EVALUATING MECHANICAL DAMAGE OF FRESH POTATO DURING HARVESTING AND POSTHARVEST HANDLING

By

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To my wife, Chionetsero; my daughter, Chilungamo; and my son, Watipatsa

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LIST OF ABBREVIATIONS

a	Radius of permanent indentation
F	Impacting load
IRD	Impact Recording Device
IS	Intrumented Sphere
R	Radius of impacting sphere
D	Central indentation
G	Maximum acceleration (force of impact)
H	Drop height
h_2	Rebound height
E_{ab}	Energy absorbed by a fruit or vegetable
E	Coefficient of restitution
W	Weight
CI	Confidence interval
p	Sample proportion

Abstract of Thesis Presented to the Graduate School
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Mechanical damage is a major concern for the potato industry worldwide. Mechanical damage reduces the income for the farmer and retailers as well as the quality of the processed potato food products. Many factors affect postharvest potato mechanical damage and these are either pre harvest or postharvest. Reducing mechanical damage in potato postharvest handling systems requires identification of the contributing factors and investigation of potato bruise thresholds. A study was carried out to identify mechanical damage causing elements in the harvest and postharvest operations and investigate the bruise thresholds for Fabula and Yukon Gold cultivars. Samples were collected for damage assessment from the top and bottom of the regular wagon, bottom of inverted V supported wagon; and after dumping, before grading and after grading on the packing line. External and internal damage was assessed one day and four days after harvest respectively. Samples for the simulations of potato drops were hand dug from the field. Two tests were conducted; one day after harvest and one week after harvest. Tubers were dropped from each of the following drop heights; 30, 60, 90, 120, and 150 cm to simulate commercial drop heights, and their damage assessed.

The study found five types of mechanical damage during harvesting and packing operations: skinning, external shatter, cuts, internal shatter and black spot. The major damage was skinning. The main source damage was the harvesting operation. Dumping was responsible for skinning and internal shatter. The inverted V wagon reduced skinning but increased external shatter and black spot. Yukon Gold was more resistant to damage than Fabula. Laboratory drop simulations gave three types of damage: external shatter, internal shatter and black spot. Damage for was detected at drop heights above 90 cm and 30 cm for Fabula and Yukon Gold, respectively. Damage incidences generally increased with height, and damage changed from black spot to external shatter for Fabula. Shatter and black spot damage were associated with low and high water content respectively for Yukon Gold.

CHAPTER 1
LITERATURE REVIEW

1.1 Introduction

The potato is the fourth most important food crop in the world after wheat, maize and rice with 311 million tons produced from 19 million hectares at an average fresh weight yield of 16.4t/ha with range from 2 to 44t/ha by country (FAO, 2003). As well as being a staple food, the potato is grown as a vegetable for table use, is processed into French fries and chips (crisps) and is used for dried products and starch production. The importance of the potato as one of the world's major staple crops is increasingly being recognized because it produces more dry matter (DM) and protein per hectare than major cereal crops (Burton, 1989). In countries where food security has been achieved, the potato industries are putting more emphasis on yield of saleable product at less cost production among other objectives. These objectives will be met through many production practices, including better post-harvest handling, that influence global production and distribution.

Mechanical damage in agricultural produce is considered to be the product of mechanization. Mechanical damage not only reduces the income for potato farmers and retailers but also reduces the quality of the processed potato food products. Reducing mechanical damage during harvesting and packing operations will both reduce the loss of income and increase the quality of the processed potato food products. Mechanical damage during harvesting and packing operations of potatoes can be reduced in two steps; identifying the bruise causing components on these operations and investigating bruise thresholds forces to improve the bruising causing components. These are the goals of this study.

Potato mechanical injuries are classified into skinning, shatter bruise, black spot and pressure bruise. Skinning (abrasion) is an injury in which areas of the tuber periderm are rubbed off, giving the tuber a scuffed or feathered appearance. Shatter bruise is the result of mechanical impact which causes splitting or cracking of the potato. The splitting may be on the surface or inside of the potato. Black spot is an internal discoloration resulting from impact that damages cells in the tissue beneath the periderm. Pressure bruise is the flattening or depression of the tuber surface formed as a result of external pressure at a point of contact with another tuber, storage equipment, or storage structure. The fifth type of mechanical injury, cut, is not much talked about in the literature. Cut is penetration or division by a sharp edge of an object.

1.2 Mechanical Damage of Potatoes during Harvesting and Packing Operations

Mechanical damage during postharvest handling is a major concern for the potato industry worldwide. Consumer requirements for fresh market potatoes are often associated with visual characteristics such as shape and appearance of the tuber with freedom from defects and disorders. Defects resulting from harvest and handling – damage and bruising, distract from crop quality for all markets. In addition to visible internal or external damage which lowers the eating quality of the potato, shock and impact during mechanical handling can also stimulate sprouting which reduce viability of the tuber as seed potato (Klap, 1945).

In the USA, Preston and Glynn (1995) reported 6.3% value loss of the potato crop through damage. Volbracht and Kuhnke (1956) reported that during the storage period about 10 to 12% of potatoes are lost through shrinkage and rotting. The major part of this loss is said to be attributed to mechanical damage. Nylund et al. (1955) reported a total potato loss due to mechanical damage of 26.4% during field harvesting and subsequent handling operations. Skinning was the major type of damage and it was estimated that 15% of the skin was removed by the time the potatoes reached storage bins. Slightly skinned tubers heal with proper storage with no long term problems but increased shrinkage occurs in the tubers and early and late blight infection sometimes occurs. Moderate and severe bruises usually result in grade losses either from the bruise itself or later dry rot infection. Zahara et al. (1961) found that as much as 40 to 50% potato mechanical damage occurs before reaching the packing shed. Brook (1996) estimated that a 1% reduction in impact damage was worth approximately $7.5 million annually for the US potato industry.

1.2.1 Causes of Mechanical Damage

Mechanical damage in agricultural products is due either to external forces under static or dynamic conditions or internal forces. The forces can be the result of physical changes such as variation in temperature, moisture content, chemical and biological changes or handling. How mechanical damage occurs is a problem which has not yet been fully investigated for most causes. In regard to agricultural products, a further complication arises from the fact that no satisfactory criterion of failure is available for these materials. In intact agricultural products, failure is usually manifested through a rupture in the internal or external cellular structure of the material (Mohsenin, 1980).

Finney (1963) found that compression of the whole potato tuber produced an internal injury very similar to black heart (caused by the deficiency of oxygen in the interior of the potato). According to Wiant et al. (1951) black spot in potato is due to mechanical injury to tissues by impact. A chain analysis of ware (storage) potato in the Netherlands (Molema et al., 2000) showed that 78% of the total amount of subcutaneous tissue discoloration was caused by impacts. Muir and Bowen (1994) showed that no single skin characteristic was related to skin strength, except that the strength of the skin was always related to its thickness. Baritelle et al. (2000) described the influence of tuber properties on the types of impact damage as follows:

- impact results in deformation or in friction on the tuber and these are associated with tuber firmness;
- skin breakage and removal resulting from action of friction lead to scuffing damage and are associated with the skin strength and adhesion;
- cell wall fracture resulting from deformation of the tuber leads to internal shatter and crash (no skin breakage), and/or splitting and cracking (skin breakage) and this is associated with internal tissue strength;
- membrane damage resulting from deformation of the tuber leads to black spot and is associated with starch and membrane properties;
- pigment formation (melanin) resulting from deformation of the tuber leads to black spot and is associated with Tyrosine and phenolase.

Some researchers have attributed black heart and black spot to the action of static and dynamic forces in mechanical injury (Mohsenin, 1980). Hyde et al. (1992) reported that impacts above 100 g have more potential to cause potato damage than impacts below 50 g. Mathew & Hyde (1992) reported zero damage for 250±50 gram Russet Burbank tubers dropped onto a steel plate at drop heights of 25, 30 and 50 mm (corresponding to a peak acceleration of 69, 81 and 122 g) at tuber temperatures of 10, 15.5 and 21^{o}C respectively.

The point where the greatest damage to potatoes commonly occurs during harvesting is at the transfer between harvester and trailer (Maunder et al., 1990). Sargent et al. (1990) reported that highest impacts generally occurred at transfer points on tomato and bell pepper packing lines where there were vertical drops or unobstructed rolls onto metal or wood plates transfer points and where there were rolls down steep inclines onto rollers conveyors. Molema et al. (2000) found 340 impacts exceeding 30 g in different phases of representative Dutch ware potato handling chains using an instrumented sphere (IS) data logger. The contribution to the total number of impacts was 11% for Harvest, 0% for Storage, 10% for Transport and 79% for Packaging.The main types of damage together with their main causes are listed in the Table 1-1.

1.2.2 Bruise Prevention

Bruising does not begin with the harvester, there are many factors before harvest that can reduce or increase potato bruising. The following pre harvest factors have been reported to affect potato bruising during harvesting and postharvesting (San Luis Hills Farm, 2009):

- tuber maturity; good tuber maturity and skin set is paramount in harvesting bruise free potatoes. A good vine kill and allowing tubers to set skin long enough and not too much late nitrogen affect tuber maturity;
- plant potassium levels; good potassium levels reduces bruising;
- soil clods; are a problem in potato harvest because equipment or machine elements designed to get rid of clods can bruise potatoes (Shakers and rollers);
- field moisture; important so soil falls away from tubers as desired.

Shatter bruise is associated with immature tubers, hydrated tubers and low pulp temperatures while Black Spot is associated with over mature tubers and dehydrated tubers. The harvester and digger are main source of tuber bruising. About 30% of bruising is reported to occur after the harvester. The following are practices recommended to reduce bruise during harvest (San Luis Hills Farm, 2009):

- managing nitrates so soil and petiole nitrates drop before harvest for mature tubers;
- harvesting when tubers pulp temperature is 50–65^{o}F (10–18^{o}C);

- keeping all drops below 6–8 inches (15–20 cm);
- padding all surfaces. 3/4–1" (2–2.5 cm) of padding will cushion a 12" (30 cm) drop;
- adjusting chain speeds to keep chains full and avoid pile-ups and rollback-matching chain and ground speed to avoid bulldozing or not enough dirt and tubers on chains;
- using Hugger belts to prevent roll back and matching hugger belt speed to elevator belt below or hugger belt will skin potatoes;
- adjusting digging blades so tubers flow onto the primary chain and not into the blade;
- avoiding fast changes in tuber pulp temperature;
- using shakers only when necessary;
- dropping deviner chain onto the secondary chain to avoid back bouncing;
- looking for sharp edges and covering them with belts;
- using belted full width chain if possible. Also using belt deflectors to keep potatoes off chain links and edges of chains. Maintaining detectors since they wear out;
- Training harvester operators to minimize drops into the trucks which can be a major source of bruising.

Bruise testing during harvest at various points in the harvest operation is a very useful tool to identify and prevent tuber bruising. (San Luis Hills Farm, 2009)

1.3 Simulation of Potato Bruise Impact (Impact Test)

The most important bruise factor in every case is the loading extent, which is usually expressed in the terms of loading energy or absorbed energy (Holt, 1977; Mohsenin, 1980) reported that experiments with falling fruits striking hard flat surfaces produced results similar to colliding metal spheres. Impact testing is testing an object's ability to resist high-rate loading. An impact test is a test for determining the energy absorbed in fracturing a test piece at high velocity. Impact resistance is one of the most important properties for agricultural and biological materials, and without question, the most difficult to quantify. There are basically two types of impact tests: pendulum and drop weight (Instron, 2009)

1.3.1 Pendulum Testing

The swing pendulum is one the first methods used to test materials' abilities to resist high-rate loading (Instron, 2009). A pendulum of a known weight is hoisted to a known height on the opposite side of a pivot point. The pendulum falling from a set height possesses a certain amount of impact energy at the bottom of the swing. By clamping or supporting a specimen on the bottom, the pendulum can be released to strike and break the specimen. The pendulum will continue to swing up after the break event to a height somewhat lower than that of a free swing. The lower final height point is used to calculate the energy that was lost in breaking the specimen. Hemmat (1987) reported that impact energies are not dependent on the mass of a fruit in pendulum impactor method. Thus, this method is more appropriate for researching the susceptibility of fruit to internal damage and is more useful in making comparisons between fruits of different mass, density or shape. Fluck and Ahmed (1973) and Molema (1999) also mentioned that the pendulum impactor has the advantage that impacts energy can be quantified.

1.3.2 Drop Weight Impact Test

A second method is to drop a weight or a specimen in a vertical direction, with a tube or rails to guide it during the "free fall." Once again, with the height and weight known, impact energy can be calculated. There must be very low friction in the guide mechanism. Falling weight testing is a better simulation of functional impact exposures, and therefore closer to real-life conditions (Instron, 2009).

1.4 Impact Damage Thresholds for Fresh Potatoes

One of the most common causes of mechanical damage to agricultural products is shock and impact during mechanical handling. Some of the most common theories developed for failure of engineering materials are the maximum stress theory, maximum strain, the maximum shear theory, and maximum energy theory. When bodies collide, work is done by the normal contact force during separate phases of compression and restitution. During compression, the normal contact force does work on the deformable body; and this work deforms the body and raises the internal energy of the body. Part of the energy absorbed during compression of the body is recoverable during restitution; the recoverable part is known as elastic strain energy. The square root of the ratio of elastic strain energy released during restitution to the internal energy of deformation absorbed during compression is known as coefficient of restitution, e. The coefficient of restitution for a soft body bouncing onto a hard stationary surface is just the square root of the ratio of bounce height and drop height or simply the ratio of the velocities before and after the collision.

Fluck & Ahmed (1973) showed that bruising results from a complex relationship between acceleration force, velocity change and impact duration, all of which have to be considered. For impacts on a hard surface, the impact curve is characterized by high peak acceleration and short impact duration. For impacts on padded surfaces, the peak acceleration is lower but the duration is longer and therefore the resulting velocity change is larger (Molema et al., 2000). Bowden and Tabor (1954) divided the impact of colliding bodies into four phases; initial elastic deformation, onset of plastic deformation, full plastic deformation and elastic rebound. If the impact is not purely elastic, the kinetic energy is converted into permanent deformation of the material and eventual dissipation of this energy in the form of heat (Mohsenin, 1980). Goldsmith (1960) reported that for a sufficiently shallow indentation of predominately plastic character where deformations in the plane surface outside the region of contact are assumed absent, the radius of permanent indentation, a, and the central indentation, D, can be related by the relationship in equation (1).

$$a^2 \approx 2R_1D. \tag{1-1}$$

R_1 is the radius of the impacting sphere. When the deformation outside the region of contact is not negligible, the relationship is given by equation (2)

$$a^2 = R_1D. \tag{1-2}$$

Tabor (1951) showed that the total elastic energy, which is equal to the rebound energy, can be given by equation (3)

$$W=m_1gh_2 = 3/10(F^2/a)A \tag{1-3}$$

where

h_2 is height of rebound, m_1g is the weight of the free falling sphere, F is impact load and A is a function of Poisson's ratio and modulus of elasticity of the contacting spheres.

Many researchers use data loggers designed to quantify impacts. The Impact Recording Device (IRD) (Techmark-inc, 2009) is one such device to measure impact forces on fruits and vegetables. It was formerly called the Instrumented Sphere. The IRD is initiated from PC software and identifies the location and severity of impacts delivered to produce as it is handled. The IRD is transferred through machinery and equipment *in situ,* with the flow of fruit or produce, to experience the same bumps and bruises. Maximum acceleration and velocity change data is collected, stored on-board and later uploaded to a PC for interpretation and report generation. IRD software includes damage boundaries for various types of produce for comparison standards. Severity of impacts is calculated using both maximum acceleration (G) and velocity change (m/s) for each impact. Impacts can be monitored during loading and unloading, mechanical or hand harvesting, flume or mechanical conveying, washing, waxing, processing and packing procedures to determine location and severity of costly damage and bruise. The force and velocity change are both important in measuring impact forces on fruits and vegetables. Each fruit and vegetable has unique characteristics, which determine how it will respond to impact forces on various surfaces. Research has determined that the severity and frequency of bruise damage depends on 2 important criteria; Force (or maximum acceleration) of the impact (G) and Duration (or velocity change) of the impact (m/s). Force (G) measurements alone do not accurately predict severity or likelihood of bruise damage. The response curves shown in Figure 1-1 are typical for most fruits and vegetables that have been investigated. The Damage Boundary is not flat with respect to force (G). In Figure 1-1, the 2 impacts, A and B, are on opposite sides of the damage boundary. Impact A will cause more severe damage than impact B. (Techmark-inc, 2009)

1.5 Mechanical Damage Detection and Evaluation/Assessment

Physical damage to plant tissue is followed often by physiological responses. These responses include localized increased respiration at the site of injury, stress ethylene production, accumulation of secondary metabolities, and cellular disruption leading to decompartmentalization of enzymes and substrates (Rolle and Chism, 1987). Potato tissue responds to physical injury by initiating a number of biochemical and physiological changes. Belknap et al. (1990) reported a large transient increase in phenylalanine ammonia lyase (PAL) activity in bruised potatoes, the maximum PAL activity was observed 48 hrs after bruise induction. Bruises may not show up under normal conditions after harvest until 3–4 days later (Melrose and Mac Rae, 1987). Belknap et al. (1990) reported that initial discoloration of potatoes appears in approximately 4 hours. Completion of the reaction requires about 24 hours. Blahovec (2005) reported that a discoloration in the bruised tuber tissues appears within 48 hours for tubers stored at 10–20°C after damage. He also reported that black-spots occur in warmer more flaccid tubers, especially if potassium is deficient; and are associated with lower damaging drop heights (lower impact velocities).

Detection and evaluation of mechanical damage, particularly if the damage is invisible, can become a problem requiring special techniques and instrumentation. The usual methods of evaluation are primarily descriptive. Non destructive methods for detecting and evaluating internal defects in fruits and vegetables include x-ray, light transmittance, light absorption, ultrasonic and pulse techniques, and electrical impedance. The simplest way of describing the bruise spot shape is the relation of its thickness (depth) to its maximum diameter. This ratio was termed bruise spot ratio (Blahovec, 2004). In most cases the maximum diameter of the bruise spot is located close to the tuber vascular ring, (Blahovec, 2005). Timofeev (1956) described a method for assessing mechanical damage to fruits and vegetables resulting from impact which considered potential energy, energy consumed, and rebound of the impacting product.

$$E_{ab}=(1 - e^2)WH \qquad (1\text{-}4)$$

Where

e is the coefficient of restitution and W and H re respectively weight and height of drop of impacting fruit or vegetable.

Another method for evaluating mechanical damage is measuring rate of respiration by the damaged tissue in the fruit and vegetable. Stiles and Leach (1961) established that wounding of living plant tissue results in an increased respiration rate. The most popular damage assessment system used in UK is the Damage Index (Robertson, 1970), which has the merit in that it:

- is simple to carry out in the field or store;
- takes 25, 50 or 100 tubers at random from a sample and divides them visually into four categories; severe damage >1.5 mm deep; peeler damage 0–1.5mm deep; scuff damage to skin and undamaged;
- converts the percentages of tuber placed in the three damage categories into a single figure or ‘index’ suitable for use in the experimental correlation with the other parameters (e.g. disease development versus damage index);
- gives an index for a sample, which related to the weight of the tissue (pulp) that has to be removed to obtain a potato free from any marks when they are peeled.

Another method of evaluating bruise involves soaking tubers in a catecol solution (20 g. catecol in 3 gals. water) for 1 minute; letting them sit for 3 minutes and then peeling the tubers. Bruises show up as red cracks and marks. The more peels it takes to remove the red, the worse the bruise. Then tubers are sorted according to bruise severity: one peel to remove - slight, 2 peels - moderate, 3 or more - severe. Skinning also shows up red before tubers are peeled. The USDA Visual Aid Potatoes Official Manual and the United State Standards for Grades of Potatoes classify skinning, cuts and internal black spot as in Table 1.2 and Table 1.3. In the absence of standards, researchers have often designed their own scale for detection and evaluation of mechanical damage. Austin and Dedolph (1962) concluded that in studies of apple bruising, damage should be estimated by both diameter and depth of bruises and the volume calculated using the formula for a segment of the sphere together with measured values of maximum depth and maximum width of the bruise. Zahara et al. (1961), classified mechanical damage as follows; cracks between ½ inch (1.3 cm) and 1 ½ inches (3.8 cm) long and those with medium sized bruises were classified as moderate injury. Tubers with cracks longer than 1 ½ inches and those with severe bruises were classified as severely injured.

Many studies have been carried out on potato mechanical damage. Most of these studies have concentrated on the stored potatoes. These data cannot be used in the handling of fresh potatoes since potatoes are living tissues that are subject to continuous change after harvest and the impact forces they experience during harvesting and packing operations are different those experienced in storage. Above all, the reaction of potatoes to impact forces may depend in addition to harvesting and postharvest factors; variety of the potato, growing conditions and pre-harvest practices. Therefore there is need for studies to investigate the different fresh potato handling systems. The main objectives of this research work were:

- identify the components which contribute significant mechanical damage in harvesting and packing operations;
- investigate the mechanical damage impact threshold for fresh potatoes.

Table 1-1. Types of potato damage and the causes during harvesting (San Luis Hills Farm. 2009)

Type of damage	Causes: Field	Causes: Harvester operation	Causes: Handling from harvester to store
Split	Pressure on ridge.	Excess speed on harvester webs.	Drop into trailer. Discharge into elevator hopper.
Squash	Pressure on ridge.		Discharge into elevator hopper.
Slice		Disc/share setting.	
Scuff	Stones and hard clods.	Excess speed on harvester webs.	Mismatched hoppers and conveyors.
Cut	Stones and hard clods.	Excess speed on harvester webs	Projections on machinery.
Hole or Indentation		Projections on machinery.	Projections on machinery. Leveling pile surface.
Internal bruise	Pressure on ridge and Stones and hard clods.	Excess speed on harvester webs.	Drop into trailer and boxes. Discharge into elevator hopper. Drop on to pile; roll down face of pile.

Table 1-2. USDA classification skinning damage for potatoes

Skin rating	Definition
Practically no skinning	Not more than 5 percent of the potatoes in the lot have more than one-tenth of the skin missing or "feathered;"
Slightly skinned	Not more than 10 percent of the potatoes in the lot have more than one-fourth of the skin missing or "feathered;"
Moderately skinned	Not more than 10 percent of the potatoes in the lot have more than one-half of the skin missing or "feathered;"
Badly skinned	More than 10 percent of the potatoes

Table 1-3. USDA Classification Cuts and Internal Black spot damage for potatoes

Defects	Damage maximum allowed	Serious damage maximum allowed
Cuts	When one smooth cut affects more than 5 percent of the surface area.	Cut(s) that affect more than 10 percent of the surface area in the aggregate or when a single side cut extends beyond 1/2 the length of the potato.
Internal Black Spot.	When the spot(s) are darker than the official color chip (POT-CC-2) after removing 5 percent of the total weight of the potato.	When the spot(s) are darker than the official color chip (POT-CC-2) after removing 10 percent of the total weight of the potato.

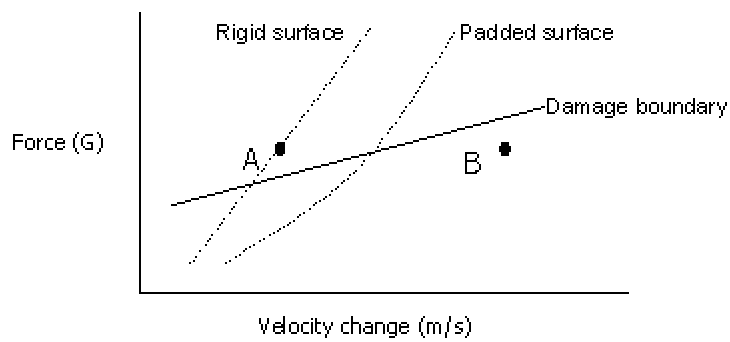


Figure 1-1. Response Curve - Force G vs Velocity change plot (Techmark-inc ., 2009).

CHAPTER 2
PACKING LINE MECHANICAL DAMAGE ASSESSMENT

2.1 Materials and Methods

2.1.1 Plant Materials

Plant materials (potato varieties; Fabula, and Yukon Gold) were collected from the packing lines and fields on Blue Sky farms in Hastings, Florida and were transported to Postharvest Horticulture laboratory of the University of Florida in plastic covered containers. Yukon Gold has oval, slightly flattened; finely flaked yellowish white skin; shallow pink eyes; light yellow flesh tubers. Fubula has oval; smooth light yellow skin; few medium deep eyes, predominantly apical; eyebrows slightly prominent; light yellow flesh tubers. Samples from the packing line were collected on May 7 and May 21 2009 and the hand dung samples were collected on May 21 and June 5 2009. All samples were collected during afternoon hours. One set of potato samples for each variety was collected from different points on the packing line. These samples were examined for external and internal mechanical damages to identify the bruising components in the harvesting and packing operations.

2.1.2 Potato Postharvest Handling at Blue Sky Farms

Potatoes are harvested mechanically and transported to the packinghouse. Potatoes are then dumped onto the conveyor on the packing line. The potatoes are elevated and dropped onto the first washer/brush bed. From the brush rolls, they are conveyed to the sorting table. Potatoes are then elevated into the accumulator. Upon exiting the accumulator they are elevated to the second washer brushes and sponge rolls. Potatoes are conveyed onto the plastic/steel rollers in the optical sizer. From the exit of the sizer, potatoes drop onto an inclined padding surface into the dryer. A Cross conveyor receives the potatoes from the dryer and conveys them to the chain. The chain conveys potatoes to the padded plate. From the padded plate, they move to the grade rollers. Potatoes are then elevated to be packed in bags (Figure 2-1). Figure 2-2 shows pictures of the elements of the packing line.

2.1.3 Identifying Bruising Components of Harvesting and Packing Operations.

The following were carried out to identify the components responsible for mechanical damage during the harvesting and packing operations:

- samples from different points on the packing line were assessed for mechanical damage to identify the sections on the packing line that contributed to mechanical damage;
- the Impact Recording Device was run on the harvesting machine and packing line;
- the drop heights were measured on the harvesting machine and the packing line.

The above three operations were used to identify the components of the harvesting and packing operations responsible for the type and degree of potato bruising. Water contents (wet basis) for the samples were determined by oven dry methods for the two varieties.

2.1.3.1 Assessing and quantifying potato mechanical injuries

Samples were collected from five points; two in the truck wagon (top and bottom of the wagon), three on the packing line (after dumping, before grading and after grading). Another set of samples was collected from the bottom of the truck wagon with inverted V support to compare with the regular wagon (Figure 2-3). The difference between the two trucks is in the mechanism that is used to reduce potato damage during offloading. In the regular truck, plywood boards are laid at the bottom of the truck so that potatoes are not loaded direct on the offloading conveyor chain. These boards are removed one by one from the tail of the truck during offloading. In the inverted V wagon, the inverted

V supports the weight of potatoes to reduce the weight on the offloading conveyor chain. Dry matter content tests for both Fabula and Yukon Gold were carried out one day after harvest to find the water content in the samples. Four empty small aluminum containers were weighed. Peels and pulp for four different tubers for each cultivar were placed in the containers. Weights of containers and peel/pulp were recorded. Containers with peels /pulp were dried in a 60^0c over for four days. Dry matter content was calculated by dividing weight of dried peel/pulp by weight wet peel/pulp multiplied by 100 to get a percent.

External mechanical injuries: External damage assessment was done immediately after harvest. A subjective scale rating of 1 to 5 was used to assess the external damages. This scale is similar to one that is used in rating disease damage in plants as suggested by Pathak and Saxena (1980). Table 2-1 shows what the ratings stand for. Each potato in each sample was examined for the type and degree of damage it suffered during the harvesting and packing operations as described in the Table 2-1. Number of potatoes for each type and degree of damage was noted in each sample.

Internal mechanical injuries: Internal damage assessment was done after storing the potatoes for four days after harvest in a 20^oC and 80% relative humidity cold room to allow the bruises to develop (Melrose and Mac Rae, 1987). A destructive method was used to assess the mechanical internal damage. Potatoes were peeled by a potato peeler and sliced in the stem (proximal) end and opposite (distal) end plane by kitchen knife (Figure 2-4). The slices were visually inspected to detect the presence of internal shatter and black spot. The internal shatter damages were assessed by measuring the two diameters of crack. These diameters were used to calculate the cross section area of the internal crack. The shapes of discolored tissue volumes were observed to be ellipsoid. The three diameters of the discolored tissue of the potato were measured manually and these diameters were used to calculate the volume of the black spot damage. Therefore the volumes of black spot were calculated using the formula for the volume of an ellipsoid. The volumes and cross section areas were plotted using bar graphs to compare the severity for each sample point.

2.1.3. 2 Packing line impact measurements

Impacts on the harvester and packing line were recorded by the Impact Recording device (IRD) dropping with potatoes during normal operation. The IRD was run five to ten times at each drop point to record the impacts above a threshold value of 50 g. Velocity changes and the maximum acceleration (G) values were read from the recorded data following uploading onto the computer.

2.2 Results and Discussion

2.2.1 Identifying Bruising Components of Harvesting and Packing Operations

Table 2-2 shows percentage water contents for both cultivars. The percentage water content for peels is higher than pulp for both cultivars. The percentage water content affects the viscoelastic properties of potato. These properties are important in the potato damage. The percentage water content for Yukon is less than that of Fabula for both peel and pulp. Since the two varieties were harvested from the same soil conditions, the difference percentage water content is due to their different physical properties. These properties influence the ability of the potato to resist damage. Indeed the two cultivars had different degrees of resistance to different types of damage as seen in the proceeding sections.

2.2.1.1 Assessing and quantifying potato external mechanical injuries:

Incidences: Three types of external damages (skinning, external shatter and cut) were observed in the samples for both Fabula and Yukon Gold varieties (Figure 2-5). The major damage type was found to be skinning (Figures 2-6 and 2-7). There was a high degree of skinning even before the potatoes were dumped on the packing with Fabula 80% and Yukon Gold 40% of skinned potatoes. This shows that there was significant skinning during harvesting. There were more skinned potatoes at the top of the truck than at the bottom for Fabula while for Yukon Gold it was the reverse (Figure 2-6 and Figure 2-7). However, the difference for Yukon Gold was larger than for Fabula. The 90% confidence intervals in Table 2-3 show that there is enough evidence to state that the harvester was responsible for skinning in the Fabula samples as all the confidence intervals for proportions difference between proceeding sample points contain zero. This indicated that the packing line contributed very little to skinning as compared to the harvesting operation. The packing line did contribute significant skinning for Yukon Gold and dumping and the components between dumping and before grading were responsible as the confidence intervals of proportions difference for these points do not contain zero (Table 2-3). It is evident from the confidence intervals of proportion difference in Table 2-3 that the harvesting operation was responsible for the most of the external damages for both cultivars. Samples from the bottom of the regular truck showed only skinning damage, 80%, while those from the truck with inverted V had skinning, 72%, and external shatter, 4% (Figure 2-8). This shows that use of the inverted V truck reduces skinning but increases the external shatter and does not show any effect on the cut damage.

Severity of external damage: The packing line increases the severity of skinning for Fabula as shown in Figure 2-9. The percentages for moderate, severe and extreme skinning were increasing from sampling points in the truck to sample point ‘before grading’ while the slight skinning percentages generally decrease. There were still the severe and extreme skinning after grading -point 5 (4% and 8% respectively). The USDA Visual Aid Pot classifies these as moderately and badly skinned. While there are many incidences in the severe and extreme skinning with increasing magnitude for Fabula through the packing line, Yukon Gold samples showed mainly slight and moderate skinning with the generally similar magnitude (Figure 2-10). There was generally an increase in slight skinning through the packing line and there was a significant difference between ‘before grading’ and ‘after grading’. Samples from the regular truck had higher slight skinning than those of truck with inverted V while for moderate skinning, the inverted V truck had a slightly higher value. The regular truck however showed severe skinning (Figure2-11).

The percentages for external shatter observed were less than 10% for all ratings at five sample points of Fabula and three sample points for Yukon Gold. Yukon Gold showed fewer and lower shatter percentages as compared to Fabula, (Figure 2-12 and Figure 2-13). There were no significant variations in severity of the external shatter through the packing line in both Fabula and Yukon Gold. External shatter was detected for inverted V truck samples and not in the regular truck samples (Figure 2-14). Only extreme cuts were detected in Fabula samples from points 3, 4 and 5 and there were no variations in severity (Figure 2-15). Yukon Gold showed moderate, severe and extreme cuts but were too few and low in some of the sampling points and no variation was noted (Figure 2-16). Although the cuts showed up in the samples on the packing line, the nature of the cuts showed that these potatoes suffered these cuts during harvesting. No cuts were detected for both the regular and inverted V trucks for Fabula.

2.2.1.2 Assessing and quantifying potato internal mechanical injuries

Incidences of internal mechanical damage: Two types of internal mechanical injuries were detected; internal shatter and black spot. The two types of injuries varied with type of injury and variety of potato. Table 2-4 shows that there was significant difference in proportions for sample between black spot and internal shatter for Fabula between points Bottom R Truck & Bottom V truck; and Truck & Dumping respectively. Although the confidence interval for bottom R Truck & bottom V truck contains zero, the confidence interval is skewed more to lower limit. Therefore it can be stated with 90% confidence that dumping significantly contribute internal shatter for Yukon Gold and the inverted V truck contributed black spot for Fabula. The harvester also contributed to the black spot incidences. Internal shatter was observed in samples from point 3 and point 5 (Figure 2-17) and there were no cases of internal shatter observed in Fabula samples from the truck. Both the graph and 90% confidence interval test show that dumping is responsible the internal shatter on the packing line for Fabula. There were no internal shatter incidences detected for Yukon Gold (Figure 2-18). There were no internal shatter cases for either regular or inverted V truck.

Severity of internal damage: There was a wide variation in severity of the black spot with more black spot cases observed in Fabula than in Yukon Gold (Figures 2-20 and Figure 2-21). The bars at each sampling point show the volume of the black spot for each bruised potato. The pattern in the bar graph for Fabula does not give any indication of the effect of the packing line on the severity of the black spot. The bruise volumes and number of tubers with bruises were very low for Yukon Gold for all sampling points except sampling point 5 (after grading). The high bruise volumes of the 2 out of 25 potatoes at point 5 for Yukon Gold are not a strong indication that there is an increase black spot severity after point 4. Samples from the bottom of the V-truck showed more potatoes with black spot than the ones from the regular truck (Figure 2-22). There were two cases at point 3 and one case at point 5 of internal shatter for Fabula (Figure 2-23). No internal shatter damage was detected from Yukon Gold samples. The above results indicate that the harvester contributes a large part of the internal bruises in the harvesting and packing handling for this packing house. However components between points 3 and 5 on the packing line also contribute internal bruising to some degree.

2.2.2 Harvester and Packing Line Impact Measurements

The average Max G, average Velocity change and vertical heights measured for the drops on the packing line are summarized in Table 2-5 for the harvester and Table 2-6 for the packing line. The measurements from the harvester show that the impacts on the pickup were greater than those associated with the drop into the wagon. These impacts from the harvester are reasonably high and would be expected to cause bruising hence the higher incidences and severity of damage in the truck as seen earlier. On the packing line, the highest impacts were recorded for the drops on sorting table to elevator to the accumulator and Exit from Odenberg sizer to drying rolls. Again the impacts are high enough to cause potato bruise. While the height for ‘Sorting table to elevator to accumulator’ drop is the highest (0.51m) that of ‘Exit from Odenberg sizer to drying rolls’ drop is 0.23m and is lower than some of the drop heights on the packing line. This drop has higher max G and velocity change because the impact is not just a function of height but of padding as well. The two drops were both between the sampling points; ‘after dumping’ and ‘before grading’. This must the explanation for the increase in total skinning on the sampling point “before grading’ compared to the sampling point ‘after dumping’. The plots of Max G against velocity change for both harvester and packing line impacts show that two highest impacts in each case would be in the damage region on the potato damage boundary curve (Figure 2-24 and Figure 2-25).

2.3 Summary

The major external mechanical damage in the harvesting and packing operations for Fabula and Yukon Gold is skinning. Most of the potatoes were slightly skinned for both varieties. Overall, there was more skinning in Fabula samples than Yukon. The harvester contributes a great part of the skinning for both varieties. There was more skinning during harvesting for Fabula than Yukon Gold. The packing line contributed skinning to Yukon more than it did to Fabula. There was no significant difference in damage for both Fabula and Yukon Gold between samples from the top and the bottom of the truck. The regular and the inverted V trucks had differences in damage incidences and severity. The packing line increased the severity of the skinning. The major parts of skinning and internal shatter on the packing line were contributed by dumping. There were more incidences of black spot on the harvester. The inverted V truck reduces skinning but introduced black spot. Harvester, Sorting table to elevator to accumulator and Exit from Odenberg sizer to drying rolls had higher impacts than the rest of the drops.

Table 2-1. Rating, degree and description of external damages

Rating	Degree of damage	Description of damage		
		Skinning	External shatter	Cut
5	No damage	No skin removed	No cracks	No portion of potato pulp removed
4	Slight	0 - 6% of skin removed	<1 cm long crack	0 - 6% of potato pulp removed
3	moderate	6 – 12% of skin removed	1 – 2.5 cm long crack	6 – 12% of potato pulp removed
2	Severe	12 - 25% of skin removed	2.5 - 5 cm long crack	12 - 25% of potato pulp removed
1	Extreme	More than 25% of potato skin removed	More than 5 cm long crack	More than 25% of potato pulp removed

Table 2-2. Percentage water content for Fabula and Yukon Gold.

Fabula		Yukon Gold	
Peel	Pulp	Peel	Pulp
95.94	85.74	92.62	80.74

Table 2-3. Confidence interval of proportions difference for external damage between sampling points (90%CI)

Between sample points	Skinning		External shatter		Cut	
	Fabula	Yukon Gold	Fabula	Yukon Gold	Fabula	Yukon Gold
Top truck & Bottom truck	-0.17 ; 0.23	-0.33 ; 0.13	-0.04 ; 0.26*	-0.10 ; 0.16	-0.12 ; 0.12	-0.23 ; 0.09*
Truck & Dumping	-0.14 ; 0.13	-0.45 ; -0.14*	-0.19 ; 0.03	-0.14 ; 0.04*	-0.19 ; -0.01*	-0.05 ; 0.14
Dumping & Before grading	-0.22 ; 0.15	0.06 ; 0.50*	-0.09 ; 0.23	-0.10 ; 0.16	-0.12 ; 0.19	-0.16 ; 0.10
Before & After grading	-0.09 ; 0.30	-0.46 ; -0.02	-0.23 ; 0.09	-0.25; 0.05*	-0.19 ; 0.12	-0.10 ; 0.16

*Proportions difference confidence interval contains zero, the damage proportions between the two sampling points are significant.

Table 2-4. Confidence interval of proportions difference for internal damage for the sample points for Fabula and Yukon Gold (90%CI)

Between sample points	Black spot		Internal shatter	
	Fabula	Yukon Gold	Fabula	Yukon Gold
Top of truck & Bottom of truck	-0.13 ; 0.21	-0.19 ; 0.12	-0.12 ; 0.12	-0.12 ; 0.12
Truck & Dumping	-0.16 ; 0.08	-0.13 ; 0.11	-0.19 ; -0.01*	-0.11 ; 0.04
Dumping & Before grading	-0.18 ; 0.18	-0.17 ; 0.17	-0.07 ; 0.21	-0.12 ; 0.12
Before grading & After grading	-0.18 ; 0.18	-0.26 ; 0.12	-0.16 ; 0.10	-0.12 ; 0.12
Bottom R Truck & Bottom V truck	-0.36 ; 0.02			

*Proportions difference confidence interval contains zero, the damage proportions between the two sampling points are significant.

Table 2-5. Maximum G's, Velocity changes for the drops on the harvester

Drop	Max G	Vel. Change (m/s)
Pick up in the field	94.10	2.24
Into the Wagon	81.60	1.91

Table 2-6. Maximum G's, Velocity changes and measured heights for drops on the packing line.

Drop	Max G	Vel. Change (m/s)	Height (m)
Wagon to conveyor	71.69	1.29	0.41
First elevator to first brush bed	63.69	1.68	0.28
Exit 1st brush rolls	69.98	1.19	0.25
Sorting table to elevator to accumulator	101.43	1.55	0.51
Exit from accumulator	72.15	1.28	0.20
Maedin elevator to main brush	73.00	1.15	0.25
Exit brush bed to sponge rolls	65.67	1.05	0.15
Sponge roll to take-away conveyor	73.81	1.13	0.15
Exit from Odenberg sizer to drying rolls	100.73	2.12	0.23
Dryer exit to take-away conveyor	73.62	1.22	0.25

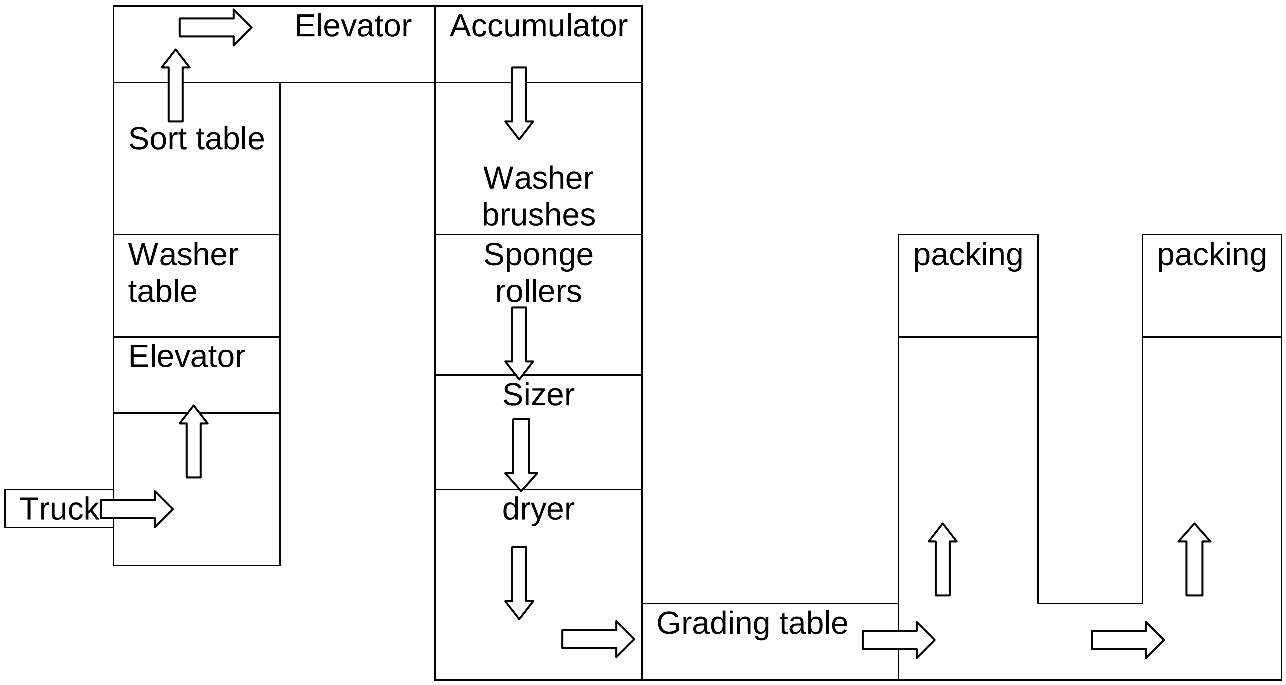


Figure 2-1. Flow of potatoes on the packing line

Figure 2-2. Harvesting and packing operations. A) Loading in a wagon B) Truck waiting dumping C) Dumping D) Washer brushes E) Dryer F) Packing

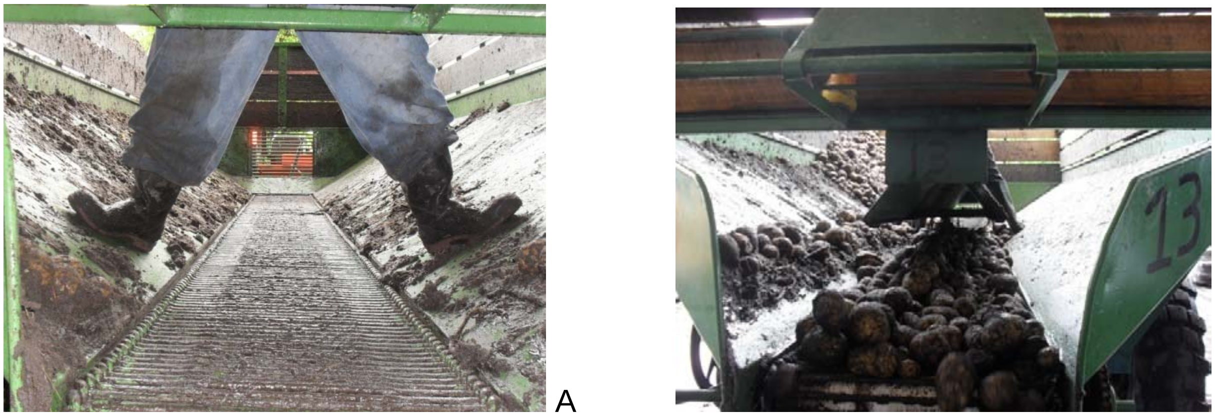


Figure 2-3. Types of truck wagons A) Regular B) inverted V truck wagon

Figure 2-4. Sliced potato for assessment of internal mechanical damage

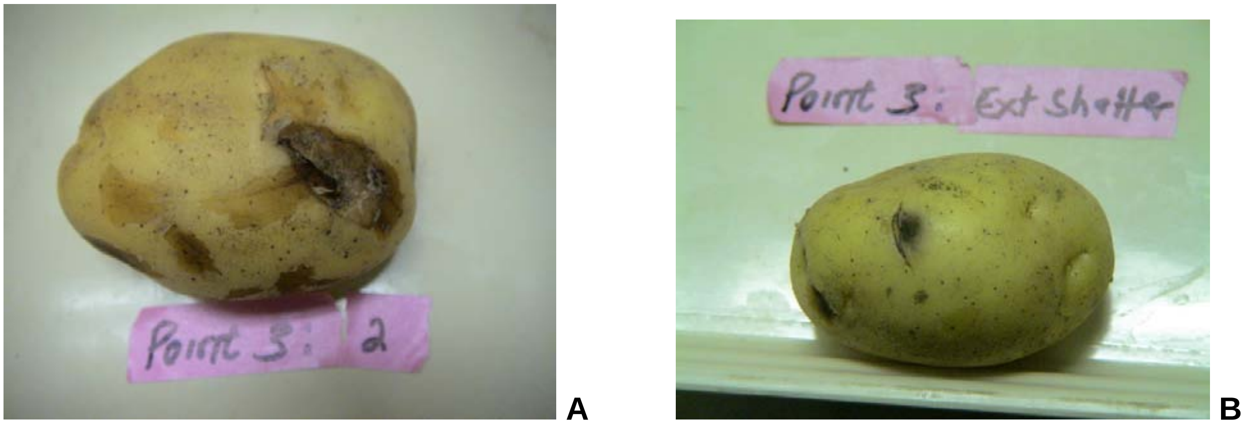


Figure 2-5. Potato external damage. A) Skinning and cut B) external shatter

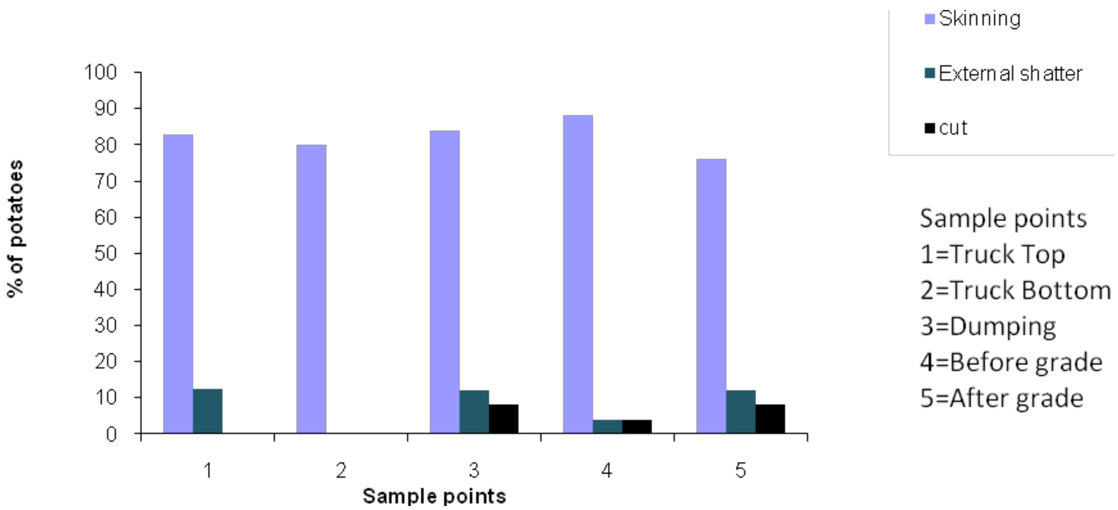


Figure 2-6. Skinning, external shatter and cut damage for Fabula for different sample points

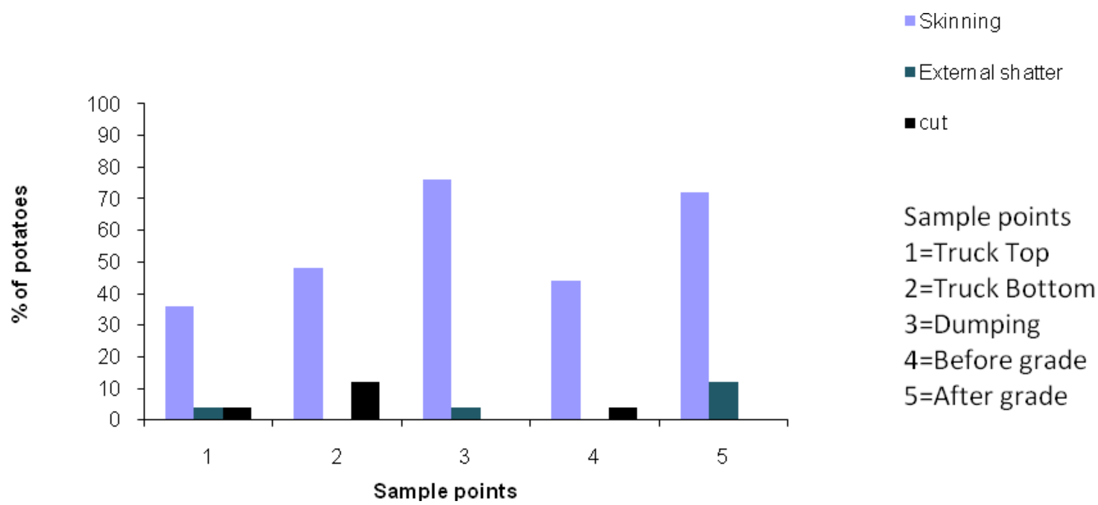


Figure 2-7. Potatoes with skinning, external shatter and cut damage for Yukon Gold for different sample points

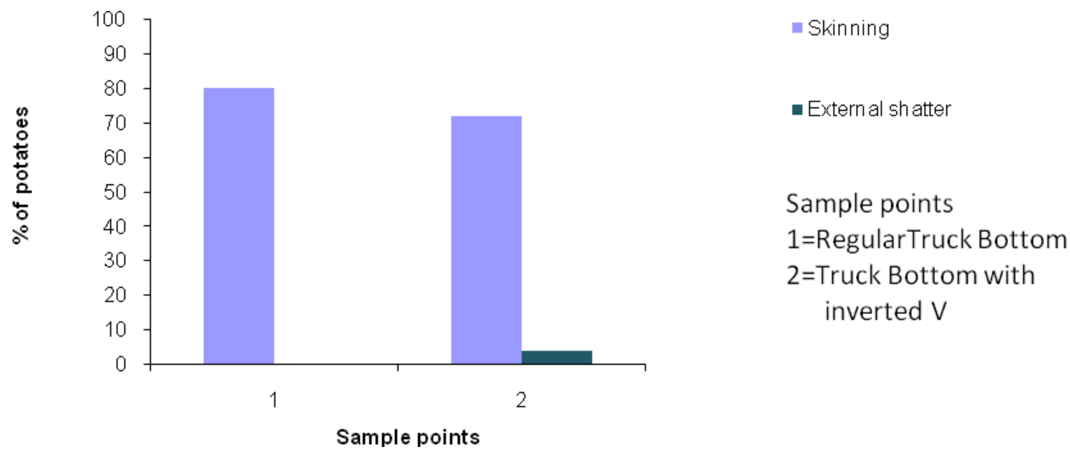


Figure 2-8. Potatoes with skinning and external shatter damage for Fabula samples from regular truck bottom and truck with inverted V.

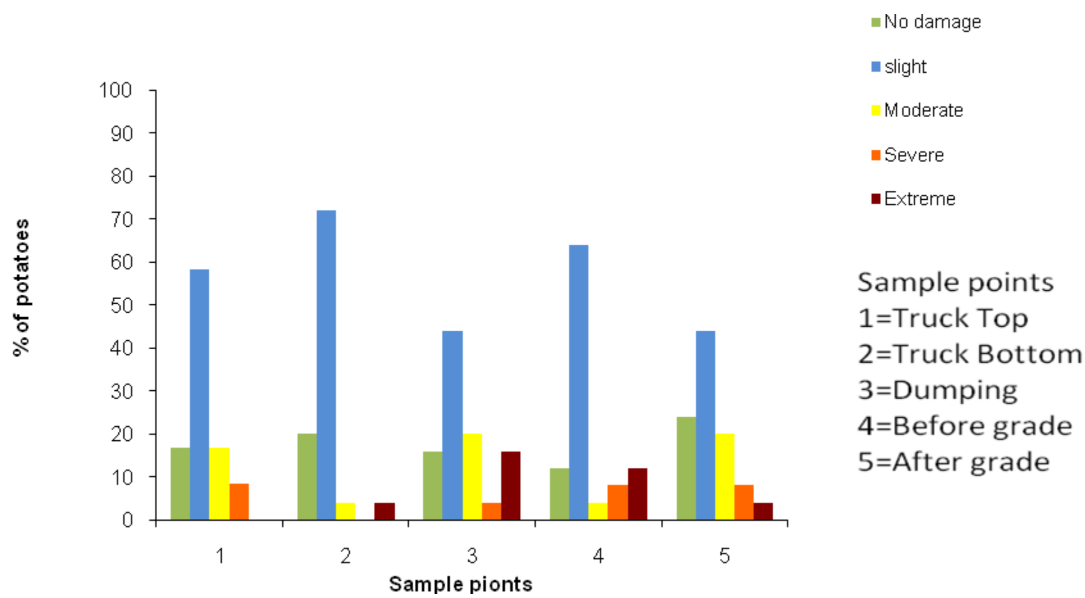


Figure 2-9. Potatoes with different rating of skinning damage in Fibula samples

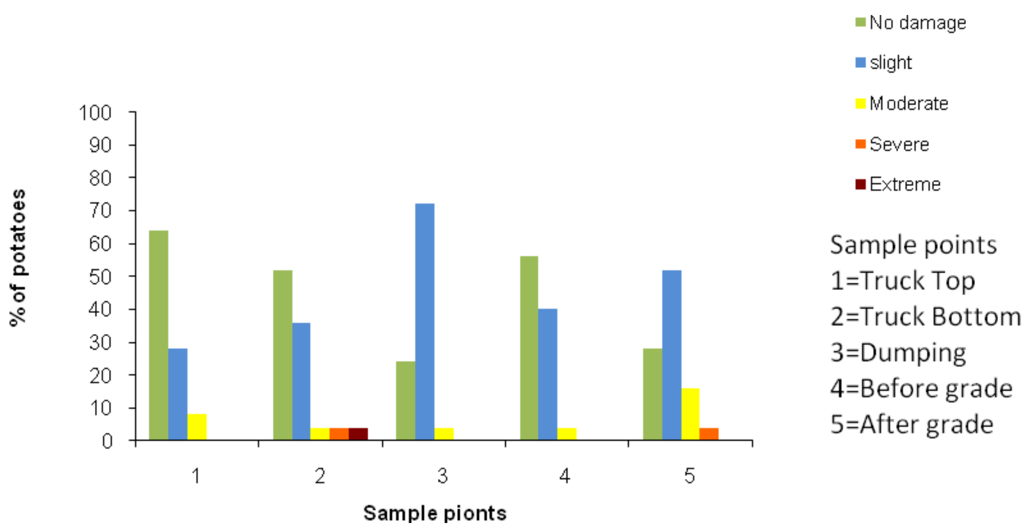


Figure 2-10. Potatoes with different rating of skinning damage in Yukon Gold

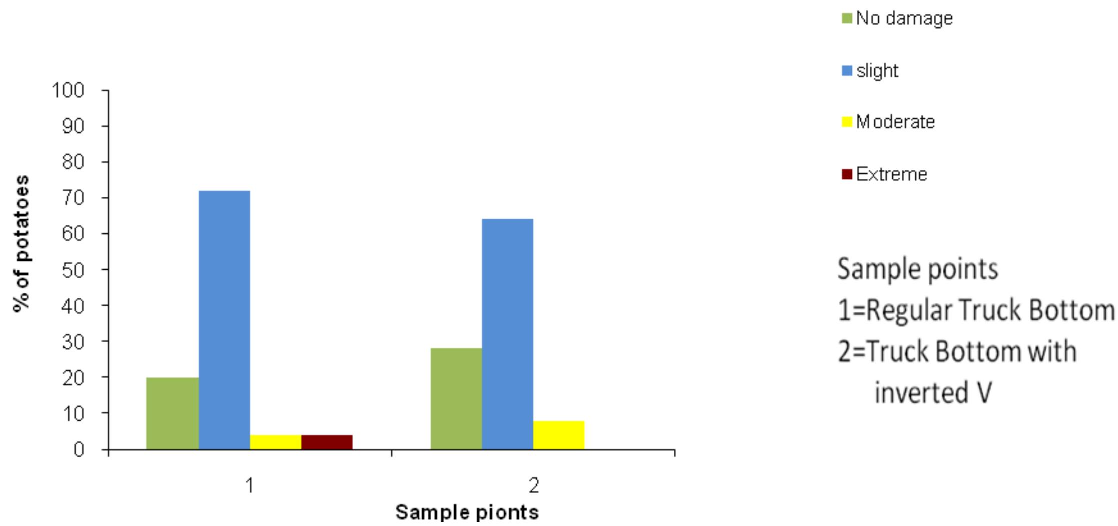


Figure 2-11. Potatoes with different rating of skinning damage for Fabula samples from regular truck bottom and truck with inverted V.

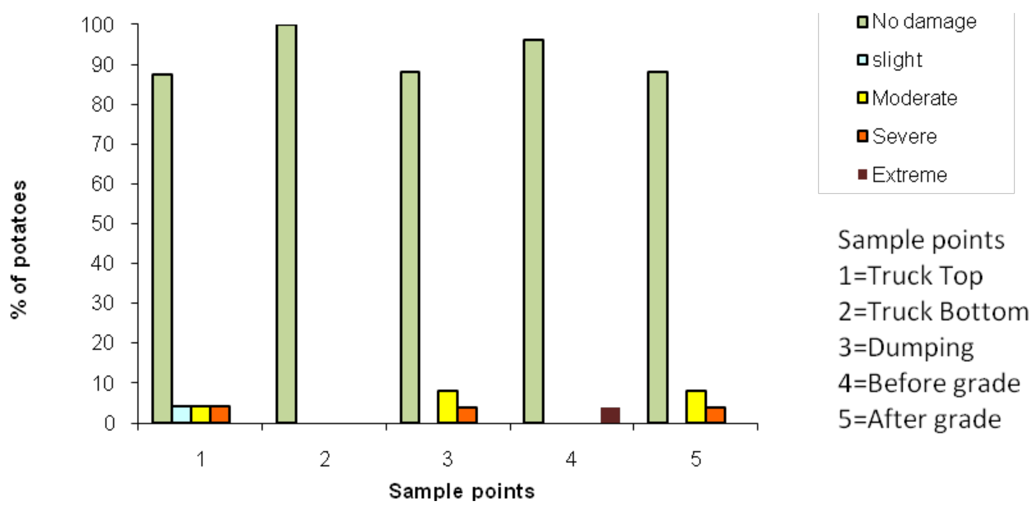


Figure 2-12. Potatoes with different rating of external shatter damage for Fabula

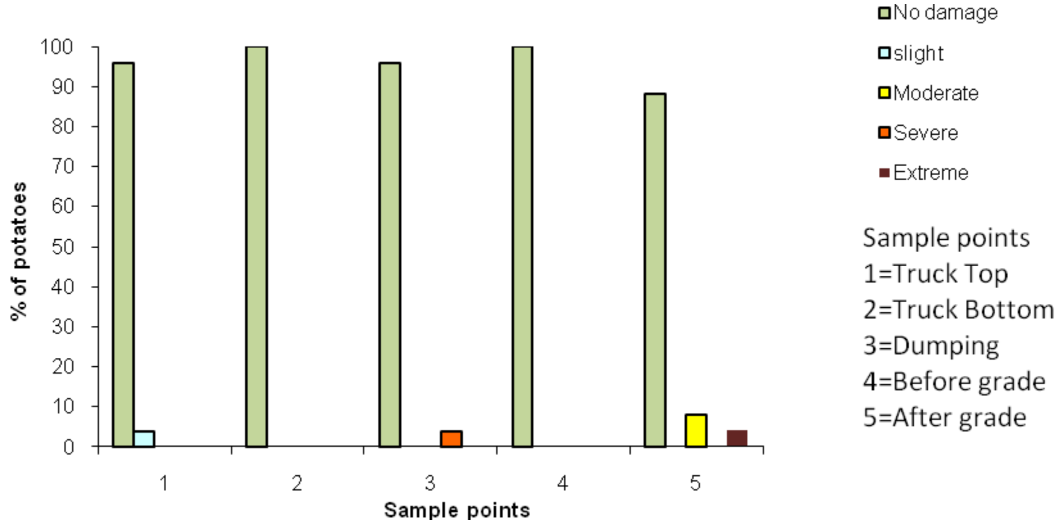


Figure 2-13. Potatoes with different rating of external shatter damage for Yukon Gold

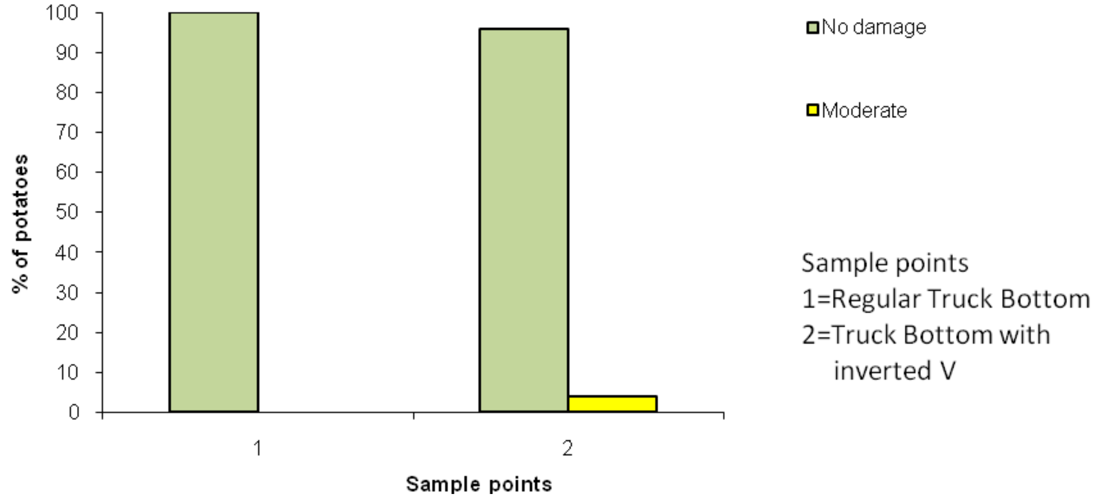


Figure 2-14. Potatoes with different rating of external shatter damage for Fabula samples from regular truck bottom and truck with inverted V.

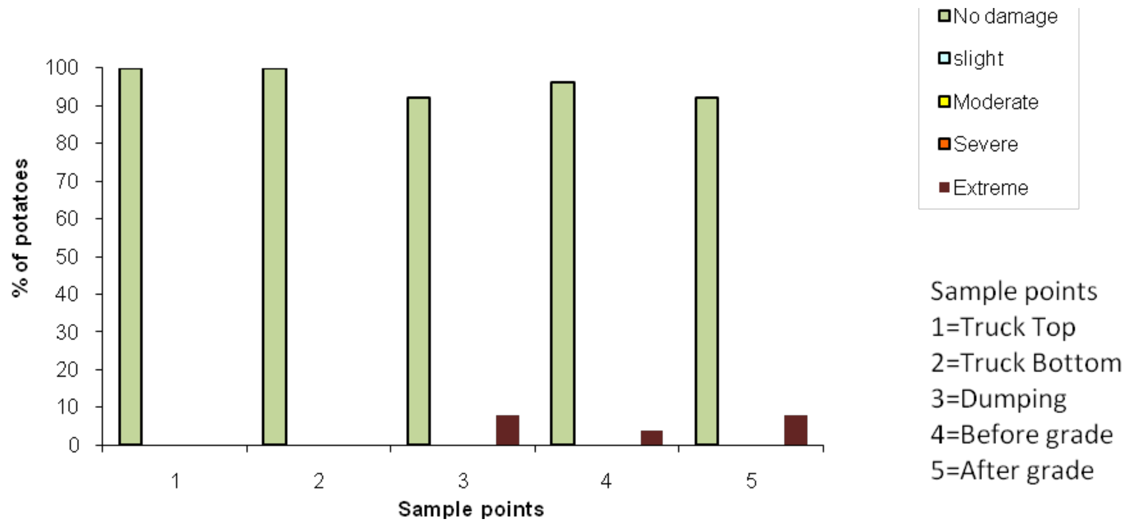


Figure 2-15. Potatoes with different rating damage of external cuts rating for Fabula

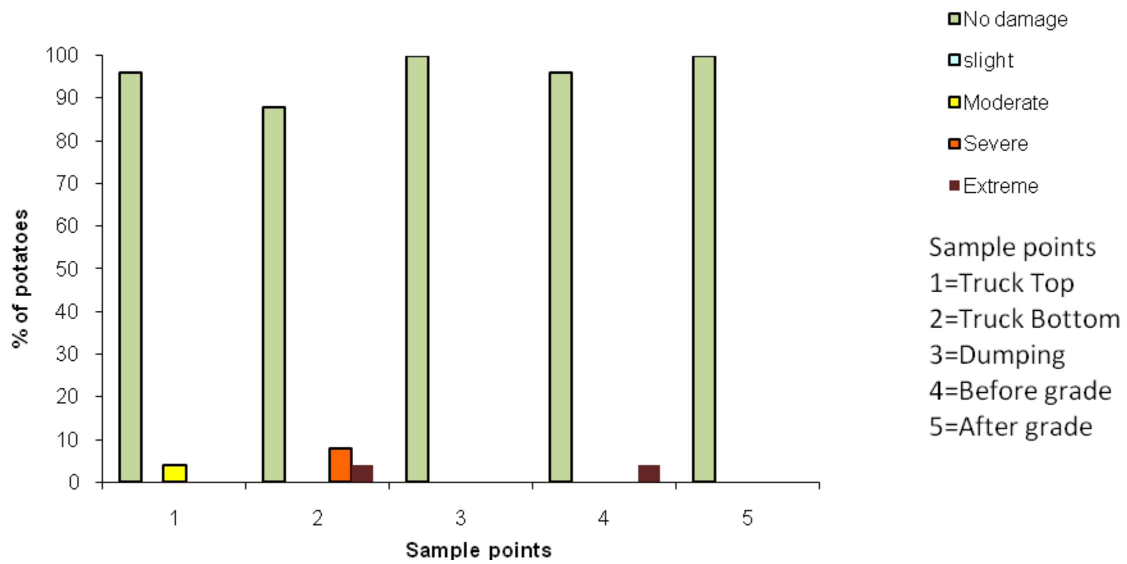


Figure 2-16. Potatoes with different rating damage of external Cut rating for Yukon Gold.

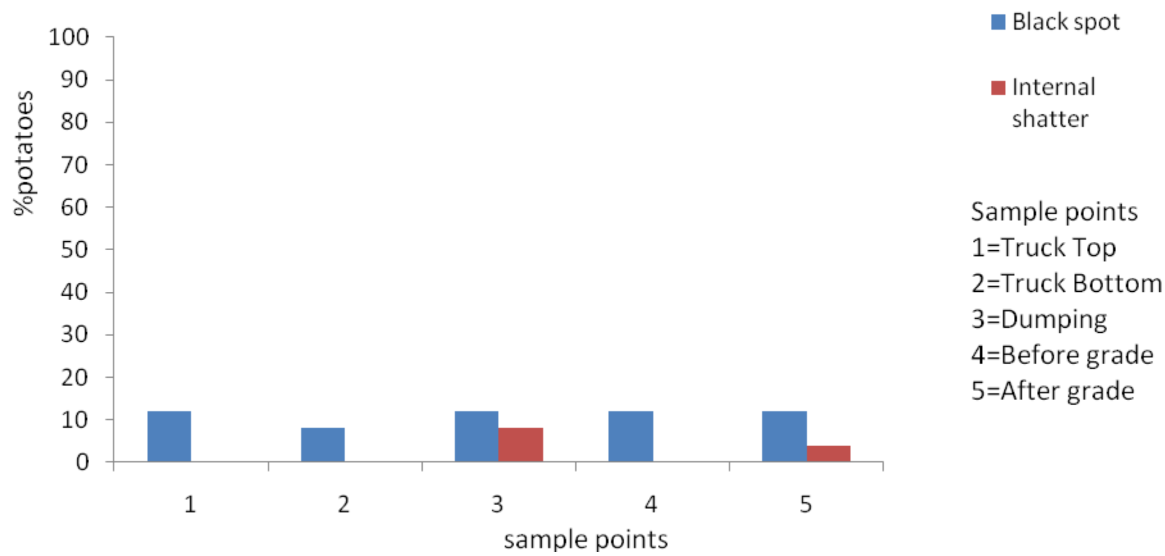


Figure 2-17. Potatoes with internal shatter and black spot damage for Fabula.

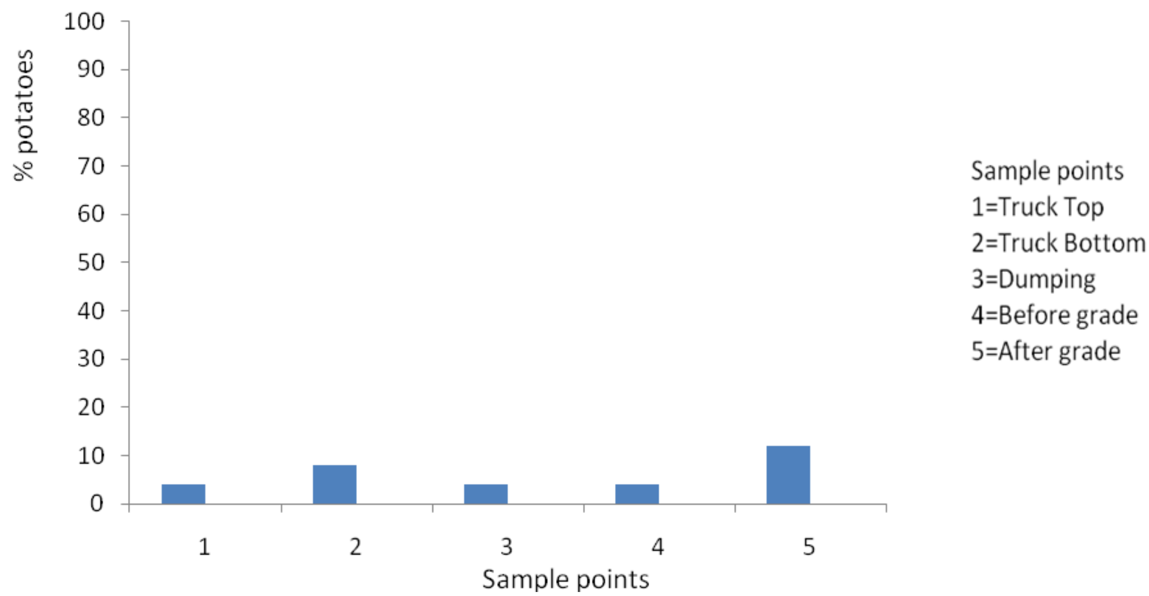


Figure 2-18. Potatoes with black spot damage for Yukon Gold.

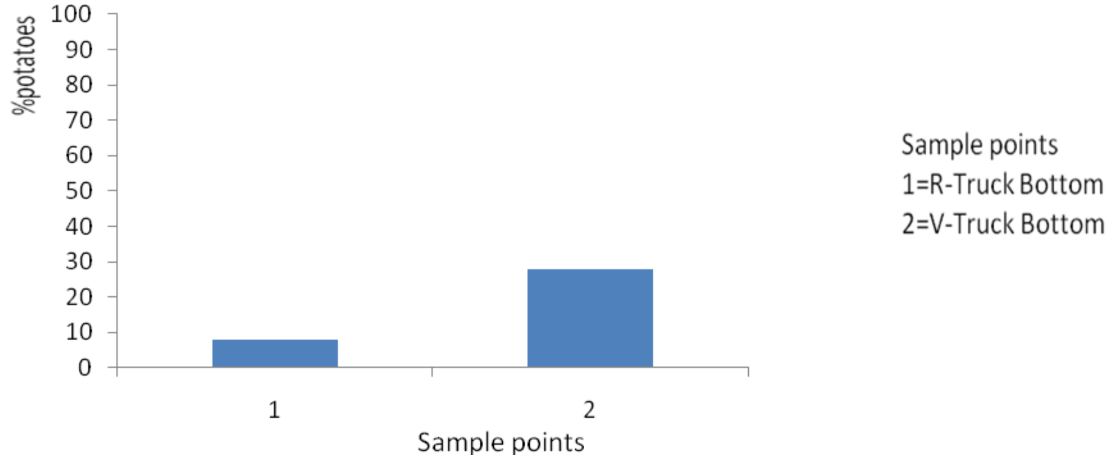


Figure 2-19. Potatoes with black spot damage for the regular truck and the inverted V truck for Fabula.

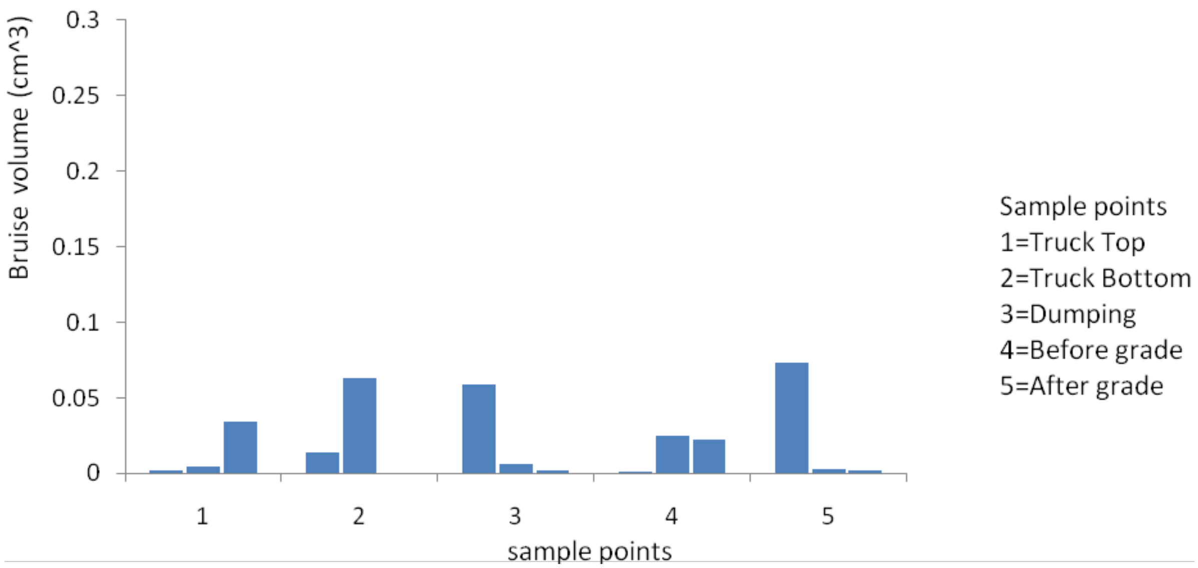


Figure 2-20. Severity of Black spot for Fabula on different sampling points (Number of bars for each height = number of tubers detected with bruise, volume of bruise = severity of black spot)

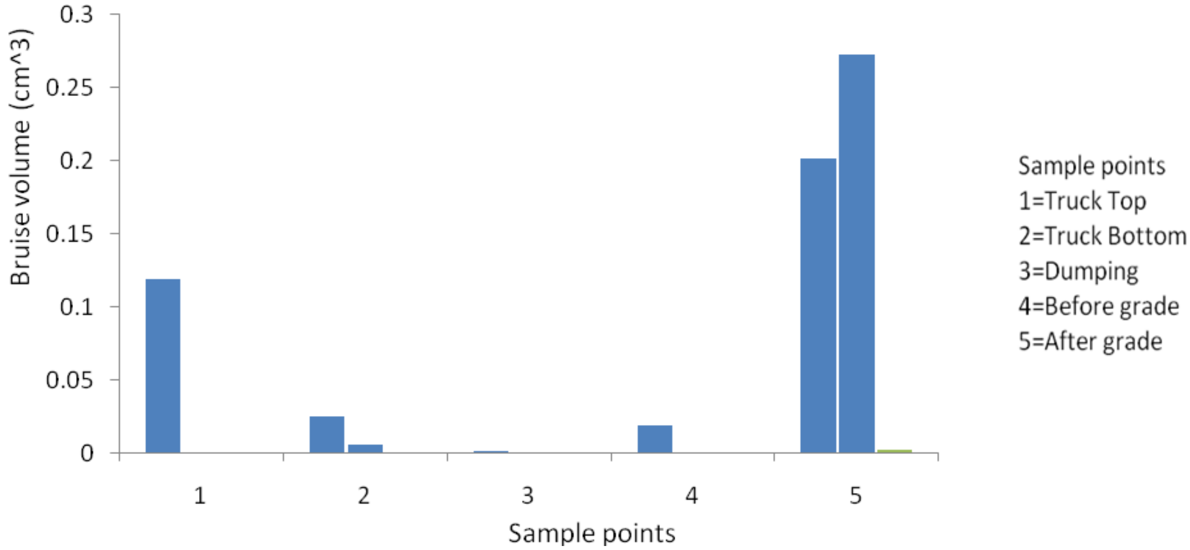


Figure 2-21. Severity of Black spot for Yukon Gold on different sampling points. (Number of bars for each height = number of tubers detected with bruise, volume of bruise = severity of black spot)

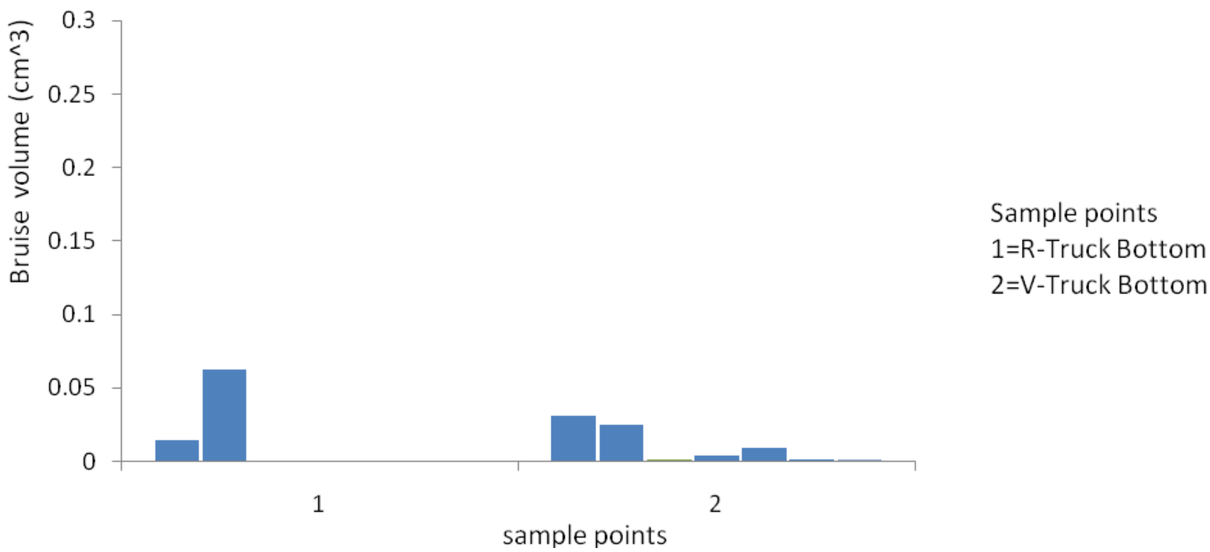


Figure 2-22. Severity of Black spot for Fabula Regular and V-truck bottom sampling points . (Number of bars for each height = number of tubers detected with bruise, volume of bruise = severity of black spot)

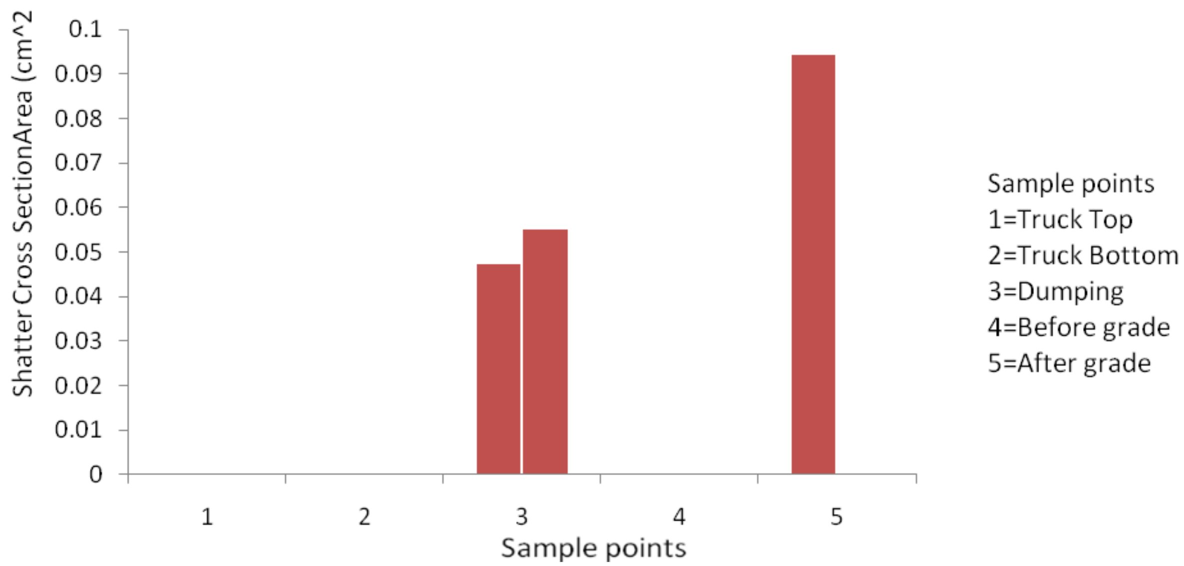


Figure 2-23. Severity of Internal Shatter for Fabula. (Number of bars for each height = number of tubers detected with bruise, Cross sectional area of shatter = severity of shatter)

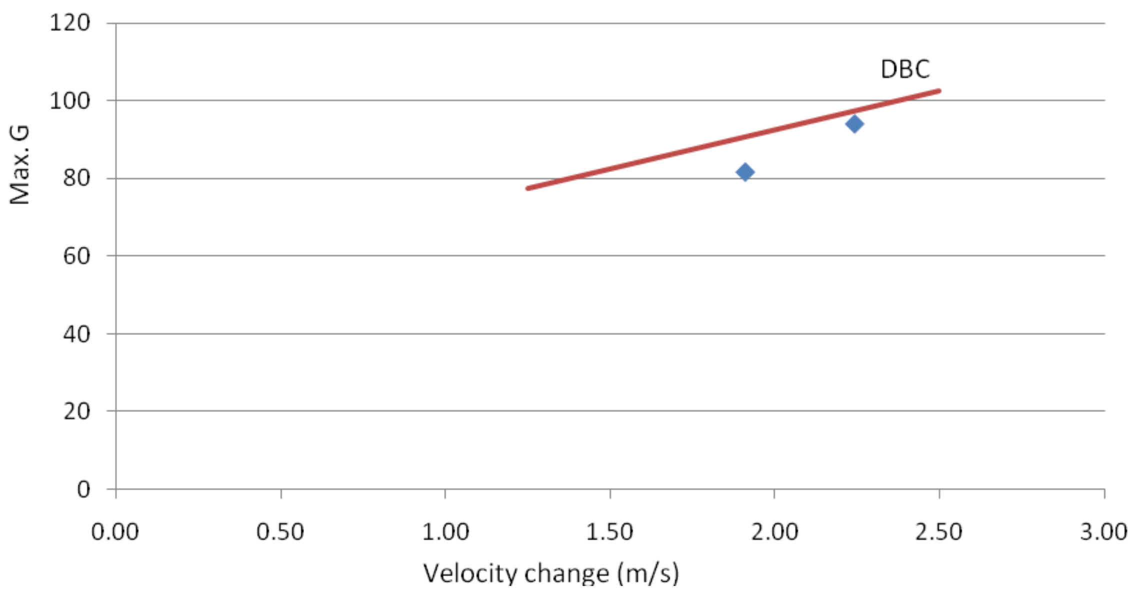


Figure 2-24. Velocity Change vs Max. G for the harvester impacts with the damage boundary curve (DBC).

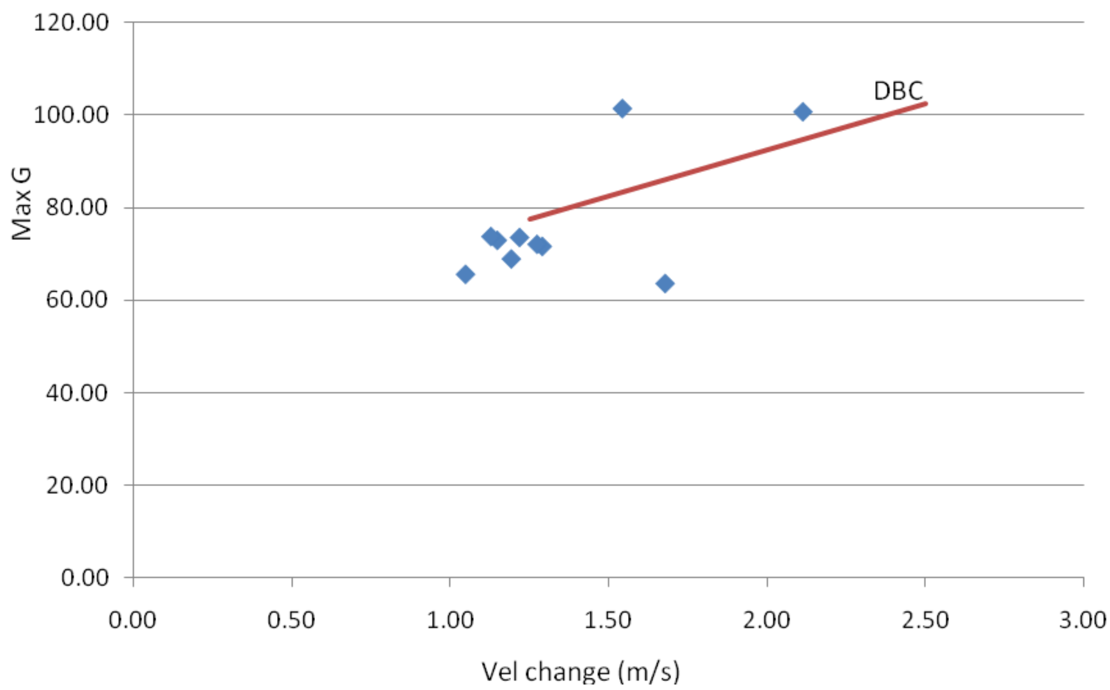


Figure 2-25. Velocity Change vs Max. G for the packing line impacts with the damage boundary curve (DBC)

CHAPTER 3
INVESTIGATING THE IMPACT THRESHOLD FOR FRESH POTATOES.

3.1 Materials and Methods

Drop weight and pendulum impacts were simulated to estimate bruise impact energy, acceleration and velocity change using tubers and IRD. Tubers were hand dug on Blue Sky Farm in Hastings and Randy Byrd & Son farm in Elkton, Florida. Tubers were transported to the Postharvest Horticultural Laboratory of the University of Florida in plastic covered containers. Two sets of samples were collected; one for the drop weight impact tests and the other for the pendulum impact tests. The impacted tubers were assessed for mechanical damage after four days of cold room storage at 20^{o}C and 80% RH. External and internal damages were assessed as described in Section 2.1.3.1. One test was carried out for each simulation (drop weight and pendulum) for Fabula variety. Only the ‘one week after harvest’ test was carried out for Fabula. Two tests were carried out for each simulation (drop weight and pendulum) for the Yukon Gold variety. The first test was done one day after harvest and the second test was done one week after harvest to find the effect of water content on impact thresholds. Dry matter content for the samples was determined by oven drying methods to investigate the effect of dry matter content on potato mechanical damage as stated in Section 2.1.3.1.

3.1.1 Drop Weight Impact Simulations

Tuber and IRD impact simulations were carried out for the weight drop impact. Tuber simulation was used to estimate mechanical damage impact threshold and impact energies (energy absorbed by the tubers) while the IRD was used to determine accelerations and velocity changes for different drop heights.

3.1.1.1 Drop weight tuber Impact simulations

Two tests were done for drop weight impact simulations. One test was to estimate mechanical damage impact threshold and the other one was to estimate the energy absorbed by the tubers. Tubers were dropped from known heights in both tests. In the first test, tubers were dropped (on the stem end, which known to be more susceptible to bruise) onto a concrete surface and tuber damage was assessed. Tuber damage was assessed after impacts and rebound heights were measured to calculate rebound energy of the tubers. For both tests, a string was tied around the tuber's lower stem end hemisphere (Figure 3-1).

The tuber was suspended by the string to minimize the rotation of the tuber while dropping. For the first test to estimate damage threshold, each tuber was held at the desired height and the string released, allowing the fruit to drop directly onto concrete surface/steel plate. The concrete/steel plate surface around the drop point was cushioned for the tubers to fall on after one bounce. White chalk dust was scattered on the concrete to indicate the location of the impact. The procedure was repeated 4 times with potatoes of different masses dropped from heights 30, 60, 90,120 and 150 cm. These potatoes were stored in a 20^{o}C cold room for four days to let internal mechanical damages develop. On the fourth day, the potatoes were assessed for internal mechanical damages to identify the threshold drop height. The damages were quantified for each drop height to estimate the trend of the damage with increasing drop height. In the test to measure impact energy, a video camera was used to record rebound heights on the lined paper board. Rebound heights were read from the lined board during replay of the recorded video. The bruise impact energy was estimated from the drop and rebound heights of the potatoes.

3.1.1.2 Drop weight IRD impact simulations

The Impact Recording Device (Trigger threshold- Selectable 0–400 G) described in section 1.4 was dropped onto the concrete and steel plate surfaces from the heights 15, 30, 45 and 60 to measure the acceleration and velocity change for the drop heights. Data from the IRD was uploaded onto the computer for analysis of maximum G's and velocity changes. The accelerations and velocity changes were used to estimate mechanical damage impact threshold for the tubers. Concrete surface accelerations and velocity changes were compared to those from the steel surface.

3.1.2 Pendulum Impact Simulations.

Pendulum impact simulations were done to compare with the weight drop simulations. The pendulum impactor built by Lee (2005) was modified for the potato impact simulations (Figure 3-2). A rectangular plate (1269g, 7.62 x 7.62 x 2.54 cm) with a smooth surface was used to simulate equivalent weight drop heights of potatoes (masses 125g–310g). The plate replaced the lead sinker (230 g) of Lee (2005) for tomato drop simulations. The steel plate and a bag were suspended from a steel cross-bar by two steel rods and a string respectively. The bag was used to suspend the potato/IRD during impact simulations. The pendulum impactor was mounted on a steel frame attached to the wood board. A one meter steel ruler was mounted on a sliding bar stand in the middle of the board to indicate desired heights (equivalent to vertical drops of 30 cm, 45 cm, 60 cm and 90 cm). The impacts were made by raising the pendulum impactor to the desired equivalent weight drop height on the ruler and release it to impact the potato/IRD hanging in a bag (Figure 3-2). Drop heights were converted into pendulum impact height by solving the following energy balance equation:

$$Mrg = mhg \tag{3-1}$$

Solving for r, $r = (m/M)h$

where M = mass of pendulum (g), r = drop height of pendulum (cm), g = gravitational acceleration (9.8 m/s^2), m = mass of potato (g), h = drop height of potato (cm). The steel plate impacting face was marked with white chalk on the impacting surface to mark the impact points on the potatoes.

3.1.2.1 Pendulum impact simulations for potato

Sample potatoes were impacted by a steel flat pendulum of mass 1269g, as described in section 3.2.0, from equivalent potato heights 30, 45, 60 and 90 cm. The potatoes were assessed for mechanical damage after four days in a 20^{o}C cold room to determine the mechanical damage thresholds. A video camera (Sony, HDR - SR 5, 4.0 MP) was used to record the pendulum and potato heights on the lined paper board for the impact energy test. The heights were read from the paper board during replay of the recorded video.

3.1.2.2 Pendulum impact simulations for IRD

The Impact Recording Device (Figure 3-3) was suspended in the bag and impacted by a steel flat pendulum of mass 1269g from equivalent potato heights 30, 45, 60 and 90 cm to measure the acceleration and velocity change for the drop heights.

The data from the IRD was uploaded onto the computer for analysis. The accelerations and velocity changes were compared with those from Impact Recording Device weight drop test.

3.2 Results and Discussion

3.2.1 Drop Weight Impact Simulations for Tubers

The following types of mechanical damage were detected; external shatter, internal shatter and black spot in the weight drop impact simulations for both Fabula and Yukon Gold.

3.2.1.1 Fabula

Incidences: All the three types of damage were detected starting from 90 cm drop height. External shatter and black spot were the predominant types of damage. As the drop height increased above 90 cm, the percentage of potatoes with external shatter generally increased, internal shatter remained constant and black spot decreased (Figure 3-4).

Severity: There was no clear relationship between the number of damaged tubers and drop height. However, the degree of damage for individual tubers generally increased with drop height for all the three damage types (Figure 3-4). There were many incidences of external shatter and black spot but very few for internal shatter (Figure 3-5, Figure 3-6, and Figure 3-7) .16% of the tubers were found with internal shatter for each of the three drop heights (90,120,150 cm).

3.2.1.2 Yukon Gold

Incidences: Two drop tests were carried out for Yukon Gold; one day after harvest and one week after harvest. Incidences of damage in the first test were detected from drop height 60 cm and in the second test they were detected from 30 cm.

There were fewer incidences for damage in the first test than the second and the severities of damage of individual tubers for two tests generally increased with drop height (Figure 3-8 and Figure 3-9). The incidences of external shatter were higher than for the other two types of damage for the test done one week after harvest. This must be due to the differences in water content.

Severity: The external shatter damage incidences observed in the ‘one week after harvest’ test were more severe than was observed in the ‘one day after harvest’ test. In the latter test, external shatter showed above drop height 90 cm and there was only one incidence out of the six for drop heights 90 cm and 120 cm and four at 150 cm. The incidences of external shatter appeared from drop height 30 cm with one incidence for heights 30 and 60 cm. The number of tubers with external shatter was not related to drop height in the test done one week after harvest (Figure 3-10 and Figure 3-11).

There were few cases of internal shatter for both tests with only two cases of internal shatter (at drop height 90 cm) in the ‘one day after harvest’ test. For the ‘one week after harvest’ test, internal shatter incidences were observed from drop height 30 cm through 150cm except for 60 cm drop height. There was no relationship between incidences and drop height, for both tests. The severity of damage was not also related to the drop height in ‘one week after harvest’ test (Figure 3-12). There were more severe cases in the one week after harvest than the ‘one day after harvest’ test (Figure 3.13). This suggests that as the water content decreases, the tubers are more susceptible to internal shatter. Black spot incidences were observed above drop height 60 cm for the ‘one day after harvest’ test as compared to 30 cm for the ‘one week after harvest’ test. There were more incidences in the former test than the latter. Generally, severity increased with drop height for both tests with more severe damage cases in the ‘one day after harvest’ test although two extreme cases were observed at drop heights 120 cm and 150 cm (1.82 cm^3 and 1.18 cm^3 respectively) in the ‘one week after harvest’ test (Figure 3-14 and Figure 3-15).

3.2.2 Drop Weight Impact Simulations for IRD

Impacts from concrete and steel surfaces showed almost equal values of maximum G’s and velocity change. This was important in the analysis of the impacts from the two surfaces. Table 3-1 shows the average maximum G’s with their corresponding velocity changes for the heights from which the IRD was dropped. The values of maximum G’s in Table 3-1 were much higher than those reported on the harvester and packing line (Table 2-8). Although the major damage observed on both harvester and packing line was skinning (Figure 2-2), external shatter, internal shatter and black spot were significant. There was no skinning observed in the in tuber drop simulations. In the ‘one week after harvest’ drop tests, Fabula was able to resist damage (external shatter, internal shatter and black spot) up to 60 cm drop height (Figure 3-4). The incidences of damage for Yukon Gold were observed from drop height of 60 cm in the ‘one day after harvest’ test and 30 cm for the ‘one week after harvest’ test. This means that Fabula was able to withstand the impact of 373.6G’s in the ‘one week after harvest’ test while Yukon Gold sustained damage by an impact about 257.2G’s. A plot of maximum G versus velocity change for the drop height indicated that there is a linear relationship between the drop height and maximum G (Figure 3-16). All the points are above the superimposed damage boundary curve. This explains why damage was detected for drop heights of 30 cm for Yukon Gold. However, while the severity of damage generally increased with drop height in the tuber drop simulations, there was no relationship between the number of tubers damaged (incidences) and drop height. This must be due to the differences in physical properties in individual tubers that exist within the same cultivar. It can stated from the above discussion that potato damage is a complex action involving several factors including potato variety, dry matter content, action of the force, individual potato physiology, mass of potato, drop height, cushioning and other pre-harvest factors. In this work, impact energy estimation test showed that impact energy of dropped potato mostly depended on the drop height as compared to the potato mass (Figure 3-17).

3.2.3 Pendulum Impact Simulations for Tubers and IRD

There was a big difference between the results from weight drop simulations and the pendulum simulations of the tubers. The weight drop test for equivalent heights on the pendulum gave no significant potato damage as compared to the weight drop simulation. This was due to fact that the stiffness of potatoes is very well high so that most of the pendulum energy was converted to the movement of the potato. This was supported by a comparison between simulations of weight drop impact energy and pendulum impact energy (Figure 3-18). It was seen that the impact energies for the pendulum tests were less than those from the weight drop test for equivalent drop heights. The potato needed to be supported for the steel plate to transfer equivalent drop weight impact energy to it. In this work however, supporting the tubers would not simulate the drops the tubers experience during harvesting and post harvest handling very well.

3.3 Summary

Three types of damage were observed in the weight drop simulations; external shatter, internal shatter and black spot. No cases of skinning were observed from the simulations. This indicated that skinning is not the action of drop forces that were simulated. While the incidences of damage generally increased with the drop height for both varieties, in Fabula, the incidences changed from black spot to external shatter as drop height increased. It was observed that Yukon Gold's resistance to damage generally decreased with decrease in water content. For both varieties there was more external shatter and internal shatter damage than black spot in the 'one week after harvest' tests than the 'one day after harvest' test. Black spot was prominent in the 'one day after harvest' test. This is an indication that external shatter and internal shatter are associated with low water content tubers while black spot is associated with high water content tubers. For the potato mass range used in this work, it was observed that the amount of energy absorbed by the tuber mostly depends on drop heights as compared to the tuber mass. Therefore potatoes dropped from the same height experienced very similar impact forces. The impact energies from the pendulum simulations were lower than the weight drop simulations for equivalent drop heights.

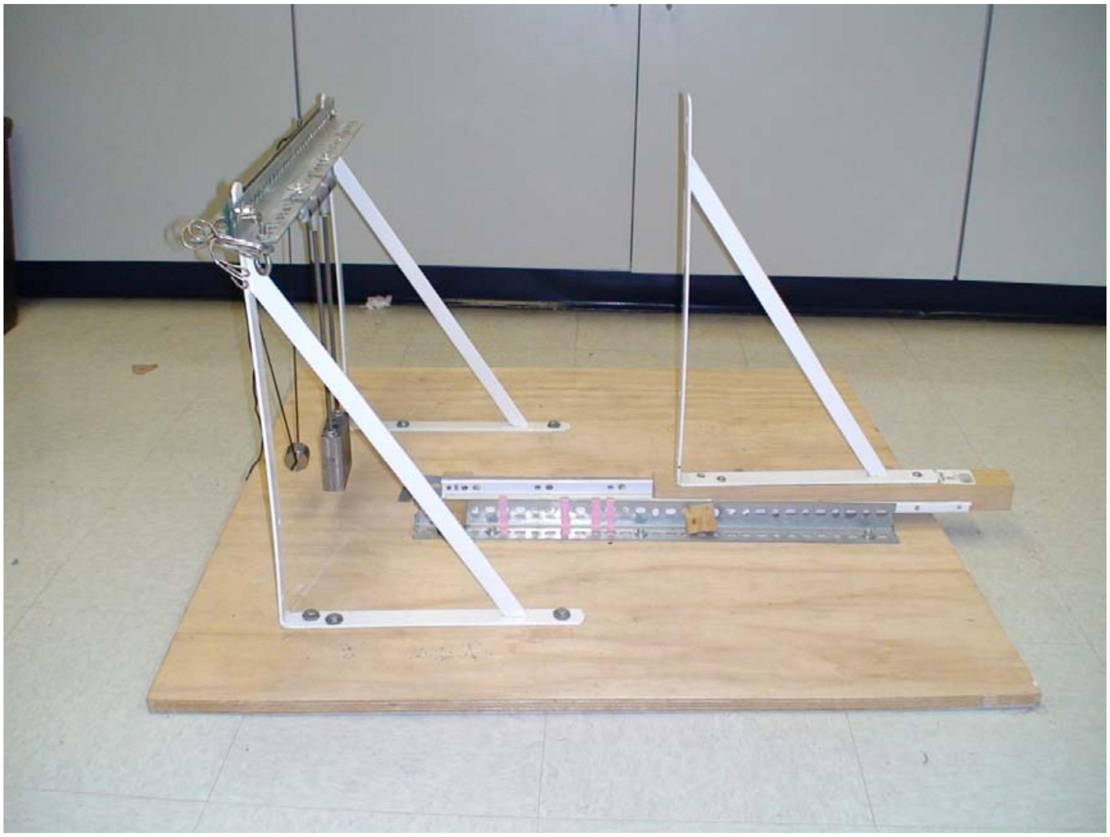
Table 3-1. Percentage peel water content for Fabula and Yukon Gold.

Fabula		Yukon	
1 day	1 week	1 day	1 week
95.94	92.42	92.62	91.51

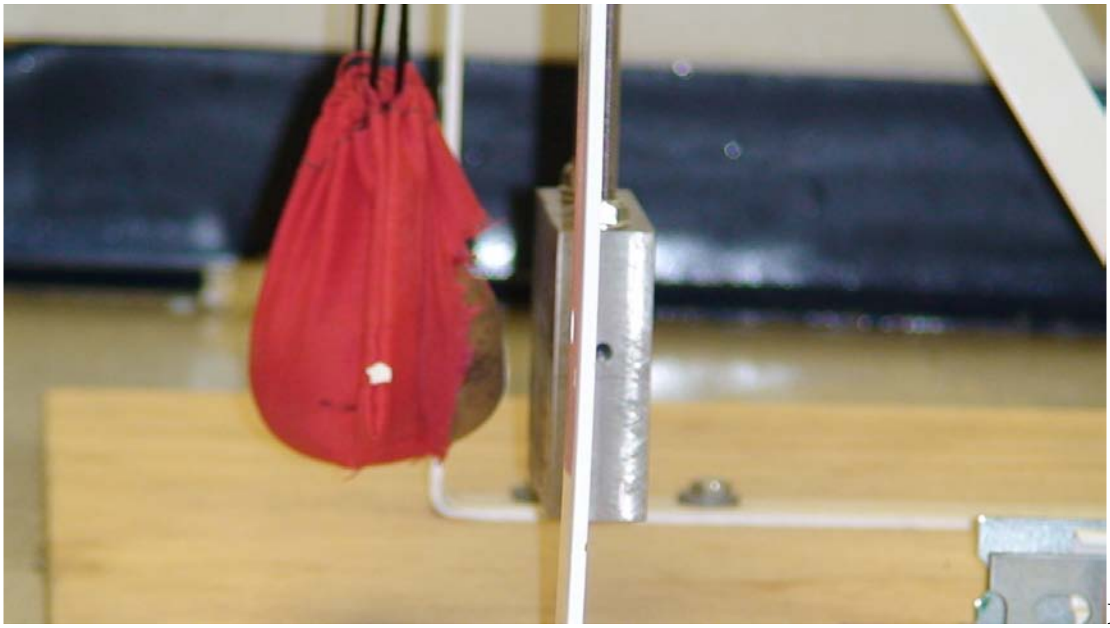
Table 3-2. Max G and velocity change for different drop heights onto unpadded surface.

Drop Height (cm)	Max G	Velocity change (m/s)
15	181.20	2.42
30	257.23	3.54
45	324.33	4.49
60	373.63	5.10

Figure 3-1. Simulations of potato drop.



A



B

Figure 3-2. Pendulum simulations A) Pendulum impactor B) Potato and steel plate in resting position

Figure 3-3. Impact Recording Device data logger

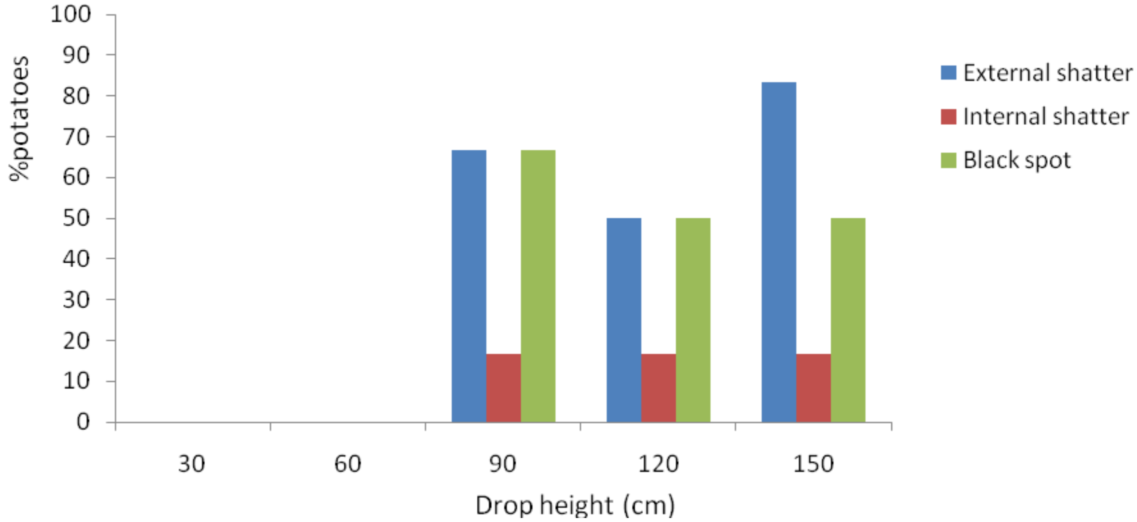


Figure 3-4. Potatoes with external shatter, internal shatter and Black spot damage for Fabula for different drop heights in '1 week after harvest' test.

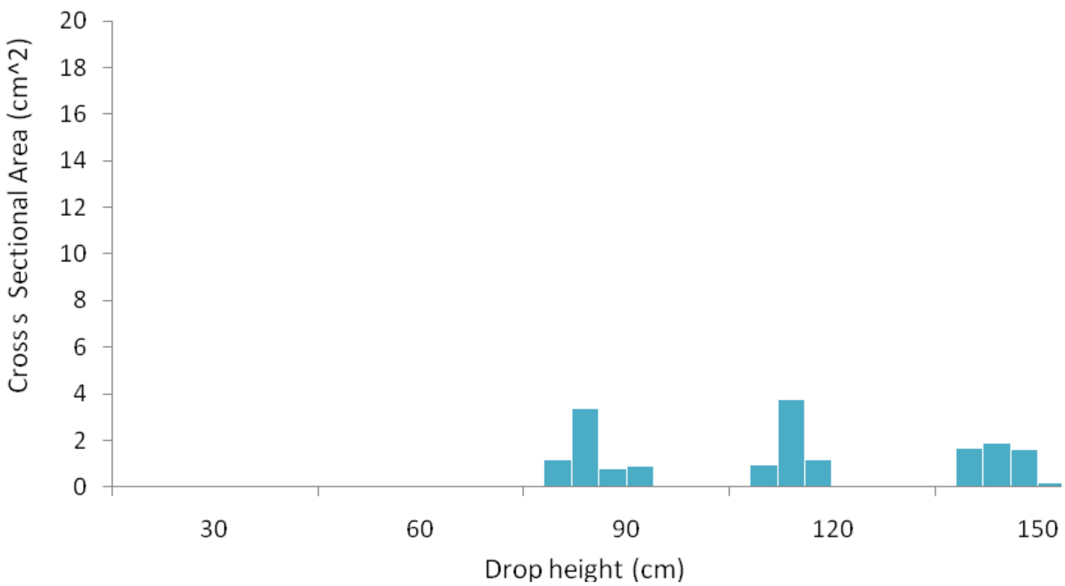


Figure 3-5. Severity of external shatter from '1 week after harvest' drop test for Fabula (Number of bars for each height = number of tubers detected with bruise, and Cross sectional area of shatter = severity of shatter)

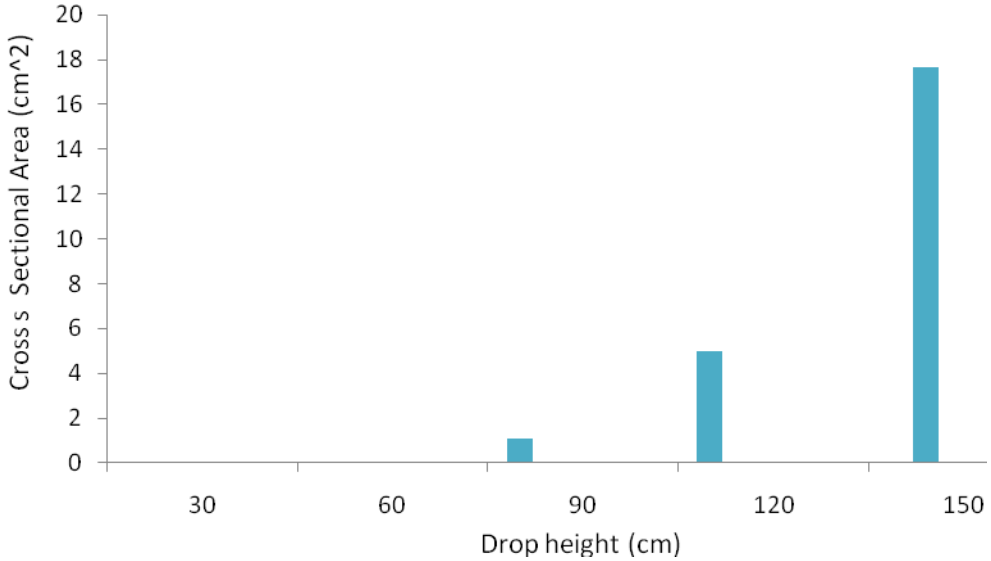


Figure 3-6. Severity of internal shatter from ‘1 week after harvest’ drop test for Fabula (Number of bars for each height = number of tubers detected with bruise, Cross sectional area of shatter = severity of shatter).

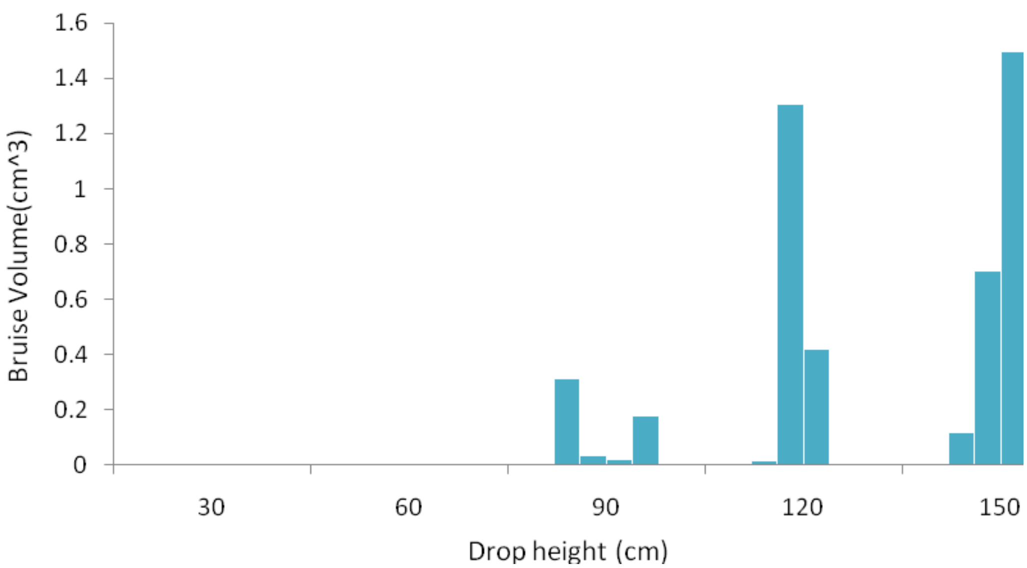


Figure 3-7. Severity of black spot from ‘1 week after harvest’ drop test for Fabula (Number of bars for each height = number of tubers detected with bruise, volume of bruise = severity of black spot)

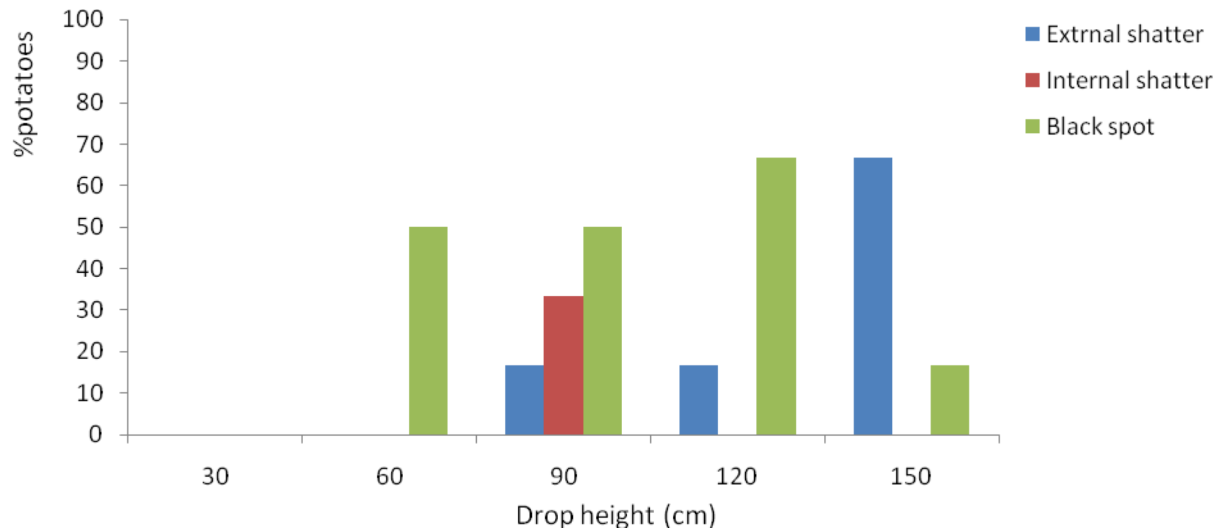


Figure 3-8. Potatoes with external shatter, internal shatter and Black spot damage for different drop heights in '1 day after harvest' test for Yukon Gold.

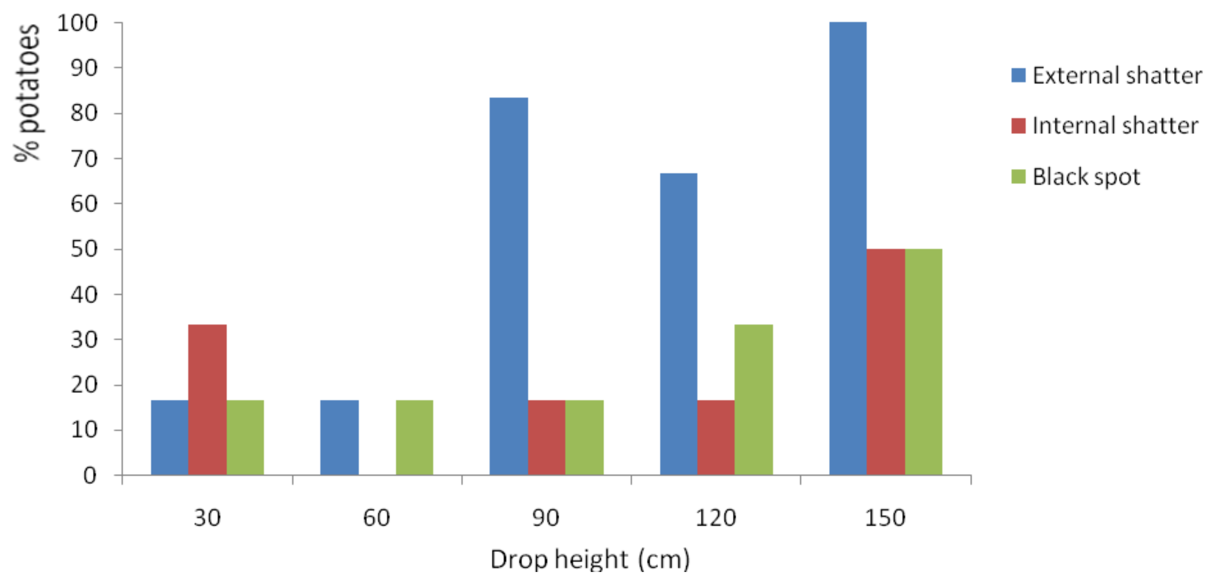


Figure 3-9. Potatoes with external shatter, internal shatter and Black spot damage for different drop heights in '1 week after harvest' test for Yukon Gold.

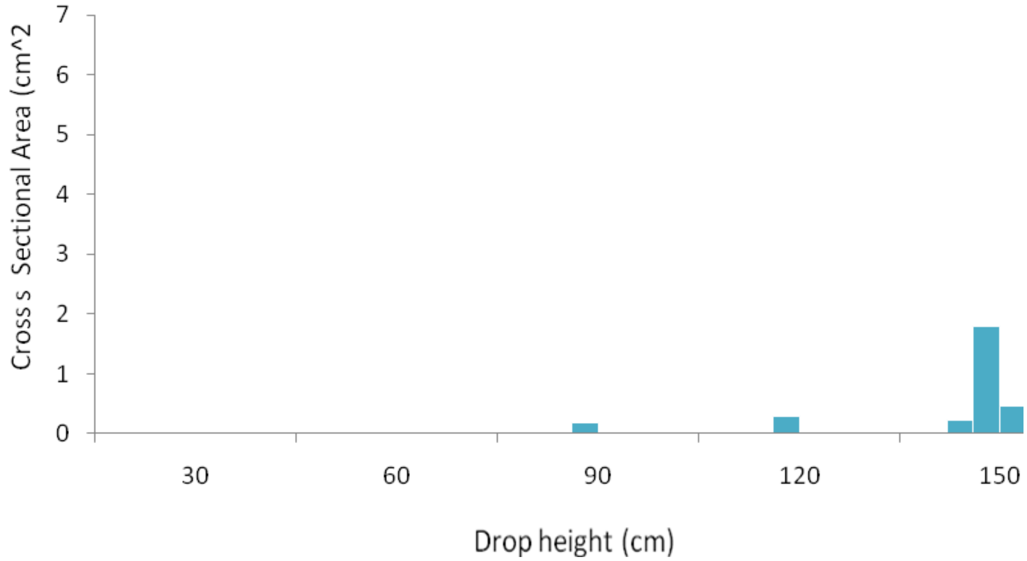


Figure 3-10. Severity of External shatter from ‘1 day after harvest’ drop test for Yukon Gold.(Number of bars for each height = number of tubers detected with bruise, Cross sectional area of shatter = severity of shatter)

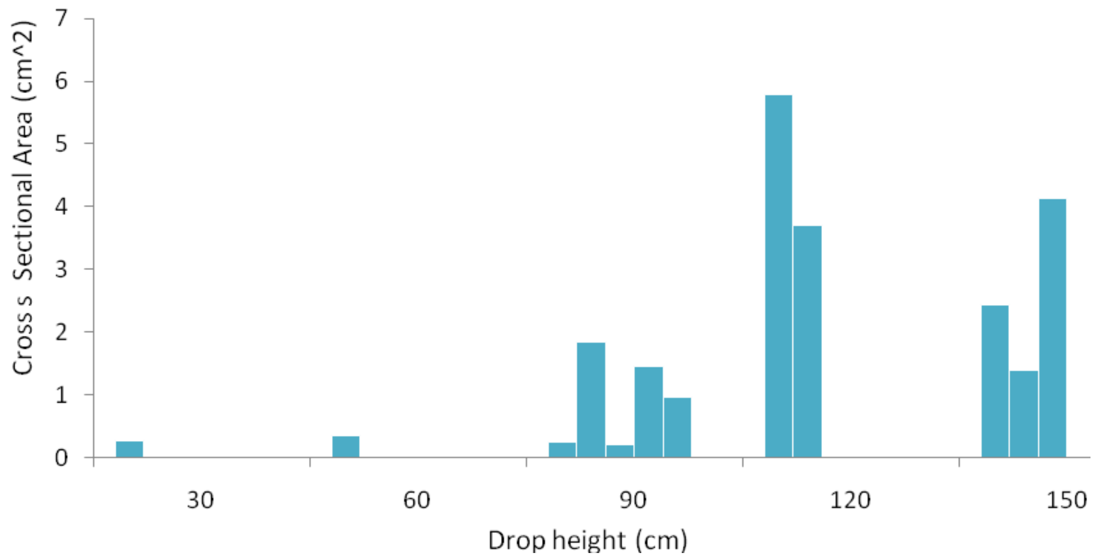


Figure 3-11. Severity of External shatter from ‘1 week after harvest’ drop test for Yukon Gold.(Number of bars for each height = number of tubers detected with bruise, Cross sectional area of shatter = severity of shatter).

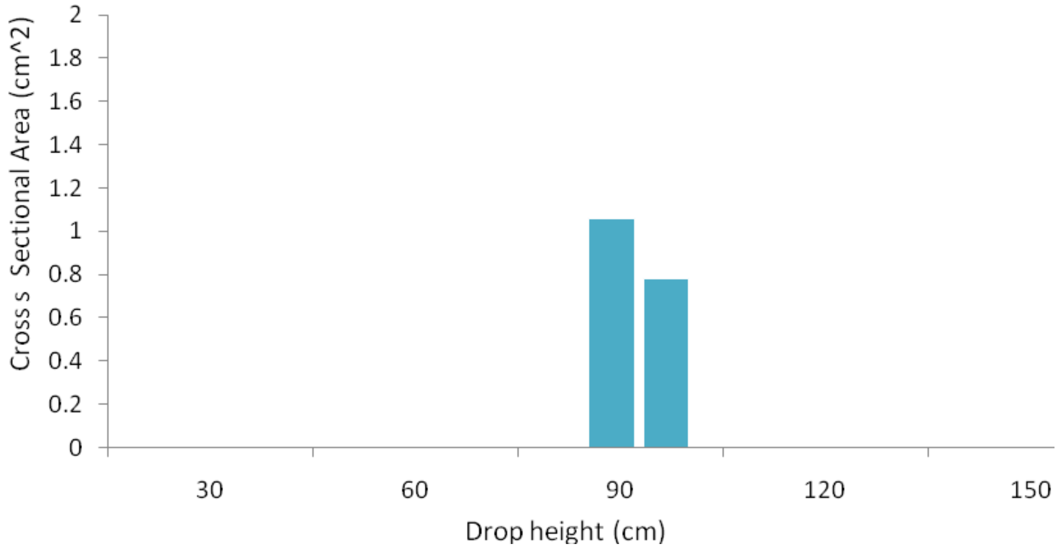


Figure 3-12. Severity of Internal shatter from '1 day after harvest' drop test for Yukon Gold. (Number of bars for each height = number of tubers detected with bruise, Cross sectional area of shatter = severity of shatter)

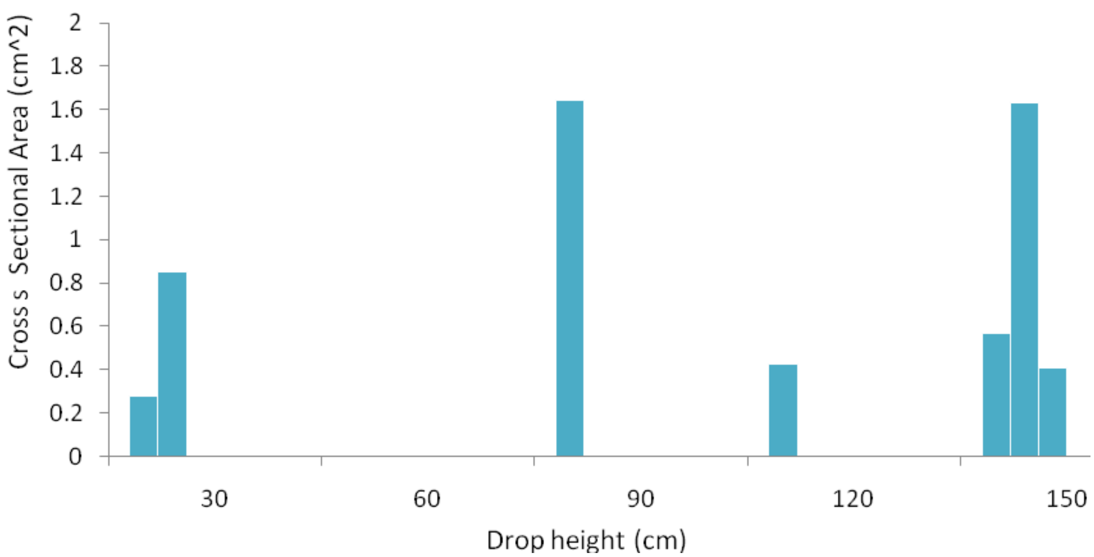


Figure 3-13. Severity of Internal shatter from '1 week after harvest' drop test for Yukon Gold. (Number of bars for each height = number of tubers detected with bruise, Cross sectional area of shatter = severity of shatter)

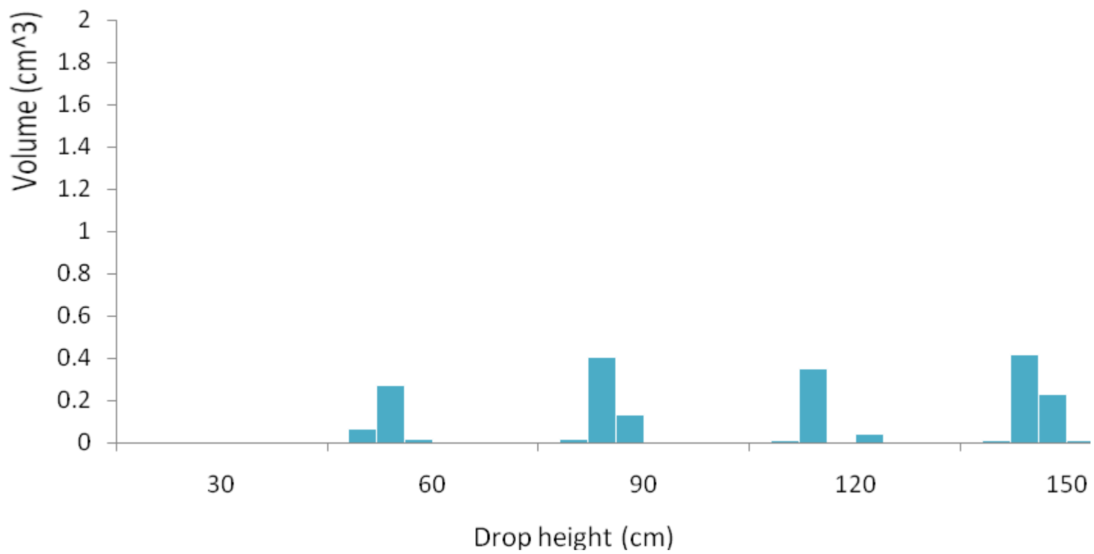


Figure 3-14. Severity of Black spot from ‘1 day after harvest’ drop test for Yukon Gold (Number of bars for each height = number of tubers detected with bruise, volume of bruise = severity of black spot).

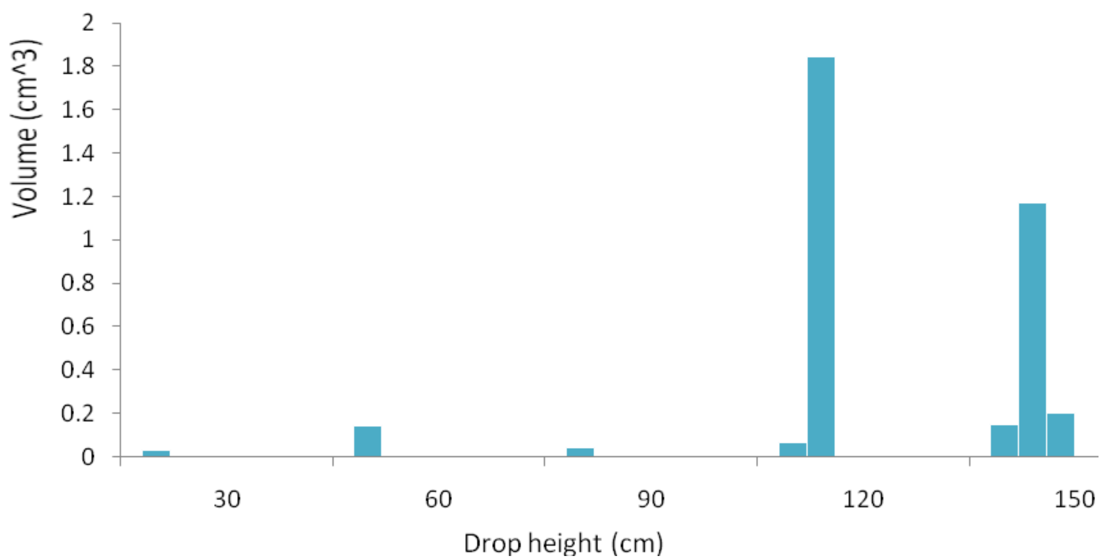


Figure 3-15. Severity of Black spot from ‘1 week after harvest’ drop test for Yukon Gold.(Number of bars for each height = number of tubers detected with bruise, volume of bruise = severity of black spot)

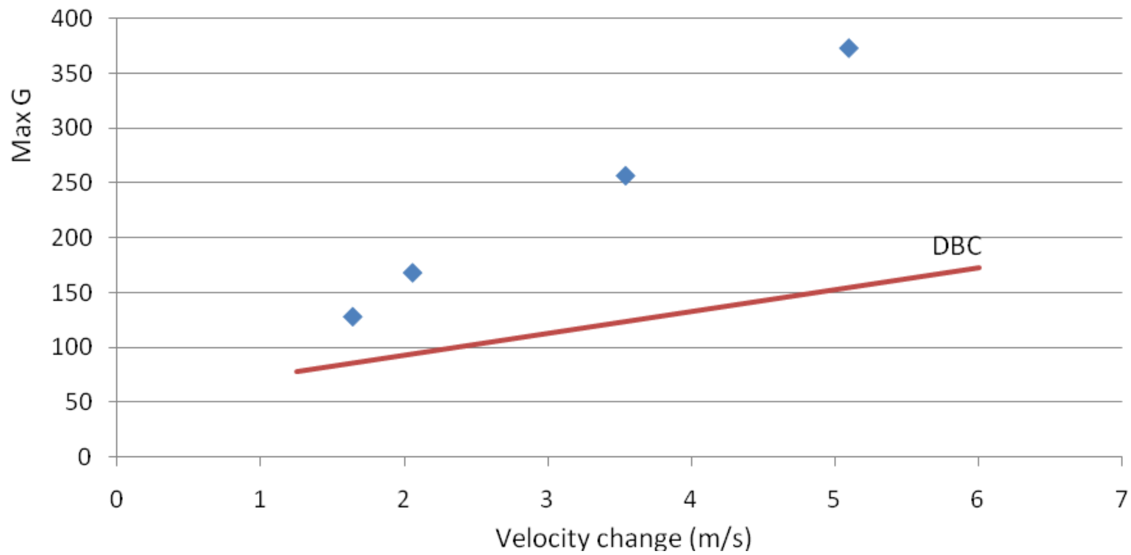


Figure 3-16. Maximum G versus velocity change for different drop heights with damage boundary curve (DBC).

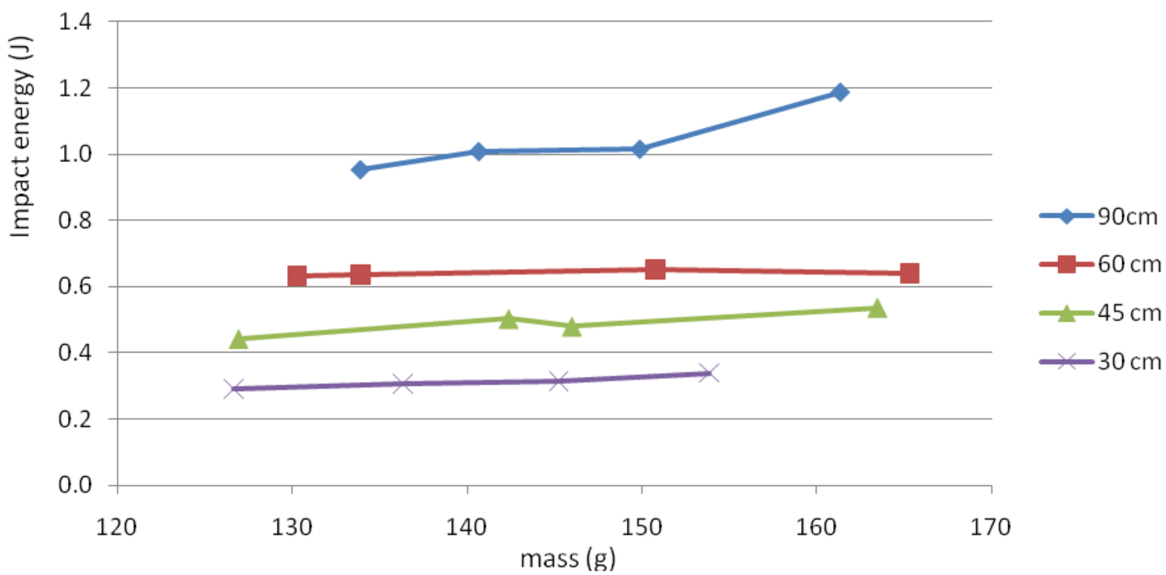


Figure 3-17. Impact energy against potato mass for different drop heights.

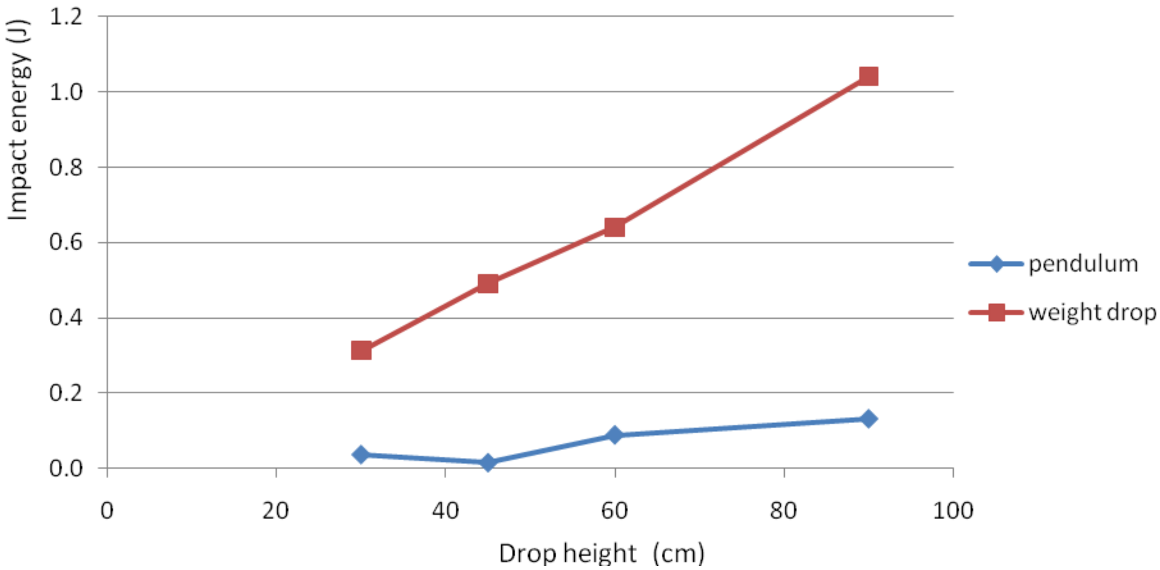


Figure 3-18. Impact energies versus drop height for the pendulum and weight drop simulations.

CHAPTER 4
CONCLUSIONS

The major type of external mechanical damage in the harvesting and packing operations for Fabula and Yukon Gold was skinning. The average percentages of potatoes detected with skinning for Fubula and Yukon Gold were 82.3% and 55.5% respectively for the sampling points. Yukon Gold had more resistance to skinning than Fabula. Since peel water content of Yukon is less than that of Fabula Table 3-1, this might be taken as one factor for the difference in skinning. For both cultivars, the harvester contributes a great part of the skinning. The packing line contributed less incidences of skinning to Fabula but increased the severity. The packing line contributed more skinning incidences to Yukon Gold than to Fabula. The highest skinning rating was 'slight' skinning for both cultivars. The regular and the inverted V truck wagons had differences in damage incidences and severity. The inverted V truck wagon had less incidences and severity of skinning than the regular wagon. The percentages of External shatter and cuts damage were generally low for both cultivars (less than 10%) and there were no big variations across the packing line.

Black spot was the major type of internal damage that was detected for both Fabula and Yukon Gold. The harvester was the main sources of black spot. There were more severe cases of black spot for Fabula than Yukon Gold. The inverted v truck had more incidences of black spot than the regular truck. The two maximum G values (94.1 and 81.6) from the harvester were higher than most of the values from the packing line except for the values of 'Sorting table to elevator to accumulator' and 'Exit from Odenberg sizer to drying rolls' drops (101.43 and 100.73 respectively). The following were concluded from the mechanical damage assessment on the harvester and packing line study:

- the major source of skinning is the harvesting operation;
- while the packing line does not significantly increase incidences of skinning it increases the severity;
- Yukon Gold was more resistant to skinning than Fabula;
- skinning and internal shatter on the packing line were contributed by dumping;
- the harvesting operation is responsible for the large part of black spot and cuts;
- use of the inverted V truck reduces skinning but introduced black spot;
- most the mechanical damage on the packing line was caused by the two impact drops; ‘Sorting table to elevator to accumulator’ and ‘Exit from Odenberg sizer to drying rolls’.

Three types of damage were observed in the weight drop simulations; external shatter, internal shatter and black spot. No cases of skinning were observed from the simulations. This indicated that skinning is not the action of drop forces that were simulated. While the incidences of damage generally increased with the drop height for both cultivars, for Fabula, the damage incidences changed from black spot to external shatter as drop height increases. It was observed that Yukon Gold’s resistance to damage generally decreased with decrease in water content of peel. For both cultivars, there was more external shatter and internal shatter damage than black spot in the ‘one week after harvest’ tests than the ‘one day after harvest’ test of Yukon Gold. Black spot was prominent in the ‘one day after harvest’ test for Yukon Gold. For the potato mass range used in this work, it was observed that the amount of energy absorbed by the tuber mostly depended on drop height as compared to the tuber mass. Therefore potatoes dropped from the same height experienced very similar impact forces.

However, energy absorbed by the potato in the weight drop test was higher than a suspended potato in the pendulum test for an equivalent drop height. The following were concluded from the drop simulations results;

- potato drop impacts on the flat surface did not cause skinning damage;
- bruise resistant for Yukon Gold decreased with the decrease in water content;
- bruise incidence was not directly related to the drop height;
- bruise Severity was directly proportional to drop height and this agreed with the relationship between the maximum G and drop height in the IRD simulations;
- external shatter and internal shatter were associated with low water content tubers while black spot was more associated with high water content tubers for Yukon Gold disagreeing with what reported by San Luis Hills Farm, (2009);
- pendulum impact from an equivalent 'damage' weight drop height did not transfer enough energy to cause damage to the suspended potato;
- one week after harvest, Fabula was more resistant to mechanical damage from drop impacts than Yukon. The bruise resistance for Yukon Gold decreased from 'one day after harvest' test to 'one day after harvest' test.

From the above conclusions, the harvester is main source of tuber bruising and these results agree with what was reported by San Luis Hills Farm, (2009). It is recommended that the harvesting practices as listed by San Luis Hills Farm, (2009) be examined to reduce the potato mechanical damage for the harvesting operation of the Blue Sky Farm. While the measured maximum G's on the packing line had values above 50G, the values for 'Sorting table to elevator to accumulator' and 'Exit from Odenberg sizer to drying rolls' were higher than the rest. These drop points require attention too. The best drop simulations to use to determine the bruise threshold on the packing line were the 'one day after harvest' test. Only Yukon Gold had the 'one day after harvest' test. The drop simulation damage first occurred at 60 cm for Yukon Gold which had maximum G much higher than any of the measured values on either the harvester or the packing line (373.6 G versus highest 101.43 on the packing line). This means that Yukon Gold could withstand impacts of 324.3 G at 45 cm drop height. The value of maximum G at 15 cm (181.2 G) is already higher than the highest on the packing line. The drop simulations values could not be connected to skinning as no skinning was detected in the simulations. If Yukon Gold could withstand the impact of 324.2 G in the drop simulation and sustain damage at 94.1 G and 101.43G on the harvester and the packing line respectively, one explanation could be the repeated impacts on the harvester and packing line. These impacts could accumulate to cause damage. Despite the few irregularities results of this study may have, it is believed that the study provides some useful information to potato farmers growing Fabula and Yukon Gold cultivars in Hastings area in central Florida to reduce mechanical damage. The study could also provide important information for future research on the mechanical damage of fresh potatoes.

LIST OF REFERENCES

Bajema, R.W., G. M. Hyde.1998. Instrumented pendulum for impact characterization of whole fruit and vegetable specimens, *Transactions of the ASAE* 41(5): 1399-1405

Blahovec, J. 2005. Impact induced mechanical damage of Agria potato tubers. *Transactions of the ASAE*. 51 (2): 39–43.

Blahovec, J. 2006. Shape of bruise spots in impacted potatoes. *Postharvest Biology and Technology*. Elsevier Science 39:33, 278-284.

Brown, G.K., C.L. Burton, S.A. Sargent, N.L. Schulte Pason, E.J. Timm, D.E. Marshall. 1989. Assessment of apple damage on packing line, *Transactions of the ASAE* 5(4): 475 – 484.

Campbell,D.T., S.E. Prussia, R.L. Shewfelt, Evaluating postharvest injury to fresh market tomatoes, 1985, http://ageconsearch.umn.edu/bitstream/26478/1/17020016.pdf, Accessed on August 2009.

Canadian Food Inspection Agency. Canadian potato descriptions, 2009, http://www.inspection.gc.ca/english/plaveg/potpom/var/indexe.shtml#y, Accessed on October, 2009.

Cargill B.F. 1986. Engineering for Potatoes. Michigan State University and American Society of Agricultural Engineers, St Joseph, Michigan.

Fluck R.C., E.M. Ahmed. 1973. Impact testing of fruits and vegetables. *Florida Agricultural Experiement stations* 4506: 660-666.

Instron, Impact testing, 2009, http://www.instron.us/wa/applications/test_types/impact/default.aspx?, Accessed on August 2009.

Lee Eunkyung. 2005. Quality changes induced by mechanical stress on roma-type tomato and potential alleviation by 1-Methylcyclopropene. M.S. thesis. Horticultural Sciences Dept. University of Florida.

Macaulay, M.A. 1987. Introduction to Impact Engineering. Chapman and Hall Ltd, New York.

Mathew, R., G.M. Hyde. 1997. Potato impact damage thresholds. *Transactions of the ASAE* 40(3):705-709.

Mohsenin, N.N. 1980. Physical Properties of Plants and Animal Materials. Gordon and Breach Science Publishers, New York.

Molema, G.J., P.C. Struik, B.R. Verwijs, A. Bouman, J.J. Klooster. 2000. Impact measured by an instrumented sphere. *Potato Research Journal* 43: 225- 238.

Pringle, B., C. Bishop, R. Clayton. 2009. Potato Postharvest. MPG Books Group, UK.

San Luis Hills Farm. Bruise prevention, 2009, http://www.slhfarm.com/bruiseinfo.html, Accessed on September, 2009.

Sargent, S.A., J.K. Brecht, J.J. Zoellner. 1990. Analysis of tomato and bell pepper packing lines using the instrumented sphere. *Transactions of the ASAE* 90-6024.

Shewfelt. R. L., S.E. Prussia. 1993. Postharvest Handling. A System Approach. Academic Press, San Diego.

Singh, D.P., A. Singh. 2005. Disease and insect resistance in plants. Science Publishers, Enfield.

Stevenson, W.R., R. Loria, G.D. Franc, D.P. Weingarter. 2001. Compendium of Potato Disease. The American phytopathological Society. St. Paul, Minnesota.

Stronge, W.J. 2000. Impact Mechanics. Cambridge University, New York.

Techmark-inc. Impact recording devices, 2008, http://www.techmark-inc.com/impact.asp., Accessed on September, 2009.

Thompson, A.K. 2003. Fruit and Vegetables Harvesting. Handling and Storage. Blackwell, Oxford.

USDA. 1998. Manual of Official Visual Aids for potatoes. Fruit and Vegetable Programs Fresh products Branch, Washington, DC. 20250.

Vreugdenhil, D., J. Bradshaw, C. Gebhardt, F. Govers, D.K.L. MacKerron, M.A. Taylor, H.A. Ross. 2007. Potato Biology and Biotechnology Advances and Perspectives. Elsevier, Amsterdam.

Zahara. M,, J. McLean, D. Wright. 1961. Mechanical injury to potato tubers during harvesting. *California Agriculture* 15(8):4-5.

BIOGRAPHICAL SKETCH

Jonathan Chiputula was born in 1970 in Dowa, Malawi, where he grew up. He obtained his Malawi School Certificate at Robert Blake Secondary School in 1992 and Bachelor's degree in mechanical engineering from University of Malawi in 1998. He worked as a Data analyst in the Striga Project at Bunda College of University of Malawi in 1999. He joined Dimtech Farm Emprise in 2000 as an Engineer. Between 2002 and 2008, he worked in the Agricultural Engineering Department, Bunda College of University of Malawi as teaching assistant. He joined University of Florida in 2008 as master's student where he received his Master of Science degree in agricultural and biological engineering in December, 2009. Jonathan is married to Chionetsero They have a daughter and a son; Chilungamo and Watipatsa.