64&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>6</td>
<td>$Si_1Sg_3S0_3$</td>
<td>1.29&lt;sup&gt;g&lt;/sup&gt;</td>
<td>4.64&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>7</td>
<td>$Si_1Sg_3S0_1$</td>
<td>1.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.75&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>8</td>
<td>$Si_1Sg_3S0_2$</td>
<td>1.53&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>4.77&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>9</td>
<td>$Si_1Sg_3S0_2$</td>
<td>1.54&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.77&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>10</td>
<td>$Si_2Sg_1S0_1$</td>
<td>1.30&lt;sup&gt;def&lt;/sup&gt;</td>
<td>4.55&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>11</td>
<td>$Si_2Sg_1S0_2$</td>
<td>1.31&lt;sup&gt;def&lt;/sup&gt;</td>
<td>4.57&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>12</td>
<td>$Si_2Sg_1S0_3$</td>
<td>1.16&lt;sup&gt;i&lt;/sup&gt;</td>
<td>3.64&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>13</td>
<td>$Si_2Sg_2S0_2$</td>
<td>1.15&lt;sup&gt;j&lt;/sup&gt;</td>
<td>3.63&lt;sup&gt;h&lt;/sup&gt;</td>
</tr>
<tr>
<td>14</td>
<td>$Si_2Sg_2S0_3$</td>
<td>1.16&lt;sup&gt;i&lt;/sup&gt;</td>
<td>3.64&lt;sup&gt;h&lt;/sup&gt;</td>
</tr>
<tr>
<td>15</td>
<td>$Si_2Sg_3S0_1$</td>
<td>1.33&lt;sup&gt;c&lt;/sup&gt;</td>
<td>4.41&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>16</td>
<td>$Si_2Sg_3S0_2$</td>
<td>1.33&lt;sup&gt;c&lt;/sup&gt;</td>
<td>4.43&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>17</td>
<td>$Si_2Sg_3S0_3$</td>
<td>1.33&lt;sup&gt;cde&lt;/sup&gt;</td>
<td>4.42&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>18</td>
<td>$Si_3Sg_1S0_1$</td>
<td>1.26&lt;sup&gt;h&lt;/sup&gt;</td>
<td>4.82&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>19</td>
<td>$Si_3Sg_1S0_2$</td>
<td>1.25&lt;sup&gt;g&lt;/sup&gt;</td>
<td>4.83&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>20</td>
<td>$Si_3Sg_1S0_3$</td>
<td>1.26&lt;sup&gt;h&lt;/sup&gt;</td>
<td>4.82&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>21</td>
<td>$Si_3Sg_2S0_1$</td>
<td>1.13&lt;sup&gt;n&lt;/sup&gt;</td>
<td>4.28&lt;sup&gt;f&lt;/sup&gt;</td>
</tr>
<tr>
<td>22</td>
<td>$Si_3Sg_2S0_2$</td>
<td>1.15&lt;sup&gt;l&lt;/sup&gt;</td>
<td>4.25&lt;sup&gt;f&lt;/sup&gt;</td>
</tr>
<tr>
<td>23</td>
<td>$Si_3Sg_2S0_3$</td>
<td>1.15&lt;sup&gt;lm&lt;/sup&gt;</td>
<td>4.26&lt;sup&gt;f&lt;/sup&gt;</td>
</tr>
<tr>
<td>24</td>
<td>$Si_3Sg_3S0_1$</td>
<td>1.23&lt;sup&gt;x&lt;/sup&gt;</td>
<td>3.95&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>25</td>
<td>$Si_3Sg_3S0_2$</td>
<td>1.23&lt;sup&gt;x&lt;/sup&gt;</td>
<td>3.95&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>26</td>
<td>$Si_3Sg_3S0_3$</td>
<td>1.23&lt;sup&gt;x&lt;/sup&gt;</td>
<td>3.95&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

$Si_1 = 10$ m/min  $Sg_1 = 25$ rpm  $So_1 = 5$ m/min
$Si_2 = 15$ m/min  $Sg_2 = 50$ rpm  $So_2 = 10$ m/min
$Si_3 = 20$ m/min  $Sg_3 = 75$ rpm  $So_3 = 15$ m/min

LSD (DI Onion) = 0.0202
LSD (ER Onion) = 0.0293

<sup>a,b,c</sup> Mean followed by the same letters are not significant at 5% probability level.
5.3.6 Effect of take-in conveyor speed on grading error

The data regarding grading error have been presented Appendix D-3 (Table-2). Three levels of take-in conveyor speed of 10, 15 and 20 m/min were selected to change the feed rate. The effects of different take-in conveyor speeds (Si) on grading error were studied. Statistically analyzed results are shown in the Table 5.14.

Table 5.14 Effect of take-in conveyor speed on grading error.

<table>
<thead>
<tr>
<th>Take-in conveyor speed (Si) m/min</th>
<th>Grading error (ER) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>4.61&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>15</td>
<td>4.20&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>20</td>
<td>4.34&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mean</td>
<td>4.38</td>
</tr>
<tr>
<td>LSD(0.05)</td>
<td>0.0098</td>
</tr>
</tbody>
</table>

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

Table 5.14 indicated that grading error increased as the Si increased from 15 to 20 m/min and also increased when the take-in conveyor speed was decreased to 10 m/min. This behavior might be due to higher speed of grading spool at lower speed of take-in conveyor and vice-versa. Grading error was 4.61, 4.20 and 4.34 % at take-in conveyor speed of 10, 15 and 20 m/min respectively. The results indicated that take-in conveyor speeds significantly affect the grading error at 5 % probability level and contributed 29.2 % to the total grading error of the system.

5.3.7 Effect of grading spool speed on grading error.

In order to study the effects of grading spool speeds of 25, 50 and 75 rpm on grading error the data and presented in Appendix D-3 (Table-2). The data of grading error for onions were analyzed statistical and results are presented in Table 5.15. During
the experiment it was observed that the grading spool speeds have significant effect on the grading error and contributed about 30.2% to the total grading error of the system. At grading spool speed of 25, 50 and 75 rpm, grading error was 4.6, 4.18 and 4.38% respectively. It was found that grading spool speeds of 25, 50 and 75 rpm have

Table 5.15 Effect of grading spool speed on grading error

<table>
<thead>
<tr>
<th>Grading spool speed (Sg) (rpm)</th>
<th>Grading error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>4.6a</td>
</tr>
<tr>
<td>50</td>
<td>4.18c</td>
</tr>
<tr>
<td>75</td>
<td>4.38b</td>
</tr>
<tr>
<td>Mean</td>
<td>4.38</td>
</tr>
<tr>
<td>LSD(0.05)</td>
<td>0.0098</td>
</tr>
</tbody>
</table>

\(^{a,b}\) Means followed by the same letters are not significant at 5% probability level. Each ER value is a mean of 27 observations.

statistically the different effects on the grading error. At the grading spool speed (Sg) of 25 rpm grading error was maximum that was 4.6%. The reason was that at grading spool speed of 25 rpm and take-in conveyor speed of 20 m/min, over loading of the grading unit was observed that caused product to pass over to the next higher size bank due to poor re-orientation that resulted higher grading error. On the other hand at 75 rpm (Sg), grading error was greater than that observed at 50 rpm. This might be due to excessive re-orientation of the product at lower feed rate (Si = 10 m/min) that caused the product to jump due to high peripheral velocity of the diablo rubber discs. Thus grading spool speed of 50 rpm was considered optimum to record minimum grading error.

5.3.8 Effects of take-away conveyor speed (So) on grading error

Effects of take-away conveyor speed on grading error were studied and statistically analyzed results are shown in ANOVA (Appendix E-6). The results indicated
that the effect of take away conveyor speed (So) on grading error were non significant at 5% probability level. The ANOVA (Appendix D-6) indicates that take-away conveyor speed shared only 0.0026% of the total grading error of the system that explained its poor impact on grading error.

The interaction of the take-in conveyor speed (Si) and the grading spool speed Sg) has been presented in Fig. 5.16 through 5.18. ANOVA revealed that interaction Si × Sg was significant at 5 probability level and contributed 40.6 % share to the total grading error of the system. At all the selected take-away conveyor speeds grading error values were greater for take-in conveyor speed of 20 m/min than the other two speeds (10 and 15 m/min). Take-in conveyor speed of 10 m/min offered the lower grading error at all the take-away conveyor speeds for grading spool speed of 25 rpm. Figures 5.16, 5.17 and 5.18 revealed that minimum grading error of 3.63% (α = 0.05) was produced by the grader at take-in conveyor speed of 15 m/min, grading spool speed of 50 rpm and take-away conveyor speed of 10 m/min. While maximum grading error of 4.83 % was observed at treatment No.20 (take-in conveyor speed 20 m/min, grading spool speed of 25 rpm and take-away conveyor speed at 10 m/min), that was probably due to high feed rate that caused the product to gather over and above the capacity of grading unit that could not be entertained at lower grading spool speed of 25 rpm.

5.3.9 Model of Grading Error for Onion Grading

Regression analysis was employed in order to develop a mathematical model from the data presented in Appendix D-3 (Table-2). The model explained the contribution of variables in the estimation of total grading error. The equation developed is as follows having a high value of coefficient of correlation (R² = 0.99).

\[ ER(\%) = -3.96 + 9.91S_i + 10.878S_g - 2.6317 S_g^2 - 13.217 S_i S_g \\
+ 3.28 S_i^2 S_g^2 + 3.1267 S_i^2 S_g - 0.7933 S_i^2 S_g^2 \]

5.6
Fig. 5.16. Grading error vs grading spool speed at take-away conveyor speed of 5 m/min for onion grading.

Fig. 5.17. Grading error vs grading spool speed at take-away conveyor speed of 10 m/min for onion grading.

Fig. 5.18. Grading error vs grading spool speed at take-away conveyor speed of 15 m/min for onion grading.
The Equation 5.6 indicated that Si, Sg, and the interactions Si \times Sg, contributed 29.2, 30.2 and 40.6\% respectively. Thus it was found that Si and Sg contributed approximately 59.4 \% of the total grading error of the system while take-away conveyor speed had a little effect in producing the error for onion grading. The interaction Si \times Sg also played a significant role in producing grading error.

5.3.10 Effect of treatments on grading error for onion

In order to investigate the effects of combinations of various machine parameters on grading error data were recorded and presented in Appendix D-3 (Table-2). The data were analyzed statistically and the ANOVA is given in Appendix E-6. The results of grading error (ER) of grader for onion are presented in Table 5.13. The ANOVA indicated that treatments significantly affected the grading error at 5\% probability level. Table 5.13 showed that treatment No 20 (Si = 20 m/min, Sg = 25 rpm and So = 10 m/min) resulted in maximum grading error value that was 4.83 \%. Treatment No 14 (Si = 15 m/min, Sg = 50 rpm and So = 10 m/min) resulted in lowest grading error mean value of 3.63\%. Highest grading error at treatment No. 20 was due to high speed of take-in conveyor (20 m/min) and low speed of grading spools (25 rpm). At lower speed, grading spool were not able to re-orientate the crop properly that caused the grading table over loaded with the onion bulbs and hence resulted in producing high grading error. Treatment Nos. 13, 14, and 15, produced minimum and statistically the same results but significantly different from treatment Nos. 25, 26 and 27 at probability level of 5\%. Treatment Nos. 25, 26 and 27 yielded larger values than the treatments Nos.13, 14 & 15 but lower than all the other treatments. This behavior of the grading system was due to high speed of grading spool and maximum feed rate that disturbed the orientation of crop. Similarly treatment Nos. 22, 23 and 24 did not differ statistically but had greater values than treatment Nos. 25, 26 and 27. From the Table 5.13 it is clear that take-in conveyor speed of 15 m/min with grading spool speed of 50 rpm, resulted lowest grading error of 3.63\%. Nevertheless when the take-in conveyor speed and grading spool speed were increased to 20 m/min and 75 rpm respectively, the grading error was also increased.
Table 5.13 shows that treatment Nos. 13, 14 and 15 were statistically non-significant for grading error and had the lower values of grading error than the other treatments. Similarly treatment Nos. 13, 14, 15, 23 and 24 were not significantly different for damage index and treatment No. 22 was not statistically different from treatment No. 24 for damage index. At treatment No. 22, damage index was minimum (1.13) and grading error at this treatment was 4.28%. At treatment No. 14 grading error was minimum (3.63%) and damage index was 1.15 that was statistically same as of treatment No 13, 15, 23 and 24 while treatment No 22 and 24 also had statistically the same damage index. On the basis of these results, for higher throughput (12 t/hr), treatment No 26 (Si = 20 m/min, Sg = 75 rpm and So = 10 m/min) yielded 1.21 damage index at 3.93% grading error and for lower throughput (9 t/hr) treatment No 14 produced damage index 1.15 at grading error of 3.63%. It was concluded that treatment No 14 and 26 have the lower values of damage index and grading error as the both damage index and grading error were within the tolerance limit and are acceptable for marketing.

5.4 Mango Grading

5.4.1 Effect of take-in conveyor speed on damage index

In order to study the effects of take-in conveyor speed on damage index data were recorded at three levels of take in conveyor speed (Si) of 10, 15 and 20 m/min. The data were statistically analyzed and results are shown in Table 5.16. Table 5.16 elaborated the effects of take-in conveyor speed (Si) on damage index. Results at take-in conveyor speeds of 10, 15 were statistically the same at 5% probability level. While damage index at take-in conveyor speed of 20 m/min was significantly different from damage index values at the other two speeds. Damage index values were 7.03, 6.70 and 6.70 at 20 m/min, 15 m/min and 10 m/min respectively. From ANOVA (Appendix E-7) it is clear that take-in conveyor contributed only 6.99% to the total damage index. Damage index decreased 4.69% when the take-in conveyor speed was decreased from 20 to 15 m/min and no further decrease was found when the take-in conveyor speed was further decreased to 10 m/min.
Table 5.16 Effect of take-in conveyor speed on damage index

<table>
<thead>
<tr>
<th>Take-in conveyor speed (Si) (m/min)</th>
<th>Damage Index (DI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>6.70^b</td>
</tr>
<tr>
<td>15</td>
<td>6.70^b</td>
</tr>
<tr>
<td>20</td>
<td>7.03^a</td>
</tr>
<tr>
<td>Mean</td>
<td>6.81</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.078</td>
</tr>
</tbody>
</table>

^a,b,c Means are followed by the same letters are not significantly different at 5% probability level. Each DI value is a mean of 27 observations.

5.4.2 Effect of grading spool speed on damage index

The effects of different grading spool speeds of 25, 50 and 75 rpm on damage index were studied and the data were recorded and analyzed statistically.

Table 5.17. Effect of grading spool speed on damage index.

<table>
<thead>
<tr>
<th>Grading spool speed (Sg) rpm</th>
<th>Damage index</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>6.44^b</td>
</tr>
<tr>
<td>50</td>
<td>6.39^b</td>
</tr>
<tr>
<td>75</td>
<td>7.60^a</td>
</tr>
<tr>
<td>Mean</td>
<td>6.81</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.078</td>
</tr>
</tbody>
</table>

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

ANOVA depicted that the effect of grading spool speeds (Sg) on damage index is significantly different at 5% probability level and contributed about 92.39% to the total damage index of the system (Appendix E-7). Statistically analyzed results are shown in
Table 5.17. The results indicated that minimum damage index of 6.39 was observed at grading spool speed of 50 rpm, while 18.93% increase in damage index was observed at 75 rpm. It is clear from the Table 5.23 that grading spool speed 50 rpm was suitable for proper grading. Relatively higher DI at 25 rpm might be due to improper re-orientation and higher shape index. Similarly at 75 rpm, higher peripheral speed of diabolo shaped discs might be held responsible for excessive damage of the crop.

5.4.3 Effect of take-away conveyor speed on damage index

In order to investigate the effects of take-away conveyor speeds on damage index during grading data were recorded and presented in Appendix D-4 (Table -1) The ANOVA (Appendix E-7) indicates that the effects of different take away conveyor speeds (So) on damage index were non significant at 5% probability level and contributed negligible role in producing the damage index. All the exposed metal surfaces of take away conveyor were cushioned with padding material that protected the crop from any injury or internal mechanical damage.

The interaction of different machine parameters like Si × Sg at different take-away conveyor speed were studied and presented graphically in Fig 5.25 through 5.27. It was found that all the interaction of Si × Sg like 10 m/min × 25 rpm, 15 m/min × 50 rpm, 15 m/min × 25 rpm and 10 m/min × 50 rpm were appropriate combinations for lower damage index.

5.4.4 Model of damage index for mango grading

Mango is delicate crop towards mechanical injury and requires a very careful post harvest handling. To study the effects of different machine parameters on damage index of the crop, a co-variate analysis was employed. The co-variate analysis yielded the following model for damage index in terms of machine parameters Si, Sg, So.

\[
DI = 10.41 - 2.97Si - 5.19Sg + 0.66Si^2 + 1.39Sg^2 - 0.68SiSg - 5.7
\]
The equation 5.7 indicated that Si, Sg, So and the interaction Si x Sg contributed 6.99, 92.39, 0.0087 and 0.56 % respectively to the total damage index. Take-in conveyor and grading spool speed altogether contributed approximately 99.38 % of the total damage index while take-away conveyor did not damage the crop. Further the grading spool speed had shared 92.39% and was responsible for damaging the crop. The only interaction Si x Sg significantly affected the results in comparison with the other interactions and played a moderate role in producing the damage index. The high value of $R^2$ (0.96) indicated that the fitted model was appropriate to explain the relationship between machine and crop parameters.

5.4.5 Effect of treatments on damage index

The data of damage index for mango grading at various combinations of machine parameters i.e. take-in conveyor speed (Si), grading spool speed (Sg) and take-away conveyor speed (So) were recorded and presented in Appendix D-4 (Table-1). Statistically analyzed results of damage index for mango has been presented in Table 5.26 and ANOVA in Appendix E-7 (Table-2). The ANOVA indicated that treatments were highly significant towards the damage index at 5% probability level. Table 5.18 shows that treatment No. 4 (Si = 10 m/min, Sg = 50 rpm and So = 5 m/min) yielded lowest damage index (6.14) and treatment No 25 (Si = 20 m/min, Sg = 75 rpm and So = 5 m/min) resulted highest damage index value of 7.76 that was probably due to high feed rate and highest grading spool speed which resulted repeated impacts on the mangoes due to high peripheral speed of diablo shaped rubber discs of the grading spools. Treatment Nos. 7, 8, 9, 25, 26 and 27 produced statistically the same damage index values which were significantly different and higher than those of treatment Nos. 19, 20, 21, 22, 23 and 24. Reason was only the effect of grading spool speed as higher damage index was observed at 75 rpm grading spool speed and lower damage index at lower spool speed. Treatment Nos. 3, 4, 5, 6, 10, 11, 12, 13, 14 and 15 yielded statistically the same results but lower than that of treatment No 19, 20, 21, 22, 23, and 24. It is clear from the
Fig 5.19. Damage index vs grading spool speed at take-away conveyor speed 5 m/min for mango grading.

Fig 5.20. Damage index vs grading spool speed at take-away conveyor speed of 10 m/min for mango grading.

Fig 5.21. Damage index vs grading spool speed at take-away conveyor speed of 15 m/min for mango grading.
Table 5.18 Effect of treatments on damage index and grading error of mangoes.

<table>
<thead>
<tr>
<th>TRT</th>
<th>Treatment combinations</th>
<th>Damage index</th>
<th>Grading error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Si1Sg1S01</td>
<td>6.37&lt;sup&gt;fg&lt;/sup&gt;</td>
<td>5.84&lt;sup&gt;i&lt;/sup&gt;</td>
</tr>
<tr>
<td>2</td>
<td>Si1Sg1S02</td>
<td>6.42&lt;sup&gt;ef&lt;/sup&gt;</td>
<td>5.96&lt;sup&gt;j&lt;/sup&gt;</td>
</tr>
<tr>
<td>3</td>
<td>Si1Sg1S03</td>
<td>6.36&lt;sup&gt;gh&lt;/sup&gt;</td>
<td>5.98&lt;sup&gt;j&lt;/sup&gt;</td>
</tr>
<tr>
<td>4</td>
<td>Si1Sg2S01</td>
<td>6.14&lt;sup&gt;h&lt;/sup&gt;</td>
<td>6.08&lt;sup&gt;k&lt;/sup&gt;</td>
</tr>
<tr>
<td>5</td>
<td>Si1Sg2S02</td>
<td>6.19&lt;sup&gt;gh&lt;/sup&gt;</td>
<td>6.07&lt;sup&gt;j&lt;/sup&gt;</td>
</tr>
<tr>
<td>6</td>
<td>Si1Sg2S03</td>
<td>6.16&lt;sup&gt;h&lt;/sup&gt;</td>
<td>6.14&lt;sup&gt;j&lt;/sup&gt;</td>
</tr>
<tr>
<td>7</td>
<td>Si1Sg3S01</td>
<td>7.54&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>6.90&lt;sup&gt;k&lt;/sup&gt;</td>
</tr>
<tr>
<td>8</td>
<td>Si1Sg3S02</td>
<td>7.57&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>6.94&lt;sup&gt;kn&lt;/sup&gt;</td>
</tr>
<tr>
<td>9</td>
<td>Si1Sg3S03</td>
<td>7.55&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>6.94&lt;sup&gt;kn&lt;/sup&gt;</td>
</tr>
<tr>
<td>10</td>
<td>Si2Sg1S01</td>
<td>6.28&lt;sup&gt;gh&lt;/sup&gt;</td>
<td>7.51&lt;sup&gt;efgh&lt;/sup&gt;</td>
</tr>
<tr>
<td>11</td>
<td>Si2Sg1S02</td>
<td>6.32&lt;sup&gt;gh&lt;/sup&gt;</td>
<td>7.61&lt;sup&gt;efg&lt;/sup&gt;</td>
</tr>
<tr>
<td>12</td>
<td>Si2Sg1S03</td>
<td>6.29&lt;sup&gt;gh&lt;/sup&gt;</td>
<td>7.26&lt;sup&gt;ghi&lt;/sup&gt;</td>
</tr>
<tr>
<td>13</td>
<td>Si2Sg2S01</td>
<td>6.33&lt;sup&gt;gh&lt;/sup&gt;</td>
<td>7.48&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>14</td>
<td>Si2Sg2S02</td>
<td>6.32&lt;sup&gt;gh&lt;/sup&gt;</td>
<td>7.24&lt;sup&gt;ghi&lt;/sup&gt;</td>
</tr>
<tr>
<td>15</td>
<td>Si2Sg2S03</td>
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<td>7.39&lt;sup&gt;ghi&lt;/sup&gt;</td>
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<tr>
<td>16</td>
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<td>9.46&lt;sup&gt;*&lt;/sup&gt;</td>
</tr>
<tr>
<td>17</td>
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<td>9.84&lt;sup&gt;4&lt;/sup&gt;</td>
</tr>
<tr>
<td>18</td>
<td>Si2Sg3S03</td>
<td>7.45&lt;sup&gt;c&lt;/sup&gt;</td>
<td>8.57&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>19</td>
<td>Si3Sg1S01</td>
<td>6.63&lt;sup&gt;de&lt;/sup&gt;</td>
<td>9.43&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>20</td>
<td>Si3Sg1S02</td>
<td>6.66&lt;sup&gt;d&lt;/sup&gt;</td>
<td>9.47&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>21</td>
<td>Si3Sg1S03</td>
<td>6.66&lt;sup&gt;d&lt;/sup&gt;</td>
<td>9.58&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>22</td>
<td>Si3Sg2S01</td>
<td>6.67&lt;sup&gt;d&lt;/sup&gt;</td>
<td>8.40&lt;sup&gt;bcd&lt;/sup&gt;</td>
</tr>
<tr>
<td>23</td>
<td>Si3Sg2S02</td>
<td>6.67&lt;sup&gt;d&lt;/sup&gt;</td>
<td>8.41&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>24</td>
<td>Si3Sg2S03</td>
<td>6.71&lt;sup&gt;d&lt;/sup&gt;</td>
<td>8.52&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>25</td>
<td>Si3Sg3S01</td>
<td>7.76&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.99&lt;sup&gt;bde&lt;/sup&gt;</td>
</tr>
<tr>
<td>26</td>
<td>Si3Sg3S02</td>
<td>7.74&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>7.97&lt;sup&gt;cdef&lt;/sup&gt;</td>
</tr>
<tr>
<td>27</td>
<td>Si3Sg3S03</td>
<td>7.75&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>7.82&lt;sup&gt;defg&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Si<sub>1</sub> = 10 m/min     Sg<sub>1</sub> = 25 rpm     S0<sub>1</sub> = 5 m/min
Si<sub>2</sub> = 15 m/min     Sg<sub>2</sub> = 50 rpm     S0<sub>2</sub> = 10 m/min
Si<sub>3</sub> = 20 m/min     Sg<sub>3</sub> = 75 rpm     S0<sub>3</sub> = 15 m/min

LSD (DI Mango) = 0.2331
LSD (ER Mango) = 0.583

<sup>a,b,c</sup> Mean followed by the same letters are not significant at 5% probability level.
comparison that the treatments having 10 or 15 m/min take in conveyor speed and 25 rpm or 50 rpm grading spool speed had caused lower damage while the treatments having 75 rpm with either take in conveyor speed yielded higher damage index. However, treatment No. 4 (Si=10 m/min, Sg= 50 rpm and So = 5 m/min) produced the lowest damage index of value 6.14 and suitable for mango grading.

5.4.6 Effect of take-in conveyor speed on grading error

The data regarding grading error have been presented appendix D-4. Three levels of take-in conveyor speed were used to change the feed rate. The crop was fed to the grader at three feeding rates of 6, 9 and 12 t/hr at the corresponding take-in conveyor speeds of 10, 15 and 20 m/min to record data on grading error. The effects of different take-in conveyor speeds (Si) on grading error were studied. Statistically analyzed results are shown in the Table 5.19 and indicated that all the three take-in conveyor speeds (Si) were significantly different for producing grading error at 5 % probability level and grading error increased as the take-in conveyor speed increased from 10 to 15 m/min and

<table>
<thead>
<tr>
<th>Take-in conveyor speed (Si) m/min</th>
<th>Grading error (ER) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>6.32&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>15</td>
<td>8.04&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>20</td>
<td>8.62&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mean</td>
<td>7.66</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.1943</td>
</tr>
</tbody>
</table>

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

also increased when the take-in conveyor speed further increased to 20 m/min. This behavior was due to higher speed of take-in conveyor and over loading of the grading
unit. Grading error was 6.32, 8.04, and 8.62 % at take-in conveyor speed of 10, 15 and 20 m/min respectively. The results indicated that take-in conveyor speeds significantly affected the grading error and contributed 76.31 % to the total grading error of the system. Therefore it was observed that high take-in conveyor speed (Si) was responsible for producing maximum error and this might be due to higher feeding rate than the required capacity of the grading unit at that particular grading spool speed. Take-in conveyor speed of 10 m/min was considered suitable speed for grading mango.

### 5.4.7 Effect of grading spool speed on grading error

In order to study the effect of grading spool speeds of 25, 50 and 75 rpm, on grading error data were recorded and presented in Appendix D-4 (Table-2). Statistical analyzed results are presented in Table 5.20 and ANOVA is presented in appendix D-8.

<table>
<thead>
<tr>
<th>Grading spool speed (Sg) (rpm)</th>
<th>Grading error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>7.63&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>50</td>
<td>7.30&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>75</td>
<td>8.05&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mean</td>
<td>7.66</td>
</tr>
<tr>
<td>LSD(0.05)</td>
<td>0.1943</td>
</tr>
</tbody>
</table>

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

During the experiment it was observed that the grading spool speeds have significant effect on the grading error and contributed about 7.42 % to the total grading error of the system. It was found that grading spool speeds of 25, 50 and 75 rpm had statistically significant effects on the grading error and yielded grading error of 7.63, 7.30 and 8.05 % respectively. The reason of higher grading error of 8.05 at grading spool speed of 75 rpm was the extensive re-orientation of the product and to some extent the product might have
passed over to the next higher size bank. On the other hand at 25 rpm (Sg), grading error was increased 4.52 % than as observed at 50 rpm. Similarly when the speed increased from 50 to 75 rpm, 10.27 % increase in grading error was observed. High grading error at 25 rpm might be due to poor re-orientation of the product at higher feed rate that caused the product to over flow rather to pass through their respective banks. It can easily be concluded that 50 rpm was the appropriate grading spool speed to register minimum grading error.

5.4.8 Effect of take-away conveyor speed on grading error.

Effect of take-away conveyor speed on grading error was studied. The data were recorded and statistically analyzed as shown in ANOVA (Appendix E-8). The results indicated that the effects of take-away conveyor speed (So) on grading error were non significant at 5% probability level and shared only 0.296% of the total grading error of the system which depicted its poor impact on grading error.

The interaction of the take-in conveyor speed (Si) and the grading spool speed (Sg) has been presented in Fig 5.22 through 5.24. From ANOVA (Appendix E-8) it is clear the interaction Si × Sg was found significant (α = 0.05) and contributed 14.87% to the total grading error of the system. At all the selected take-away conveyor speeds of 5, 10 and 15 m/min grading error values were greater for highest take-in conveyor speed of 20 m/min and lower at the lowest take-in conveyor speed of 10 m/min. Take-in conveyor speed of 10 m/min with grading spool speed of 25 rpm yielded minimum grading error of 5.84% and take-in conveyor speed of 10 m/min with grading spool speed of 50 rpm produced a little bit higher error of 6.07% but was statistically the same. Therefore it was recommended that for mango grading, take-in conveyor speed of 10 m/min in combination with grading spool speed of 25 rpm or 50 rpm at any take-away conveyor speed provided the appropriate results. For example at take-in conveyor speed of 10 m/min and grading spool speed of 25 rpm and take-away conveyor speed of 5 m/min, damage index and grading error were 6.37 and 5.84 % respectively.
Fig 5.22. Grading error vs grading spool speed at take-away conveyor speed of 5 m/min for mango grading.

Fig 5.23. Grading error vs grading spool speed at take-away conveyor speed of 10 m/min for mango grading.

Fig 5.24. Grading error vs grading spool speed at take-away conveyor speed of 15 m/min for mango grading.
While for take-in conveyor speed of 10 m/min, grading spool speed of 50 rpm and take-away conveyor speed of 5 m/min, damage index and grading error were 6.14 and 6.08% respectively.

5.4.9 Model of grading error for mango grading

In order to determine the extent to which variable, of machine parameters affect the total grading error, a co-variate analysis (Regression analysis) using statistical package Minitab was employed. The co-variate analysis yielded the following model for the damage index in terms of take-in conveyor speed (Si), grading spool speed (Sg) and take away conveyor speed (So).

\[ ER = 13.89 - 12.71Si - 11.44Sg + 3.895Si^2 + 2.935Sg^2 + 16.26SiSg - 4.318Si^2Sg - 6.67Si^2So + 0.996Si^2Sg^2 \]

The Equation 5.8 indicated that Si, Sg, So and the interactions Si x Sg, Si x So, Sg x So and Si x Sg x So contributed 76.31, 7.42, 0.296, 14.87, 0.479, 0.427 and 0.207 % respectively. Therefore, it is evident that only Si contributed approximately 76.31 % of the total grading error and played major role while grading spool speed played a moderate role in producing the grading error and take away conveyor speed did not produced the grading error. The interaction (Si x Sg) significantly effected the grading error and had a strong effect in producing grading error in comparison with other interactions. The high coefficient of correlation having value of 0.95 indicated that the fitted model was appropriate to explain the relation ship between the dependent and independent variables.

5.4.10 Effects of treatments on grading error for mangoes

The data of grading error for mango grading at various combinations of take-in conveyor speed (Si), grading spool speed (Sg) and take-away conveyor speed (So) were recorded and presented in Appendix D-4 (Table-2). Effects of different combinations of machine parameters were statistically analyzed and the results of grading error for mango
grading are presented in Table 5.18. The analysis of variance has also been presented in Appendix E-8 (Table-2) indicated that treatments significantly affected the grading performance of the machine at 5% probability level. Table 5.18 indicated that minimum grading error was observed at treatment No 1 while treatment Nos. 1, 2, 3, 4, 5 and 6 had produced statistically the same values of grading error and treatment Nos. 7, 8, and 9 had produced statistically same but higher than that of treatment Nos. 1, 2, 3, 4, 5 and 6. Therefore it can be concluded that at lower take-in conveyor speed of 10 m/min, grading spool speeds of 25 rpm and 50 rpm produced statistically same and lower error values but at grading spool speed 75 rpm, error values are greater and statistically different. When the grader was operated at high take-in conveyor speed of 20 m/min in combination with any grading spool speed (Sg) that produced high grading error values as compared to the treatment having lower take-in conveyor speed of 10 m/min. This behavior of the machine parameters also justified the major contribution of 76.31% of the take-in conveyor towards the grading error as observed in ANOVA (Appendix D-8). High grading error at take-in conveyor speed of 20 m/min was due to high feed rate that was not be entertained by the lower grading spool speed and caused overloading the grading table. This situation probably forced some crop to pass over rather to pass through their respective size banks and resulted high grading error. When the results regarding the damage index and grading error were studied, it was observed that take-in conveyor speed of 10 m/min, grading spool speed of 50 rpm and take away conveyor speed of 5 m/min produced damage index and grading error values of 6.14 and 6.08 respectively. The damage index was minimum among all the treatments and grading error of 6.08% was statistically non-significant with the lowest grading error value of 5.84 among all the treatments. Hence treatment No.4 (Si = 10 m/min, Sg = 50 rpm and So = 5 m/min) was recommended suitable for mango grading.

5.5 Machine economics

During the peak season of the crop post harvest handling, shortage of manual labor adversely affects the in time marketing. Delayed marketing of fruit and vegetable can not be tolerated as a fresh product commands a premium and have a short shelf life. Human nature to choose the fruit and vegetable while purchasing at shop and limitations
for trade across the boarder has been recognized. Keeping in view necessity of marketing, the fruit and vegetable grader was developed that was capable to grade the fruit and vegetable on size basis.

In order to investigate whether the machine is economically viable and adoptable by the farming community, the detailed analysis of operational cost was worked out and presented in Appendix-F.

The grader yielded better results at 80% machine capacity. Grading cost of potato and onions were Rs.4/- per 100 kg at throughput of 9.6 t/hr while for apple and mango, the grading cost was Rs.5/- and Rs.6/- per 100 kg respectively.

From a market survey it was observed that graded potato, onion, apple and mango have 4% to 10 % higher selling price. Estimated profit was Rs 7680/ hr when grader was operated with diesel engine and grading expenditure was Rs.360/hr. Whereas grading expenditure was increased to Rs.460/hr when the grader was operated with tractor MF-210. High throughput and economical operation had made it quite feasible for on farm use.
SUMMARY

This study was carried out with the aim to design and develop a power operated operated, spool type grader. The grader was designed to grade the fruits and vegetables on size basis. The grader comprised of take-in conveyor, hoper, space bar conveyor, primary grading unit, secondary grading unit, take-away conveyors, and power transmission system and transportation wheels. Take-in conveyor was flight type and a variable drive system was designed to operate the take-in conveyor at 10, 15 and 20 m/min for varied loading capacities. The hoper having capacity to hold the 56 kg of product was developed, to collect the products coming from take-in conveyor. An adjustable opening at the lower end of the hopper was designed to load the crop on the space bar conveyor at constant rate. Space bar conveyor was developed to load the crop onto the primary grading unit. It was manufactured with a series of mild steel bars cushioned with rubber pipes to avoid the crop damage. Space bar conveyor was inclined at an angle of 18° taking into account the angle of repose of the products being graded. A series of bars were temporarily fastened and a space of 15 mm in between two consecutive bars was arranged to screen the product and other debris of size less than 15 mm. The speed of the space bar conveyor was kept constant at 20 m/min throughout in all the experiment.

Primary grading unit consisted of three rollers (60 mm dia) that were arranged in series to separate the product of size lower than 35 mm. Inter roller distance was adjustable to achieve the required product size at this unit. A deflector plate was provided over the primary grading unit to achieve a mono layer flow of the product across the grading unit. A variable speeds mechanism was arranged to operate the grading unit at 25, 50 and 75 rpm to accommodate different feed rates. The rollers were non translating and powered through chain drive system. Rotation of the products was accomplished with the rotation of non translating rollers and forward progression was achieved by providing a contact point behind the product. That contact point was attained by feeding a continuous supply of the product to the grader. In secondary grading unit, a series of diablo shaped rubber discs were pulled over a square shaft and rubber spacers were
sandwiched in between the diablo discs. Nine spools arranged in series formed upper grading table, while lower grading table comprised eleven spools. Secondary grading unit was capable to divide the product having size > 35 mm into three categories. Arrangements were provided to set the grading unit for different grading standards as desired by the market. Three take-away conveyors were manufactured to collect and convey the graded products to the packing point. A separate variable drive system was developed to operate the take-away conveyors at 5 m/min, 10 m/min and 15 m/min. A pair of pneumatic wheels was mounted for easy transportation of the grader to the farms. A power required to operate the system was 8.79 kW.

In order to evaluate field performance of the grader, four different crops, namely potato, apple, onion and mango were used. For this purpose, three machine parameters, take-in conveyor speed (Si), grading unit speed (Sg) and take-away conveyor speed (So) were selected to operate at three speed levels. Effects of the machine parameters on product damage and grading error were investigated by using 3 factor factorial CRD statistically design and the results were analyzed with the help of Minitab and PROC / GLM (General Linear Model) procedure of SAS Institute (1998). Following conclusions were drawn from the results of this study.

1. For potato grading minimum damage index (3.06) was observed at take-in conveyor speed of 20 m/min, grading spool speed of 50 rpm and take-away conveyor speed of 5 m/min while minimum grading error (4.03 %) was observed at take-in conveyor speed of 20 m/min, grading spool speed of 50 rpm and take-away conveyor speed of 10 m/min. 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 a 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. At take-in conveyor speed 20 m/min, grading spool speed of 50 rpm and take-away conveyor speed of 15 m/min produced minimum damage index at throughput of 9.6 t/hr.

2. For apple grading, minimum damage index of 5.8 was observed at take-in conveyor speed of 20 m/min, grading spool speed of 75 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 speed of 20 m/min and grading spool speed (25 rpm) yielded higher values of grading error while take-in conveyor speed of 10 m/min in combination with grading spool speed of 75 rpm had resulted high damage index values. Take-in conveyor, grading spool and take-away conveyor speeds of 15m/min, 50 rpm and 10 m/min were appropriate for optimum results.

3. For onion grading, minimum damage index of 1.13 was observed at take-in conveyor speed of 20 m/min, grading spool speed of 50 rpm while maximum damage index of 1.54 was investigated at take-in conveyor speed 10 m/min, grading spool speed 75 rpm. Maximum grading error was yielded at take-in conveyor speed of 20 m/min, grading spool speed of 25 rpm and take-away conveyor speed of 10 m/min. Whereas minimum grading error was observed at take-in conveyor speed of 15 m/min, grading spool speed of 50 rpm and take-away conveyor speed of 10 m/min. Take-in conveyor speed contributed 47.24 % of the total damage index while grading spool speed (Sg)
shared 44.14 % of the total damage index. Similarly 29.2 % and 30.2 % of total grading error was contributed by the take-in conveyor and grading spool speed respectively. Take-in conveyor speed of 15 m/min and grading spool speed of 50 rpm produced the same results for damage index as observed at take-in conveyor speed of 20 m/min and grading spool speed of 50 rpm. Whereas for grading error, take-in conveyor speed of 15 m/min yielded lower value. Therefore moderate speeds of take-in conveyor and grading spool (15m/min and 50 rpm) were suitable for onion grading.

4. For mango grading, lower damage index of 6.14 was investigated at take-in conveyor speed of 10 m/min and grading spool speed of 50 rpm. While maximum damage index of 7.76 was observed at take-in conveyor speed of 20 m/min and grading spool speed of 75 rpm. Similarly minimum grading error of 5.84% was observed at take-in conveyor speed of 10 m/min and grading spool speed of 25 rpm while maximum grading error of 9.58% was resulted at take-in conveyor speed of 20 m/min and grading spool speed of 25 rpm. Take-in conveyor speed and grading spool speed contributed 6.99 and 92.39 % respectively, to the total damage index. For grading error, take-in conveyor speed and grading spool speed shared 76.31 % and 7.42% respectively to the total grading error of the grader. Take-in conveyor speed of 20 m/min and grading spools speed of 25 rpm were responsible for high grading error, whereas lower take-in conveyor speed of 10 m/min and higher grading spool speed of 75 rpm, yielded higher values of damage index. The grader produced optimum results at take-in conveyor speed of 10 m/min, and grading spool speed of 50 rpm and yielded damage index and grading error as 6.14 and 6.08 % respectively.

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. Grading expenditure of 4, 6 and 12 rupees per 100 kg was worked out for 12, 9 and 6 t/hr throughputs.
Conclusions and Recommendations

1. A high capacity grading machine was developed for sizing of fruits and vegetables like apple, mango, potato and onion at farm level.
2. Different set of operating conditions were required for fruit and vegetables having different shape index.
3. An increase in take-in conveyor speed increased the feed rate that directly affected the grading efficiency of the grading unit at lower grading spool speed.
4. An increase in grading spool speed at the lower speed of the take-in conveyor speed may harm the products due to repeated impacts.
5. Take-in conveyor speed and the grading spool speed were directly linked with each other. Change of either speed affected the working of the other unit for damage index and grading error.
6. Take-in conveyor and grading spools were responsible for producing grading error and damage index, while take-away conveyor had no significant effect on grading error and damage index.
7. Minimum grading error 4.03 % and minimum damage index 3.06 was observed at take-in conveyor speed of 20 m/min and grading spool speed of 50 rpm during potato grading.
8. Minimum grading error 5.44% was observed at take-in conveyor speed of 15 m/min and grading spool speed of 50 rpm. Take-in conveyor speed contributed 42.64% while grading spool speed shared 35.7% to the total grading error during apple grading.
9. Minimum grading error 3.63% and minimum damage index 1.13 were observed at grading spool speed of 50 rpm while take-in conveyor speed of 15 m/min produced minimum value of grading error. Hence take-in conveyor seed of 15m/min and grading spool speed of 50 rpm were suitable for optimum results for onion grading.
10. For mango grading, take-in conveyor speed and grading spool speed had linear effect on damage index. Take-in conveyor speed contributed 76.31% to the total grading error while grading spool speed shared 92.39% to the total damage index. Take-in conveyor speed of 10 m/min and grading spool of 50 rpm produced optimum results for the both damage index and grading error.

11. Continuous feeding of the products at constant rate in shape of mono layer favored the optimum results.
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Appendix-A
Appendix A

Appendix A-1

Design of Angle Bar of Main Frame

Dead load of upper spool unit = 30 kg
Weight of crop on upper spool unit = 15 kg
Weight of angle bar = 6.14 kg
Length of angle bar = 1295 mm
Total weight on angle frame = 75 kg
Steel density = 7850 kg/m³
Total weight on the upper spool unit = 45 kg

Because the spools were supported by two equal sided mild steel angle bars having size 50.8 × 50.8 × 6.35 mm therefore weight on one angle bar: -

Load on one side = 45/2 = 22.5 kg

Total Weight of angle bar itself and load on the spool = 22.5 + 6.14 = 28.64 kg ≈ 29 kg

Factor of safety = 4

Designed load = (weight of crop on spool × factor of safety) + weight of angle bar (22.5 × 4) + 6.14

= 96.14 kg
≈ 97 kg

\( w = \frac{97}{1.295} = 74.9 kg/m \) length

Distance of C₁ along X-axis = \( x_1 = 47.63 \) mm
(From reference axis)

Distance of C₂ along X-axis = \( x_2 = 25.4 \) mm

Distance of C₁ along Y-axis = \( y_1 = 22.23 \) mm
Distance of $C_2$ along Y-axis = $y_2 = 47.63$ mm

Area of bar 1 = $a_1 = 282.26$ mm$^2$

Area of bar 2 = $a_2 = 322.58$ mm$^2$

$x_1 = 47.63$ mm
$x_2 = 25.4$ mm
$y_1 = 22.23$ mm
$y_2 = 47.63$ mm

\[
x = \frac{a_1 x_1 + a_2 x_2}{a_1 + a_2}
\]

\[
x = \frac{282.26 \times 47.625 + (322.58 \times 25.4)}{(282.26 + 322.58)}
\]

\[
x \approx \frac{13442.63 + 8193.53}{604.84}
\]

\[
x \approx \frac{21636.16}{604.84}
\]

\[
x = 35.77 \text{ mm}
\]

\[
y = \frac{a_1 y_1 + a_2 y_2}{a_1 + a_2}
\]
\[
-\bar{y} = \frac{(282.26 \times 22.23) + (322.58 \times 47.625)}{(282.26 + 322.58)} \\
\frac{-y}{604.84} = \frac{6274.64 + 15362.87}{604.84} \\
\bar{y} = 35.77 \text{ mm}
\]

Moment of Inertia about X-axis (centroidal) = \( I_{xx} \)

Distance of \( C_1 \) from \( C = k_1 = \bar{y} - y_1 = 35.77 - 22.23 = 13.54 \text{ mm} \)

Distance of \( C_2 \) from \( C = k_2 = y - y_2 = 35.77 - 47.625 = -11.855 \text{ mm} \)

\[
I_{xx} = I_{C_1} + a_1k_1^2 + I_{C_2} + a_2k_2^2 \\
I_{xx} = \frac{b_1d_1^3}{12} + a_1k_1^2 + \frac{b_2d_2^3}{12} + a_2k_2^2 \\
I_{xx} = (46473.75 + 51747.177 + 1083.94 + 45335.7) \\
I_{xx} = 144640.567 \text{ mm}^4 \\
I_{xx} = 14.464 \text{ cm}^4
\]

Where

\[
b_1 = 6.35 \text{ mm} \\
b_2 = 50.80 \text{ mm} \\
d_1 = 44.45 \text{ mm} \\
d_2 = 6.35 \text{ mm}
\]

Moment of Inertia about Y-axis (centroidal) = \( I_{yy} \)

Distance of \( C_1 \) from \( C \) along x-axis = \( r_1 = x_1 - x \)

= 47.625 - 35.77 = 11.855 \text{ mm}

Distance of \( C_2 \) from \( C \) along x-axis = \( r_2 = x - x_2 \)

= 35.77 - 25.4 = 10.37 \text{ mm}

\[
I_{yy} = I_{C_1} + a_1r_1^2 + I_{C_2} + a_2r_2^2 \\
I_{yy} = \frac{d_1b_1^3}{12} + a_1r_1^2 + \frac{d_2b_2^3}{12} + a_2r_2^2 \\
I_{yy} = 45230.378 + 39669 + 1083.936 + 34689.25 \\
I_{yy} = 45230.378 + 39669 + 1083.936 + 34689.25
\]

Where

\[
b_1 = 44.45 \text{ mm} \\
d_1 = 6.35 \text{ mm}
\]
\[ I_{yy} = 120672.564 \text{ mm}^4 \quad \text{b}_2 = 6.35 \text{ mm} \]
\[ I_{xx} = 12.067 \text{ cm}^4 \quad \text{d}_2 = 50.8 \text{ mm} \]
\[ I_{xx} = 14.464 \text{ cm}^4 \]
\[ I_{yy} = 12.067 \text{ cm}^4 \]
\[ I_{xy} = \sqrt{(I_{xx})^2 + (I_{yy})^2} \]
\[ = \sqrt{(14.464)^2 + (12.067)^2} \]
\[ I_{xy} = 18.836 \text{ cm}^4 \]

\[ M_A = M_B = \frac{wL^2}{12} \]
\[ RA = RB = \frac{wL}{2} \]
\[ M_x \approx \frac{wL^3}{24} \]

\[ y_{max} = \frac{1}{EI} \left[ \frac{wL^4}{384} \right] \]

\[ y_{max} = \frac{74.9(1.295)^4(100)^4}{384(210 \times 10^3)^4} \]
\[ = 1.39 \times 10^{-4} \text{ m} \]
\[ = 0.139 \text{ mm} \]

**Maximum deflection (0.139 mm)** in selected angle bar of the main frame, was calculated when the spool was loaded with 4 times greater than the actual load. This designed load on the angle bar did not produce a marked deflection in angle iron bar. Therefore during normal operation deflection was within the **safe** limit of the design.
Appendix A-2

DESIGN OF SPOOL SHAFT

Total weight of secondary grading unit upper = 30 kg
Weight of one spool = 30/9
            =3.33 kg
Weight of crop on secondary grading unit = 15 kg
Total spools in upper table of secondary grading unit = 9
Weight of crop on one spool = 15/9
            = 1.67 kg
Total weight = 3.33 + 1.67
            = 5 kg
Factory of safety = 4
Designed load (W) = 20 kg
Length of spool shaft = 889 mm
            = 0.889 m
Weight per unit length (w) = 20 /0.889
            = 22.5 kg/meter length

\[ MA = MB = \frac{wL^2}{8} \]
\[
\frac{22.5(0.889)^2}{8} = 2.2227 \text{ kg·m} \\
= 222.27 \text{ kg·cm}
\]

\[I = \frac{h^4}{12}\]

\[I = \frac{(25.4)^4}{12} = 34685.95 \text{ mm}^4\]

\[= 3.468 \text{ cm}^4\]

\[y_{\text{max}} = \frac{5wL^4}{384EI}\]

\[y_{\text{max}} = \frac{5 \times 22.5 \times (0.889)^4 \times (100)^4}{384 \times 210 \times 10^8 \times 3.468} \quad E = 210 \times 10^9 \text{ kg/m}^2\]

\[= 2.51 \times 10^{-4} \text{ m} \]
\[= 0.251 \text{ mm}\]

(Goel and Bahl, 1982)

Selected cross-section of square shaft (25.4 × 25.4 mm) was deflected 0.251 mm with a factor of safety of 4. Therefore during normal operation, the calculated deflection was within the safe limit of the design.
Appendix A-3

DESIGN OF RECTANGULAR BAR
OF
INCLINED SPACE BAR CONVEYOR

Load = 10 kg/meter length
Bars/meter length = 15
Average load on one bar = 10/15 = 0.67 kg ≈ 0.7 kg

Type of load = uniformly distributed load

\[ M = \frac{QL}{8} \]

Q = Total load on a single bar (Kg)
L = Bar length (mm)

One-kilogram product was loaded on the single bar. The bar was 520 mm long, 3 mm thick and 25 mm wide. The bending moment was determined as follows:

\[ M = \frac{0.7 \times 520}{8} \]

= 45.5 kg-mm
= 4.55 kg-cm

Ultimate stress of the material of bar = 4.218 × 10^7 × kg/m^2 (Stanton and Winston, 1977)
Factor of safety = 4
Safe bending stress (S) = 1.055 × 10^7 kg/m^2
\[ = 1.055 \times 10^3 \text{kg/cm}^2 \]
The bar under load was of rectangular cross-section having 25 mm width. Thickness (h) of the bar was determined taking into account bending moment due to the load on the bar, as follows:

\[
M = S.Z \\
0.0455 = 1.055 \times 10^7 \times (25/1000) h^2/6 \\
= 1.0174 \times 10^{-3} \text{ m} \\
h = 1.0174 \text{ mm.}
\]
Mild steel bar thickness required to bear the load rate 10 kg/meter as calculated was 1.0174 mm. But we have used bar having the thickness of 3 mm, which was greater, the calculated one. Hence the design was safe.
Appendix A-4

DESIGN OF CHAIN DRIVE SYSTEM

Designed power = Rated kW × K
Rated Power transmitted to operate the system = 3 kW
Load Factor $k_1 = 1.25$
Factor for distance regulation $k_2 = 1.25$ (for fixed center distance)
Factor for center distance of sprockets $k_3 = 1.25$
Factor for position of sprockets $k_4 = 1$
Lubrication factor $k_5 = 1.5$
Rating factor $k_6 = 1$
Service factor $K = k_1 × k_2 × k_3 × k_4 × k_5 × k_6 = 2.93$
Designed power = Rated power × K

\[ = 3 × 2.93 \]
\[ = 8.79 \text{ kW} \]

Designed power was transferred through the chain drive system on the both output shafts. Hence half of designed power was transmitted through one output shaft of the gearbox.

The driving load on one output shaft of the gearbox was calculated as follows: -

\[ F = \{(8.79/2) 1000/10}\}/\text{pitch line velocity (m/s)} \]

Pitch line velocity was calculated as under: -

Pitch line velocity “$v$” = $\pi D_1 \, n_1/60$  \, m/s

Where “$D_1$” was the Pitch circle diameter of sprocket pinion and was determined as follows: -

\[ D_1 = \text{Pitch/sin (a/2)} \]

Where  \[ a = 360/Z1 \]

$Z1$ (Number of teeth of sprocket on gear box output shaft) = 18

\[ a = 360/18 \]
\[ = 20 \]

Pitch of the sprocket was 12.7 mm and pitch circle diameter was calculated as follows: -
\[ D_1 = \text{Pitch/sin (}\alpha/2) \]
\[ 12.7/ \sin (20/2) \]
\[ = 73.135 \text{ mm} \]

Pitch line velocity \(v = \pi D_1 n_t/60 \text{ m/s} \)
\[ = 2.068 \text{ m/sec} \]

Driving load on one side of gearbox was 212.47 kg.

This driving load was transferred through chain and sprocket, Hence on the basis of driving load and actual breaking load of chain, factor of safety \(N\) was calculated as:

\[ N = \text{Breaking load/actual driving load} \]
\[ N = 2000/212.47 \]
\[ = 9.41 \]

\[ 9.41 > 9.11 \]

Factor of safety \(N\) value was compared with the range as described by GOEL and BAHL, (1982) to check either the design is safe or not. Because the calculated value (9.41) was greater than the table value (9.11) so the design was safe.

Selected chain features were as under:

- **ISO Chain Number**: 08 B
- **Pitch \((p)\)**: 12.7 mm
- **Roller diameter \((d)\)**: 8.51 mm
- **Width between inner plates**: 7.75 mm
- **Transverse pitch \((p_v)\)**: 13.92 mm
- **Breaking load**: 2000 kg
Appendix A-5

DESIGN OF MAIN GEARBOX

A gearbox was designed to transfer power (8.79 kW) to the entire unit through chain drive system. The gearbox was designed to transfer power at right angle with velocity ratio 1. Because both the shafts (input & output) were at right angle in gearbox and miter gears have 18 teeth.

\[ Q_{p1} = Q_{p2} \]

\[ Q_{p1} = \tan^{-1} \frac{1}{VR} \]

\[ VR = 1 \]

\[ Q_{p1} = 45^o \]

Formative number of teeth = \( T_{EG} = T_p \sec Q_{p1} \)

\[ = 18 \sec 45 \]

\[ = 25.46 \]

Form factor for Pinion = \( \gamma'_p = 0.124 - \frac{0.684}{T_{EG}} \)

\[ = 0.124 - \frac{0.684}{25.46} \]

\[ = 0.0971 \] (for \( 14 \frac{1}{2}^o \) composite system)

The miter gears were made of the same material and both were of equal strength.

Torque transmitted was worked out with the following formula:

\[ T = \frac{97303 \times N}{n} \]
Where

\[ T = \text{Torque (Kg-cm)} \]
\[ N = \text{Designed power (kW)} \]
\[ n = \text{Speed (rpm)} \]

Designed power required to operate the entire unit was 8.79 kW and gearbox transferred the designed power at rated speed 540 rpm. Torque worked out was 1583.88 Kg-cm.

Tangential load (N) on gear was calculated by using following formula:-

\[ W_t = \frac{2T}{D_G} \quad \quad \text{D}_G = \text{Diametral Pitch (mm)} \]
\[ D_G = mT_G \]
\[ T_G = T_P = 18 \text{ teeth} \]

\[ W_t = \frac{2T}{mT_G} \]

\[ W_t = \frac{2 \times 1583.88}{m \times 18} \]

\[ W_t = \frac{1759.86}{m} \quad \text{kg} \]

Pitch line velocity \( = v = \frac{\pi D_G N_G}{60} \)
\[ = \frac{\pi mT_G N_G}{60} \]
\[ = 0.51 \text{ m m/sec} \]

Velocity factor was calculated as follows:-

\[ C_v = \frac{6}{6 + v} \]
\[ C_v = \frac{6}{6 + 0.51m} \]
Length of pitch cone element = \( L = \frac{D_g}{2 \sin 45^\circ} \)

\[ \frac{18m}{2 \sin 45^\circ} = 12.73 \text{ m} \quad (m \text{ is module}) \]

Face width \( (b) \) was assumed as 1/3 rd of the length of pitch cone element \( (L) \).

\[ b = \frac{L}{3} = \frac{12.73}{3} = 4.2426 \text{ m} \]

To determine the module following formula was used.

\[ W_t = (\sigma_{op} \times C_v) b \pi m y_p \left( \frac{L - b}{L} \right) \]

Where

\( W_t \) = Tangential load on gear,

\( C_v \) = Velocity factor

\( b \) = Face width, mm

\( m \) = Module, mm

\( y_p \) = Form factor

\( L \) = Length of pitch cone element, mm

\[ W_t = 85 \times \left(\frac{6 - 0.51m}{6 + 0.51m}\right) 4.2426m \frac{22}{7} m 0.0971 \left(\frac{12.7279m - 4.2426m}{12.7279m}\right) \]

\[ m^3 - 20.39m - 239.92 = 0 \]

Above said expression was solved by hit and trail method and found that:
\[ m = 7.3 \text{ mm} \]

\[ b = 4.24 \times 8 = 33.92 \text{ mm} \]

Pitch circle diameter gear \( = mT_G = 8 \times 18 = 144 \text{ mm} \)

Pitch line velocity \( = v = 0.51m = 0.51 \times 8 = 4.08 \text{ m/sec} \)

Tangential load on gear \( = W_t = \frac{1759.86}{m} \)

\[ = \frac{1759.86}{8} \]

\[ = 219.98 \text{ kg} \]

Gear was checked for wear by using following expression.

\[ W_m = \frac{D_p b Q K}{\cos Q p_1} \]

Where

\( W_m = \text{Maximum load for wear, kg} \)

\( D_p = \text{Diametral Pitch mm} \)

\( b = \text{Face width, mm} \)

\( Q = \text{Ratio factor} \)

\( K = \text{Load stress factor} \)
Load stress factor was calculated by using following expression:

\[ K = \frac{(\sigma_{es})^2 \sin \phi}{1.4 \left( \frac{1}{E_p} + \frac{1}{E_G} \right)} \]

Where

\( \sigma_{es} \) = Surface endurance limit (63 kg/mm\(^2\))

\( E_G = E_p \) = Young's modulus for material of gear (8.4 \times 10^3 \text{ kg/mm}^2)

(As miter gears)

\[ K = 0.169 \]

Ratio factor was calculated with the following expression:

\[ Q = \frac{2T_{EG}}{T_{EG} + T_{EP}} = 1 \]

Where

\( T_{EG} = T_G \cdot \text{Sec Qp}_2 \)

\( T_{EP} = T_P \cdot \text{Sec Qp}_1 \)

\( T_{EP} \& T_{EG} = 25.46 \)

\[ W_w = \frac{144 \times 33.94 \times 1 \times 0.169}{0.707} \]

\[ = 219.98 \text{ kg} \]

\( W_w > W_t \)

Since maximum load for wear was much more than tangential load (\( W_t \)) therefore the design was satisfactory from consideration of wear.
Following procedure was adopted to determine the diameter of the gear shaft.

To operate the entire unit a power of 8.79 kW exerted a torque of 1562.75 kg-cm (153306 N-mm) through the gear shaft of the gearbox.

Face width = $4.242 \text{ mm}$  

where $m$ is the module

$$ = 4.2426 \times 7 = 29.698 \text{ mm}$$

Length of pitch cone element $(L) = 12.7279 \text{ m}$

$$ = 12.7279 \times 7 = 89.095 \text{ mm}$$

$$D_p = m T_p$$

$$ = 7 \times 18 = 126 \text{ mm}$$

Mean radius of the gear was determined as follows:

$$R_m = \left( L - \frac{b}{2} \right) \frac{D_p}{2L}$$

$$R_m = \left( 89.095 - \frac{29.698}{2} \right) \frac{126}{2 \times 89.095}$$

$$= 52.5 \text{ mm}$$

Tangential force acting at the mean radius $(W_t) = \frac{T}{R_m}$

$$= \frac{153306}{52.5}$$

$$= 2920.11 \text{ N}$$
Axial force acting on gear shaft \((W_{RH}) = Wt \tan \phi \cdot \sin \theta p_l\)

\[= 2920.11 \tan 14.5 \cdot \sin 45\]

\[= 533.92 \text{ N}\]

Radial force acting on the gear shaft \((W_{RV}) = Wt \tan \phi \cdot \cos \theta p_l\)

\[= 533.92 \text{ N}\]

Bending moment due to \(W_{RH} \& W_{RV}\) was determined as follows:

\[M_1 = W_{RV} \times \text{overhang} - W_{RH} \times Rm\]

Gear overhang = 63.5 mm

\[M_1 = 533.92 \times 63.5 - 533.92 \times 52.5\]

\[= 5873.12 \text{ N-mm}\]

Bending moment due to \(Wt\) was determined as follows:

\[M_2 = Wt \times \text{overhang}\]

\[= 2920.11 \times 63.5\]

\[= 185426.98 \text{ N-mm}\]

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

\[= 185519.97 \text{ N-mm}\]
The gear shaft was subjected to twisting moment \((T)\) and bending moment \((M)\). Therefore equivalent twisting moment was calculated as follows:

\[
Te = \sqrt{T^2 + M^2}
\]

\[= 240666.55 \text{ N-mm}\]

An other expression for equivalent twisting moment was as under:

\[
Te = \frac{\pi}{16} \tau (dg)^3
\]

Where

\(dg = \text{diameter of gear shaft, mm.}\)

\(\tau = \text{Shear stress for the material of gear shaft (45 MPa)}\)

Above said expression was used to determine the diameter of gear shaft \((dg)\).

\[
240666.55 = \frac{22}{7 \times 16} \times 45 (dg)^3
\]

\[dg = 30.08 \text{ mm}\]

Gear shaft of diameter 34 mm was used, which was greater than the calculated value (30.08 mm). Therefore the design was safe.
Appendix-B
V. Pulley

Appendix B-12

R241
R38
R222

38

4.4
Appendix-C
## APPENDIX - C

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
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<td>2</td>
<td>3</td>
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- \( S_{g1} \) - \( S_{g2} \) - \( S_{g3} \)
- \( S_{g4} \) - \( S_{g5} \) - \( S_{g6} \)
- \( S_{g7} \) - \( S_{g8} \) - \( S_{g9} \)

Experimental Layout for determining damage index and grading error at different machine parameters.
Appendix-D
### Appendix D-1

#### Table 1. Damage Index at different machine parameters for potato grading

<table>
<thead>
<tr>
<th>Si (m/min)</th>
<th>Sg (rpm)</th>
<th>Damage Index</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>So₁ 5 m/min</td>
</tr>
<tr>
<td>10</td>
<td>25</td>
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<tr>
<td></td>
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<td>3.44</td>
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<td>75</td>
<td>4.11</td>
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<td>25</td>
<td>3.52</td>
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<td></td>
<td>50</td>
<td>3.14</td>
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<td>75</td>
<td>3.60</td>
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<td>3.06</td>
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<tr>
<td></td>
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<td>3.33</td>
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</table>

#### Table 2. Grading error (%) at different machine parameters for potato grading

<table>
<thead>
<tr>
<th>Si (m/min)</th>
<th>Sg (rpm)</th>
<th>Grading Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>So₁ 5 m/min</td>
</tr>
<tr>
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<td>25</td>
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<td>4.48</td>
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<tr>
<td></td>
<td>75</td>
<td>4.69</td>
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<td>4.46</td>
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<tr>
<td></td>
<td>75</td>
<td>4.46</td>
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<td>4.32</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>4.65</td>
</tr>
</tbody>
</table>

Si = Take-in conveyor speed (m/min)  
Sg = Grading spool speed (rpm)  
So = Take-away conveyor speed (m/min)
Appendix D-2

Table 1. Damage Index at different machine parameters for apple grading

<table>
<thead>
<tr>
<th>Si (m/min)</th>
<th>Sg (rpm)</th>
<th>Damage Index (DI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>So₁ 5 m/min</td>
</tr>
<tr>
<td>10</td>
<td>25</td>
<td>6.55</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>6.43</td>
</tr>
<tr>
<td></td>
<td>75</td>
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<td>5.86</td>
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<tr>
<td></td>
<td>75</td>
<td>6.64</td>
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<td>20</td>
<td>25</td>
<td>6.32</td>
</tr>
<tr>
<td></td>
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<td>5.84</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>6.12</td>
</tr>
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</table>

Table 2. Grading error (%) at different machine parameters for apple grading

<table>
<thead>
<tr>
<th>Si (m/min)</th>
<th>Sg (rpm)</th>
<th>Grading Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>So₁ 5 m/min</td>
</tr>
<tr>
<td>10</td>
<td>25</td>
<td>5.14</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>6.25</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>6.44</td>
</tr>
<tr>
<td>15</td>
<td>25</td>
<td>6.2</td>
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<tr>
<td></td>
<td>50</td>
<td>5.45</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>8.40</td>
</tr>
<tr>
<td>20</td>
<td>25</td>
<td>7.90</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>7.36</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>7.45</td>
</tr>
</tbody>
</table>

Si = Take-in conveyor speed (m/min)
Sg = Grading spool speed (rpm)
So = Take-away conveyor speed (m/min)
## Appendix D-3

### Table 1. Damage Index at different machine parameters for onion grading

<table>
<thead>
<tr>
<th>Si (m/min)</th>
<th>Sg (rpm)</th>
<th>Damage Index (DI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$S_{D1}$ 5 m/min</td>
</tr>
<tr>
<td>10</td>
<td>25</td>
<td>1.33</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>1.27</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>1.52</td>
</tr>
<tr>
<td>15</td>
<td>25</td>
<td>1.30</td>
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<td></td>
<td>50</td>
<td>1.16</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>1.33</td>
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<tr>
<td>20</td>
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<td>1.26</td>
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<td></td>
<td>50</td>
<td>1.13</td>
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<td></td>
<td>75</td>
<td>1.23</td>
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</table>

### Table 2. Grading error (%) at different machine parameters for onion grading

<table>
<thead>
<tr>
<th>Si (m/min)</th>
<th>Sg (rpm)</th>
<th>Grading Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$S_{D1}$ 5 m/min</td>
</tr>
<tr>
<td>10</td>
<td>25</td>
<td>4.4</td>
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<tr>
<td></td>
<td>50</td>
<td>4.65</td>
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<tr>
<td></td>
<td>75</td>
<td>4.75</td>
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<td>3.64</td>
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<td></td>
<td>75</td>
<td>4.41</td>
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<td>4.82</td>
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<tr>
<td></td>
<td>75</td>
<td>3.95</td>
</tr>
</tbody>
</table>

$S_{i}$ = Take-in conveyor speed (m/min)
$S_{g}$ = Grading spool speed (rpm)
$S_{o}$ = Take-away conveyor speed (m/min)
Appendix D-4

Table 1. Damage Index at different machine parameters for mango grading.

<table>
<thead>
<tr>
<th>Si (m/min)</th>
<th>Sg (rpm)</th>
<th>Damage Index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>So₁ 5 m/min</td>
</tr>
<tr>
<td>10</td>
<td>25</td>
<td>6.37</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>6.14</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>7.54</td>
</tr>
<tr>
<td>15</td>
<td>25</td>
<td>6.28</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>6.33</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>7.53</td>
</tr>
<tr>
<td>20</td>
<td>25</td>
<td>6.63</td>
</tr>
<tr>
<td></td>
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<td>6.67</td>
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<tr>
<td></td>
<td>75</td>
<td>7.76</td>
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</table>

Table 2. Grading error (%) at different machine parameters for mango grading

<table>
<thead>
<tr>
<th>Si (m/min)</th>
<th>Sg (rpm)</th>
<th>Grading Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>So₁ 5 m/min</td>
</tr>
<tr>
<td>10</td>
<td>25</td>
<td>5.84</td>
</tr>
<tr>
<td></td>
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<td>6.08</td>
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<tr>
<td></td>
<td>75</td>
<td>6.90</td>
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<td>15</td>
<td>25</td>
<td>7.51</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>7.48</td>
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<td>20</td>
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<td>8.40</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>7.99</td>
</tr>
</tbody>
</table>

Si = Take-in conveyor speed (m/min)
Sg = Grading spool speed (rpm)
So = Take-away conveyor speed (m/min)
Appendix-E
Appendix E-1

Table 1. Analysis of variance for the effect of different machine parameters on damage index for potato.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>2</td>
<td>1.51152</td>
<td>1426.96</td>
<td>0.0001*</td>
</tr>
<tr>
<td>Sg</td>
<td>2</td>
<td>1.41003</td>
<td>1331.15</td>
<td>0.0001*</td>
</tr>
<tr>
<td>S0</td>
<td>2</td>
<td>0.00198</td>
<td>1.87</td>
<td>0.1642*</td>
</tr>
<tr>
<td>Si*Sg</td>
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<td>0.26910</td>
<td>254.04</td>
<td>0.0001*</td>
</tr>
<tr>
<td>Si*S0</td>
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<td>0.00066</td>
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<td>0.6489</td>
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<tr>
<td>Sg*S0</td>
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<td>0.00081</td>
<td>0.77</td>
<td>0.5515</td>
</tr>
<tr>
<td>Si<em>Sg</em>S0</td>
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<td>0.00208</td>
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<td>0.0697</td>
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<td>Error</td>
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<td>0.00106</td>
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<td>Total</td>
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<td></td>
<td></td>
</tr>
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</table>

Si = Take-in conveyor speed (m/min)
Sg = Grading spool speed (rpm)
S0 = Take-away conveyor speed (m/min).

Table 2. Analysis of variance for the effect of treatments on damage index for potato grading.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
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<th>F</th>
<th>Pr &gt; F</th>
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</thead>
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<td>0.26715</td>
<td>252.21</td>
<td>0.0001*</td>
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<tr>
<td>Error</td>
<td>54</td>
<td>0.00106</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Highly significant (α = 0.05)
Computer Programme for DI & ER (SAS Programme)

**Factor Wise Programme**

```sas
OPTIONS LINESIZE = 85;
DATA A;
INPUT R T Si Sg So DI ER;
CARDS;
    -------- (DATA) --------
RUN;
PROC ANOVA;
   CLASSES Si Sg So;
MODEL DI ER = Si Sg Si*Sg So Si*So Sg*So Si*Si*Sg*So;
MEANS Si Sg Si*Sg So Si*So Sg*So Si*Si*Sg*So/LSD;
RUN; QUIT;
```

**Treatment Wise Programme**

```sas
OPTIONS LINESIZE = 85;
DATA A;
INPUT R T Si Sg So DI ER;
CARDS;
    -------- (DATA) --------
RUN;
PROC ANOVA;
   CLASSES T;
MODEL DI ER = T;
MEANS T/LSD;
RUN; QUIT;
```

**Computer Programme for Equation Development**

```sas
OPTIONS LINESIZE = 85;
DATA A;
INPUT R T Si Sg So DI ER;
CARDS;
    -------- (DATA) --------
RUN;
PROC GLM;
   MODEL DI ER = Si Sg So Si*Si Sg*Sg So*So Si*Sg Si*So Si*Sg*So Si*So Si*Si*Sg*So Si*Si*Sg*So Si*Sg*So*So Si*Si*Sg*So*So Si*Si*Sg*So*So Si*Si*Sg*So*So;
MEANS Si Sg So Si*Si Sg*Sg So*So Si*Sg Si*So Si*Sg*So Si*So Si*Si*Sg*So Si*Si*Sg*So*So Si*Si*Sg*So*So Si*Si*Sg*So*So Si*Si*Sg*So*So;
RUN; QUIT;
```

Where,

- Si = Take-in conveyor speed in m/min.
- Sg = Grading spool speed in rpm.
- So = Take-away conveyor speed in m/min
- DI = Damage Index
- ER = Grading Error (%)
Appendix E-2

Table 1. Analysis of variance for the effect of different machine parameters on grading error for potatoes.

<table>
<thead>
<tr>
<th>Source</th>
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<th>MS</th>
<th>F</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>2</td>
<td>0.472527</td>
<td>36.59</td>
<td>0.0001*</td>
</tr>
<tr>
<td>Sg</td>
<td>2</td>
<td>0.490980</td>
<td>38.02</td>
<td>0.0001*</td>
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<td>So</td>
<td>2</td>
<td>0.028558</td>
<td>2.21</td>
<td>0.4494</td>
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<td>81.91</td>
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</tr>
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<td>Si*So</td>
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<td>1.11</td>
<td>0.3600</td>
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<td>Si<em>Sg</em>So</td>
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<tr>
<td>Error</td>
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<td>0.01291</td>
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<td></td>
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<tr>
<td>Total</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
</tr>
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</table>

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

Table 2. Analysis of variance for the effect of treatments on grading error of the grader for potato grading.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.24734</td>
<td>19.16</td>
<td>0.0001*</td>
</tr>
<tr>
<td>Error</td>
<td>54</td>
<td>0.01291</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Highly significant ($\alpha = 0.05$)
Appendix E-3

Table 1. Analysis of variance for the effect of different machine parameters on damage index for apples grading.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>2</td>
<td>1.058</td>
<td>27.39</td>
<td>0.0001*</td>
</tr>
<tr>
<td>Sg</td>
<td>2</td>
<td>2.079</td>
<td>53.86</td>
<td>0.0001*</td>
</tr>
<tr>
<td>So</td>
<td>2</td>
<td>0.011</td>
<td>0.29</td>
<td>0.747</td>
</tr>
<tr>
<td>Si*Sg</td>
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<td>0.621</td>
<td>16.08</td>
<td>0.0001*</td>
</tr>
<tr>
<td>Si*So</td>
<td>4</td>
<td>0.015</td>
<td>0.40</td>
<td>0.809</td>
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<tr>
<td>Sg*So</td>
<td>4</td>
<td>0.185</td>
<td>4.78</td>
<td>0.002</td>
</tr>
<tr>
<td>Si<em>Sg</em>So</td>
<td>8</td>
<td>0.198</td>
<td>5.14</td>
<td>0.0001*</td>
</tr>
<tr>
<td>Error</td>
<td>54</td>
<td>0.0385</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

Table 2. Analysis of variance for the effect of treatments on damage index for apples grading.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatments</td>
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<td>0.4291</td>
<td>11.14</td>
<td>0.0001*</td>
</tr>
<tr>
<td>Error</td>
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<td>0.0385</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* highly significant (α = 0.05)
Appendix E-4

Table 1. Analysis of variance for the effect of different machine parameters on grading error of the grader for apples grading

<table>
<thead>
<tr>
<th>Source</th>
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<th>MS</th>
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<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>2</td>
<td>16.33</td>
<td>22.24</td>
<td>0.0001 *</td>
</tr>
<tr>
<td>Sg</td>
<td>2</td>
<td>13.65</td>
<td>18.62</td>
<td>0.0001 *</td>
</tr>
<tr>
<td>So</td>
<td>2</td>
<td>0.1181</td>
<td>0.16</td>
<td>0.852</td>
</tr>
<tr>
<td>Si*Sg</td>
<td>4</td>
<td>7.5561</td>
<td>10.31</td>
<td>0.0001 *</td>
</tr>
<tr>
<td>Si*So</td>
<td>4</td>
<td>0.1612</td>
<td>0.22</td>
<td>0.926</td>
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<tr>
<td>Sg*So</td>
<td>4</td>
<td>0.1946</td>
<td>0.27</td>
<td>0.899</td>
</tr>
<tr>
<td>Si<em>Sg</em>So</td>
<td>8</td>
<td>0.2464</td>
<td>0.34</td>
<td>0.948</td>
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<tr>
<td>Error</td>
<td>54</td>
<td>0.7329</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

Table 2. Analysis of variance for the effect of treatments on grading error of the grader for apples grading

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Pr &gt; F</th>
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</thead>
<tbody>
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<td>3.6041</td>
<td>4.92</td>
<td>0.0001 *</td>
</tr>
<tr>
<td>Error</td>
<td>54</td>
<td>0.7329</td>
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<td></td>
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<td></td>
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</table>

* highly significant (α = 0.05)
Table 1. Analysis of variance for the effect of different machine parameters on damage index for onions grading

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
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<th>F</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>2</td>
<td>0.20495</td>
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</tr>
<tr>
<td>Sg</td>
<td>2</td>
<td>0.19148</td>
<td>1260.98</td>
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<tr>
<td>So</td>
<td>2</td>
<td>0.00030</td>
<td>1.98</td>
<td>0.1475</td>
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</tr>
<tr>
<td>Si*So</td>
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<td>0.00009</td>
<td>0.61</td>
<td>0.6602</td>
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<tr>
<td>Sg*So</td>
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<td>0.00111</td>
<td>0.73</td>
<td>0.5770</td>
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<tr>
<td>Si<em>Sg</em>So</td>
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<td>0.0866</td>
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<tr>
<td>Error</td>
<td>54</td>
<td>0.00015</td>
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<tr>
<td>Total</td>
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<td></td>
</tr>
</tbody>
</table>

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

Table 2. Analysis of variance for the effect of treatments on damage index for onion.

<table>
<thead>
<tr>
<th>Source</th>
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<tr>
<td>Treatments</td>
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<td>0.03627</td>
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<tr>
<td>Error</td>
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<td>0.00015</td>
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<tr>
<td>Total</td>
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<td></td>
</tr>
</tbody>
</table>

* highly significant (α = 0.05)
Appendix E-6

Table 1. Analysis of variance for the effect of different machine parameters on grading error of the grader for onions grading

<table>
<thead>
<tr>
<th>Source</th>
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<th>MS</th>
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<tr>
<td>Si</td>
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<td>1.1268777</td>
<td>3524.21</td>
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<tr>
<td>Sg</td>
<td>2</td>
<td>1.1650259</td>
<td>3643.52</td>
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</tr>
<tr>
<td>So</td>
<td>2</td>
<td>0.0001037</td>
<td>0.32</td>
<td>0.7244</td>
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<tr>
<td>Si*Sg</td>
<td>4</td>
<td>1.5659926</td>
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<tr>
<td>Si*So</td>
<td>4</td>
<td>0.0002648</td>
<td>0.83</td>
<td>0.5131</td>
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<td>Sg*So</td>
<td>4</td>
<td>0.000974</td>
<td>3.05</td>
<td>0.0246*</td>
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<tr>
<td>Si<em>Sg</em>So</td>
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<td>0.23</td>
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<tr>
<td>Error</td>
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<td>0.00032</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

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

Table 2. Analysis of variance for the effect of treatments on grading error of the grader for onions grading.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
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</thead>
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<tr>
<td>Error</td>
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</tr>
<tr>
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<td></td>
<td></td>
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</tbody>
</table>

* highly significant (α = 0.05)
Appendix E-7

Table 1. Analysis of variance for the effect of different machine parameters on damage index for mangoes

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
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<tbody>
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<td>Si</td>
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</tr>
<tr>
<td>Sg</td>
<td>2</td>
<td>12.5466</td>
<td>618.66</td>
<td>0.0001*</td>
</tr>
<tr>
<td>So</td>
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<td>0.00119</td>
<td>0.06</td>
<td>0.9432</td>
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<tr>
<td>Si*Sg</td>
<td>4</td>
<td>0.07606</td>
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<td>0.0092</td>
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<tr>
<td>Si*So</td>
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<td>0.00315</td>
<td>0.16</td>
<td>0.9597</td>
</tr>
<tr>
<td>Sg*So</td>
<td>4</td>
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<td>0.9716</td>
</tr>
<tr>
<td>Si<em>Sg</em>So</td>
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<td>0.04</td>
<td>1.000</td>
</tr>
<tr>
<td>Error</td>
<td>54</td>
<td>0.02028</td>
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<td></td>
</tr>
<tr>
<td>Total</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

Table 2. Analysis of variance for the effect of treatments on damage index for mango.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
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<th>F</th>
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</thead>
<tbody>
<tr>
<td>Treatments</td>
<td>26</td>
<td>1.051067</td>
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<td>Error</td>
<td>54</td>
<td>0.02028</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

*Highly significant (α = 0.05)
### Appendix E-8

Table 1. Analysis of variance for the effect of different machine parameters on grading error for mangoes.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
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<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>2</td>
<td>38.7946</td>
<td>305.81</td>
<td>0.0001*</td>
</tr>
<tr>
<td>Sg</td>
<td>2</td>
<td>3.77012</td>
<td>29.72</td>
<td>0.0001*</td>
</tr>
<tr>
<td>So</td>
<td>2</td>
<td>0.15043</td>
<td>1.19</td>
<td>0.3133</td>
</tr>
<tr>
<td>Si*Sg</td>
<td>4</td>
<td>7.55804</td>
<td>59.58</td>
<td>0.0001*</td>
</tr>
<tr>
<td>Si*So</td>
<td>4</td>
<td>0.24377</td>
<td>1.92</td>
<td>0.1201</td>
</tr>
<tr>
<td>Sg*So</td>
<td>4</td>
<td>0.21715</td>
<td>1.71</td>
<td>0.1608</td>
</tr>
<tr>
<td>Si<em>Sg</em>So</td>
<td>8</td>
<td>0.10521</td>
<td>0.829</td>
<td>0.5807</td>
</tr>
<tr>
<td>Error</td>
<td>54</td>
<td>0.12686</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

Table 2. Analysis of variance for the effect of treatments on grading error of the grader for mango grading.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
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<th>Pr &gt; F</th>
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</thead>
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<td>4.55183</td>
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<td>0.0001*</td>
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<tr>
<td>Error</td>
<td>54</td>
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<td></td>
</tr>
<tr>
<td>Total</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Highly significant (α = 0.05)
Appendix-F
Appendix-F

Economics of the Grader

Manufacturing price of the machine = Rs. 250000/-
Expected life of the grader = 10 years (2500 hrs)
Salvage value = 10% of the capital price

Fixed Cost

Depreciation

\[ D = \frac{(P - S)}{L} \]

Where

\[ D = \text{depreciation} \]
\[ P = \text{purchase price} \]
\[ S = \text{salvage or selling price} \]
\[ L = \text{expected life or time between buying and selling, yrs} \]

\[
\begin{align*}
\text{Depreciation} & = \frac{(250000 - 25000)}{10} \\
& = \text{Rs. 22500/-}
\end{align*}
\]

Interest @ 12%

\[
\begin{align*}
& = 0.12(250000 + 25000)/2 \\
& = \text{Rs. 16500/-}
\end{align*}
\]

Taxes, insurance and shelter @ 2%

\[
\begin{align*}
& = 250000 \times 0.2 \\
& = \text{Rs. 5000/-}
\end{align*}
\]

Total fixed cost per year = Rs 44000/-

Fixed cost per hour = 44000/250

= Rs. 200/hr

Variable cost

Repairs @ 15%

\[
\begin{align*}
& = 250000 \times 15/100 \\
& = \text{Rs. 37,500}
\end{align*}
\]

Repair per hr

\[
\begin{align*}
& = 37500/2500 \\
& = \text{Rs 15/hr}
\end{align*}
\]
Total cost = 200 + 15
(Fixes cost + variable cost) = Rs. 215/-

For tractor (MF-210)

Purchase price = Rs 200,000/-
Expected life = 10 years (10,000 hrs)
Salvage value = 200,000 x 0.10
= Rs 20,000/-

Fixed Cost
Depreciation, D = (P-S)/L
= (200,000-20,000)/10
= Rs 18,000/-
Interest @ 12%
= 200,000 x 0.12
= Rs 24,000/-
Taxes, Insurance
and shelter @ 2%
= 200,000 x 0.02
= Rs 4,000/-
Total fixed cost = Rs 46,000/-
Total fixed cost
per hour = 46000/1000
= Rs 46/-

Variable Cost
Repair @ 15%
= (200,000 x 0.15)/10,000
= Rs 3/-
Fuel @ 3L/hr
= 35 x 3
= Rs 105/hr
Lubricants
= 105 x 0.15
(@ 15% of fuel cost)
= Rs 15.75
Total variable cost = Rs 123.75
                   = Rs 124/-

Total cost = 46 + 124
(Fixed cost + Variable cost)/hr
           = Rs. 170/-

For diesel engine (12hp)

Fixed Cost

Purchase price = Rs. 25,000/-
Expected life = 10 year (5000 hrs)
Depreciation = (25000 - 2500)/10
              = Rs. 2250/-
Interest = 0.12 (25000 + 2500)/2
@ 12%
          = Rs 1650/-
Taxes, Insurance = 0.02 (25000)
and shelter @ 2%
                 = Rs. 500/-
Total fixed cost = Rs. 4400/-
Fixed cost/hr = 4400/500
              = Rs 8.80

Variable Cost

Repair @ 15% = (25,000 x 0.15)/5 000
              = Rs. 0.75
Fuel @ 1.5L/hr = 35 x 1.5
                = Rs 52.50/hr
Lubricants = 52.50 x 0.15
@ 15% of fuel cost
= Rs. 7.88

Total variable cost = Rs. 61/-

Total cost/hr = 8.80 + 61

(Fixed cost + Variable cost)

= Rs. 70/hr

**Labour Charges**

Labour (four laborer) = Rs.600/day

(@ Rs, 150/day for each)

Labour charges /hr = 600/8

= Rs. 75/hr

Operational Cost of the grader (with tractor)

= 215 + 170 + 75

= Rs. 460/hr

Operational Cost of the grader (with diesel engine)

= 215 + 70 + 75

= Rs. 360/hr

**Grading Cost**

**For potatoes**

Theoretical throughput of the grader = 12 t/hr

(At take in conveyor speed, Si3)

Actual machine throughput = (12000x 80)/100

(80% machine capacity).

= 9600kg/hr

Price of a bag (100kg) un graded potatoes = Rs.2000/bag

Average price of graded potatoes = Rs 2080/bag

(Different grades have different price)

Profit/100 kg = Rs. 80/-

Expenditure /100 kg = Rs. 5/-

(When the grader was operated with tractor)

Net profit /100 kg = Rs. 75/-
Expenditure /100 kg = Rs. 4/-
(When the grader was operated with diesel engine)

Net profit /100 kg = Rs. 76/-
An average yield of potatoes /ha = 18000 Kg
Net profit/ha = (18000/100)75
= Rs 13500/ha

A farmer can earn Rs 13500/- more, from a hectare with grading the potatoes and similar trend in profit was also observed in case of the other crops being graded.