A CLASSIFICATION SYSTEM FOR IMPACT RELATED DEFECTS IN POTATO TUBERS

by

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Abstract

Bruise type indicates potato tuber condition in relation to impact sensitivity. This article describes a standardized method of impacting tubers and of classifying the resulting bruises by type. It then relates bruise type to tuber condition. Such information is important because tuber conditioning can be used to reduce risk of bruising during harvesting and handling. The article describes and illustrates each class of bruise type found in both research and commercial potato production, and shows how these bruises indicate tuber condition. Growers, processors, storage operators and fresh packers can use this system to make informed decisions on adjusting modifiable factors such as temperature, hydration level, and impact velocity to reduce impact-related defects during harvesting and handling of potatoes.

Introduction

Impact damage in potatoes is costly. Brook (1996) estimated that a 1-% reduction in the number of impact-related defects in potato tubers (*Solanum tuberosum*) is worth approximately $7.5 million in an average year in the United States. One large processor estimates that each percentage point of total defects costs over $4 million annually. Managing tuber condition, handling system design, handling system operation, or all three can control impact damage. This article addresses assessment and management of tuber condition for the purpose of reducing bruising during handling.

The purpose of this bruise classification system is two-fold:

1. To provide an objective, repeatable method of evaluating tuber bruise damage, in both amount and type.

2. To use damage type as an indicator of tuber condition. Then managers can predict whether a given lot of tubers will easily bruise during handling, and either condition them or modify handling procedures and/or equipment to reduce the risk of handling damage.

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The following requirements are implicit in this approach:

- That the tubers tested must be impacted in a consistent, repeatable manner that simulates impacts that are likely in real handling situations. (Dropping spherical weights onto tubers does not simulate real handling impacts.)
- That knowledge of tuber condition relative to impact sensitivity is useful in managing crop condition and handling systems to reduce bruising.

Background

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 judgements 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). A standardized bruise classification system based on standardized impacts would provide the potato processing industry with a common-language assessment of tuber condition relative to impact sensitivity, allowing valid, objective comparisons across time and distance.

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). Figures 1 and 2 (from Thornton et al., 1974) show how damage type and amount vary with hydration (Figure 1) and temperature (Figure 2). The top curve (Figure 2) is the sum of the curves in Figure 1; the other two curves in Figure 2 are for warmer temperatures. These two Figures show the complex effects of temperature and hydration on potato bruising type and amount.

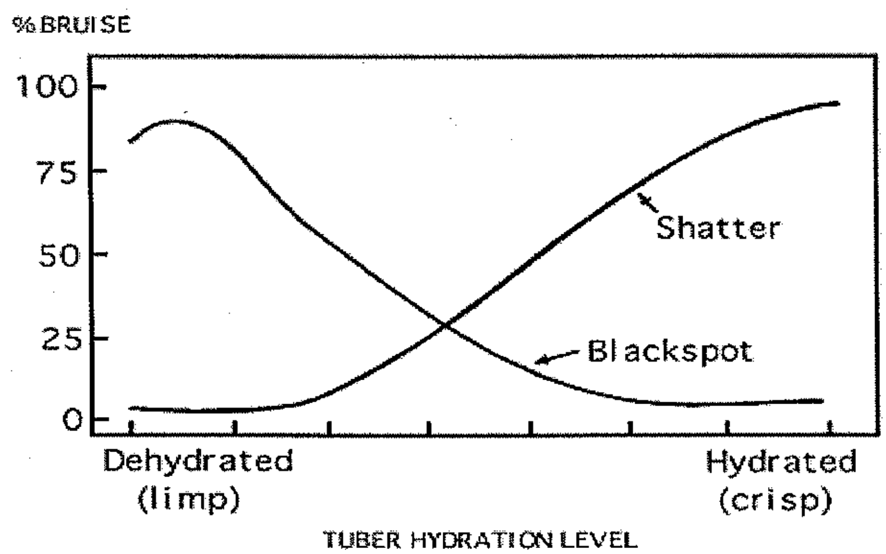


Figure 1. *Percent bruised tubers by bruise type and hydration (Thornton et al., 1974).*

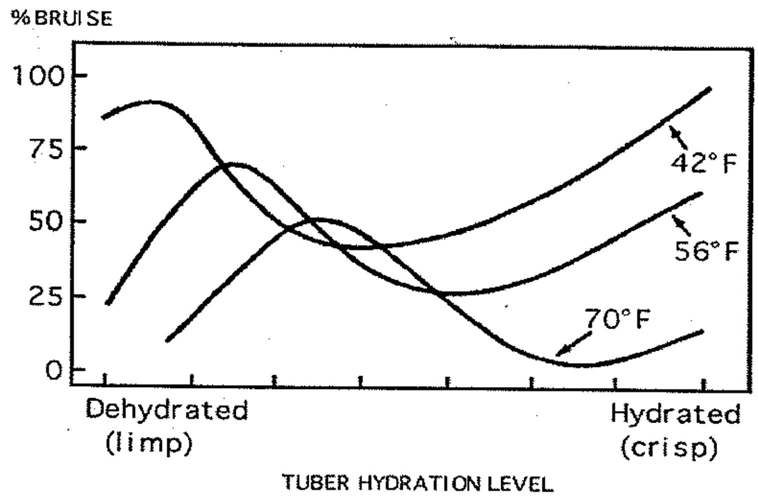


Figure 2. *Percent bruised by hydration & temperature (Thornton et al., 1974).*

Figure 3 (Mathew and Hyde, 1997) shows the effect of drop height on bruise type at relatively low temperature. Note that blackspot occurred at lower drop height, but as drop height increase the bruise type changed to more brittle failure; and above about 22 inches all damage was other than blackspot.

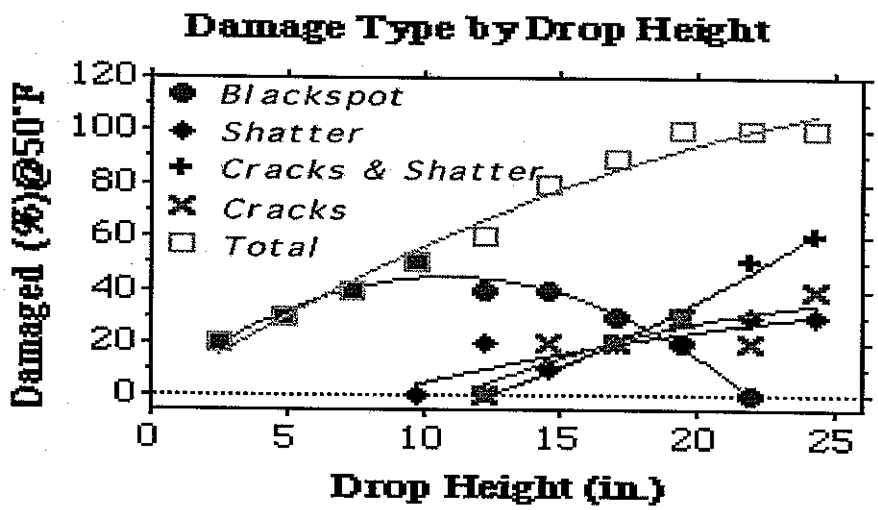


Figure 3. *Percent bruised Russet Burbank tubers and damage type by drop height at 10°C (50°F) (Mathew & Hyde 1997). Tests were run in Feb., after tubers had been stored; and impact surface was rigid steel.*

Figure 3 shows that impact bruise types are a continuous spectrum ranging from blackspot to the most brittle kind of tissue failure, cracking. Thus, if bruise type is to be used to assess tuber condition, then the impact drop height used to create the bruise for the bruise evaluation must be carefully controlled. Tuber weight must also be in a narrow range to keep the impact energy nearly constant. (Tuber size and drop height are specified later in the classification procedure.)

Managing temperature, hydration (turgor), and impact drop height through tuber conditioning or handling system modification can result in significant decreases in impact sensitivity and hence reduced handing damage. The classification system presented below is intended to be objective and widely applicable, and also to give insight into the kinds of impacts that may have caused the bruises.

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 blackspot bruise is a result of oxidation of tyrosine by polyphenol oxidase (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.

For potato tubers, there are two categories of damage: external and internal (Bajema, 1995). External damage includes skinning, cracks, shatter, cuts and scrapes (Hesen and Krosenberg, 1960; Witz, 1954) while internal damage includes cracking, shatter and blackspot (Noble, 1985; Baritelle, 1997). Internal and external damage often both occur during the harvesting and subsequent handling of tubers.

Potato processors and USDA potato inspectors generally classify any type of black discoloration as a 'blackspot bruise;' but growers and processors need a more detailed system to determine how the tubers should be conditioned to reduce impact sensitivity.

One of the most thorough potato bruise classification systems to date was presented by Hughes (1980). The governing mechanisms by which the different types of bruises occurred are presented in Figure 4. This classification system provided the basis for many of the classification systems developed after its publication (Noble, 1985; Mathew, 1992; Bajema, 1995; Baritelle, 1997).

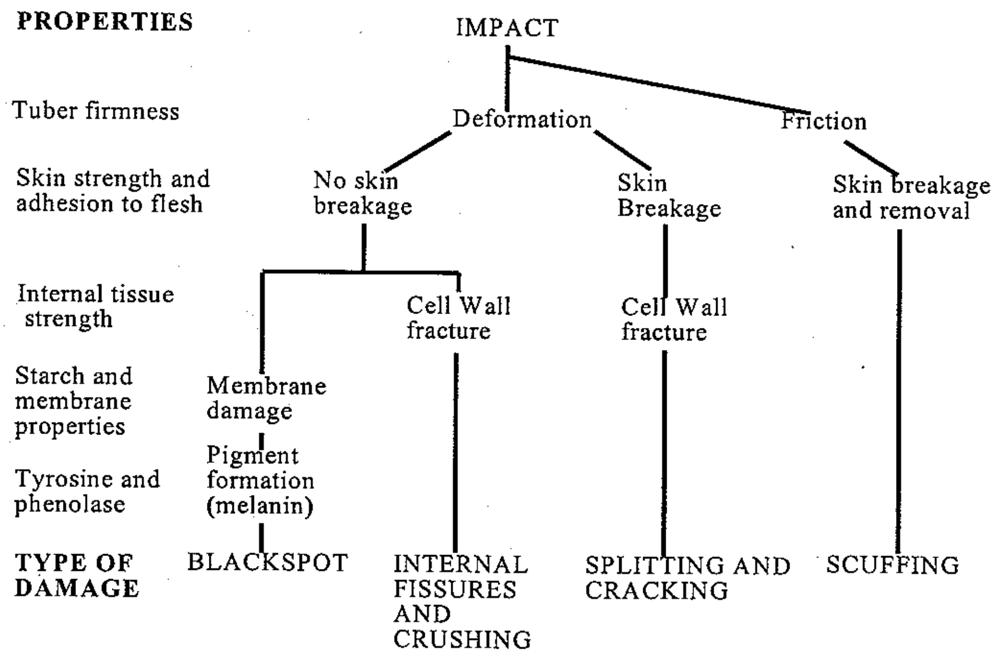


Figure 4. *A diagrammatic representation of the influence that tuber properties have on the major types of damage sustained by potatoes when subjected to mechanical loads. (Adapted from Hughes, 1980).*

Noble (1985) further refined the 'Hughes' system by classifying different types of shatter bruise (star shatter and ring shatter) and providing illustrations of each type of shatter bruise as well as illustrations of a crush type bruise and a classic blackspot bruise. His rationale for differentiating all of the bruise types was summed up in his conclusion:

> "For a given amount of energy absorbed, the type of bruise damage which is produced will depend on the impact duration and the loading velocity: ... low loading velocities will produce mostly blackspot and internal crushing; ... high loading velocities will produce mostly internal shattering."

Mathew and Hyde (1997) reported similar results.

Bajema (1995) and Baritelle (1997) presented further refinements of the Hughes classification system. In both of these systems (Bajema, 1995 and Baritelle, 1997), differentiating the multiple types of internal shatter was not found to be as important as differentiating between internal and external shatter bruise. The system described below added two new classes of bruises to Noble's system; white knot/white spot and external cracking. Bajema (1995) described white knot as a small area of obviously damaged tissue with little or no tissue discoloration. Mathew and Hyde (1997) demonstrated that dropping tubers from higher drop heights (up to 500 mm) could cause cell debonding, creating a crack to the outside of the tuber surface which may or may not discolor. The failure was thought to be between the cells and it extended through the cortex, to the tuber surface.

Classification Procedure

Achieving consistent, repeatable impacts requires that test tubers be:

1. Of relatively uniform mass (size) (225-285 g; 8-10 oz.)
2. At a temperature consistent with harvesting and/or handling temperature to be used
3. Dropped on stem end
4. Dropped from a uniform, precisely-controlled height (300 mm; 1 ft)
5. Dropped onto a flat, rigid, easily repeatable surface (smooth concrete floor or steel anvil)

After sufficient time for the bruise discoloration to develop (2 days) at room temperature, the bruises are evaluated by making a series for thin slices parallel to the tuber impact surface, continuing from the peel all the way through the bruised tissue (Figure 5). (A potato peeler or a slicer that produces consistent slice thickness in the range of 1-2 mm (1/16 inch) is adequate.) The bruises are scored according to the most brittle type of failure that occurred in a given tuber (see bruise classes below). For example, if a tuber exhibits both blackspot and crush bruising, it is scored as crush (3).

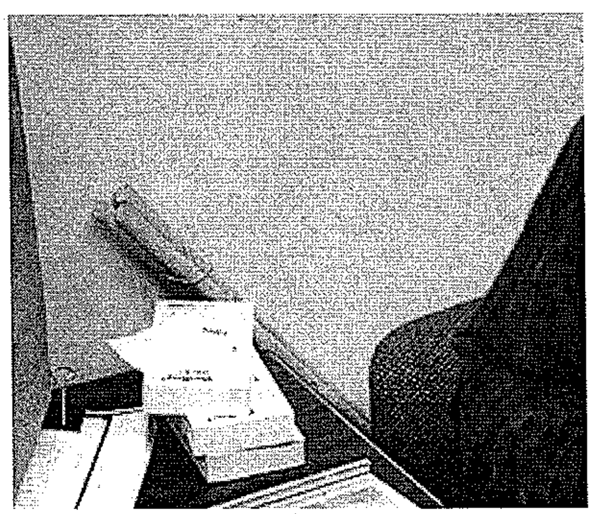


Figure 5. *Author Bajema evaluating bruise types 48 hours after tuber impacting.*

Using the information

We define the bruise classes as 1= no bruise, 2= blackspot, 3= crush, 4= white knot/white spot, 5= internal shatter, 6= external shatter, and 7= cracking (see Figure 6 and Table 1).

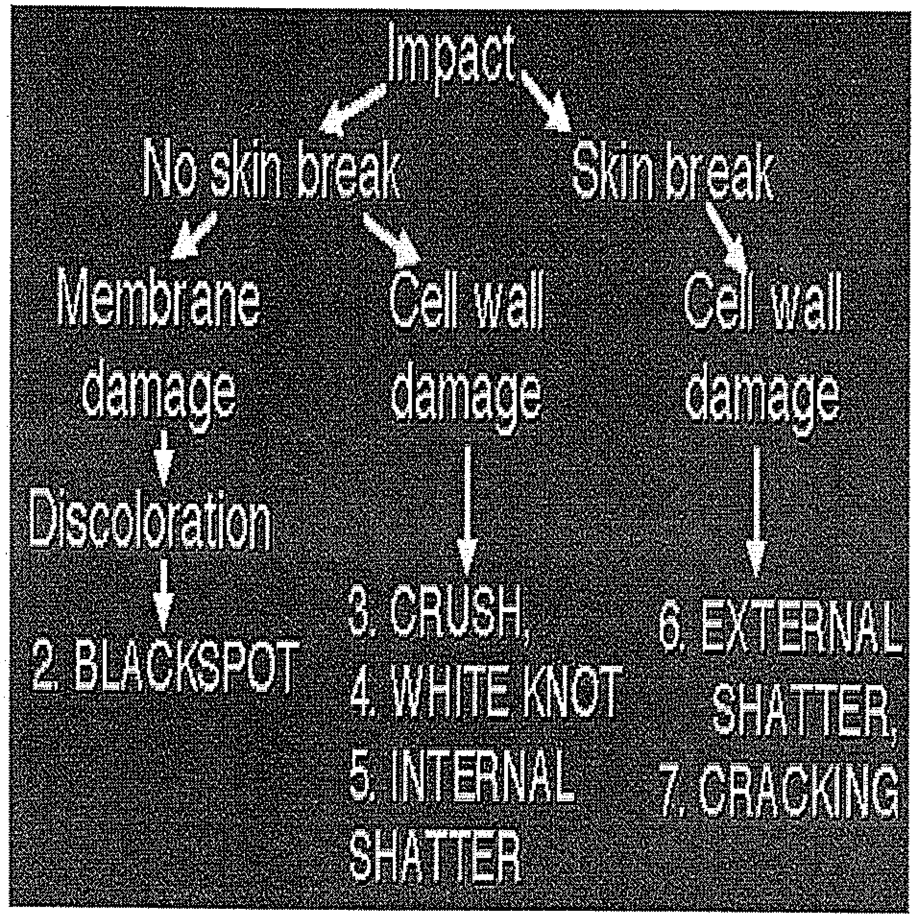


Figure 6. *Bruise types by number.*

As mentioned in conjunction with figure 3, impact bruise types are a continuous spectrum ranging from #1 blackspot to the most brittle kind of tissue failure, #7 cracking. Where a particular tuber of a particular cultivar falls in that spectrum depends on turgor (hydration level), temperature, and drop height. Thus, determining the specific types of bruises that occur provides a basis for choosing appropriate preventative measures that can reduce the amount of bruising that occurs in future handling of a tuber lot. For example, dehydrating turgid tubers slightly can dramatically shift the numbers and types of bruises that occur during handling (Thornton *et al.* 1974) from shatter bruises toward blackspot as shown in Figure 1. Altering temperature and effective drop height can further reduce amount of bruising and alter the type of what bruising does occur.

High damage scores (brittle failure) indicate cold and/or turgid tubers; low scores (preponderance of black spot bruise) indicate flaccid tubers and/or potassium deficiency (Thornton et al., 1974). (Flaccid, i.e., soft tubers can be detected by touch.)

Temperature and hydration conditioning can reduce bruising, depending upon the initial tuber condition. If time or other circumstances don't allow tuber conditioning, then impact velocities (effective drop heights) must be reduced to reduce bruising. Such velocity control is achieved by reducing number and height of drops, by assuring that conveyors are run as full as possible (without spill-out or back feeding under the previous conveyor), or both.

Classification System

The potato bruise classification system presented below is based on work by Bajema *et al.* (1996). It is the culmination of the bruise classification systems used by previous researchers from many different locations using many cultivars. The system was developed by a cooperative effort involving engineering researchers and potato. Descriptions and illustrations of each bruise type are given in Table 1. The bruises found in commercial as well as research samples are not usually as large in size as the bruises presented in the Figures; however, these larger bruises show variability in color within a given bruise. Aside from the white knot/white spot bruises, there can be a wide variety in bruise sizes ranging from one to over 2000 mm^3 (0.00006 to 0.12 $in.^3$).

Measurement of Bruise

The methods of impacting tubers and measuring resulting bruises are discussed in Bajema and Hyde (1998). For all of the illustrations presented below tubers were dropped onto a steel anvil from 200mm (8in). After impacting, the tubers are allowed to sit at room temperature (23°C) for 48 hours. Then tubers are sliced, the slices are carefully laid out (Figure 5) and measurements are then made to estimate the bruise volume. Careful inspection of each slice is then preformed and the most brittle type of failure that occurred classifies the bruise.

Discussion

Even though impact related defects (bruises) take up to 48 hours for color to develop, potato growers and processors can use this bruise classification system to make adjustments to tubers before they are handled. If there is a high incident of shatter type bruises then the grower will know that the tubers should be harvested or handled at warmer temperatures and if possible to dehydrate them slightly. Similarly, tubers can be conditioned to reduce a high incident of blackspot and crush bruises except that turgor modifications are not generally beneficial in this case. However, warmer temperatures and reductions in the impact velocity should reduce numbers and sizes of bruises. Storage operators could also perform a similar procedure before handling. All of these evaluations can be made up to 4 weeks before harvesting or handling (Bajema, 1995; Baritelle, 1997), which allows adequate conditioning time.

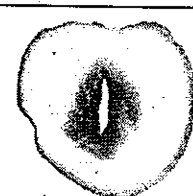
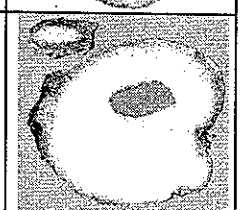
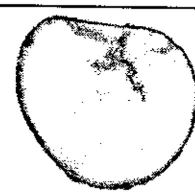
Conclusions

This paper proposes a potato bruise classification. It is possible for more than one type of bruise to be present in a given tuber, further complicating classification of the type of bruise has occurred. The bruise types are listed (Table 1) in order of increasing brittleness of tissue failure and the authors feel that the bruise with the most brittle type of failure should be the bruise that is recorded. For example, if a tuber has both crushing and internal shatter bruises (which commonly occurs at lower temperatures in less turgid tubers), the scoring would be an internal shatter.

The research community and the potato processing industry can use this classification system as a diagnostic tool for handling systems and tuber conditioning problems. Implementing system involves taking tuber samples from field or storage, applying an impacting procedure, and assessing the types of bruises present.

This information will help identify conditioning treatments needed before subsequent handling occurs. For example, if there is a high incidence of shatter bruise, the tubers should be warmed and dehydrated slightly before handling.

Table 1. *Summary of the WSU Bruise Classification System, presented by bruise name, description and photograph, order given by increasing brittleness of failure.*

Bruise Type	Bruise description	Photograph
1) No Bruise	No sign of tissue damage or discoloration	---
2) Black-spot	Has no visible cell wall or cell debonding damage although th cells are often damaged. Typically, recent bruises are blue blac and in the perimedulary tissue rather than the cortex. Discoloratio appears within 48 hours at 10-20°C. Blackspot occurs in warmer more flaccid tubers, especially if potassium is deficient; and i associated with lower damaging drop heights (lower impac velocities) (Mathew and Hyde, 1997; Thornton et al., 1974).	
3) Crush	Has obvious cell wall or cell debonding damage in addition to th blue black discoloration seen in blackspot. (Note the hole in th slice.) Like blackspot bruises, crush bruises often occur at lowe drop heights, higher tuber temperatures and/or lower hydratio levels.	
4) White Spot White Knot	White knot and crush bruises are similar except that the damage tissue does not turn the characteristic blue-black color. Free wate from the ruptured cells is absorbed by the surrounding tissue leaving a white "knot" of dehydrated cells. When cut, the bruis can often be easily picked out by hand. This bruise type is mos common in immature tubers and in tissue with low failure strain (The photo is from the Atlantic cultivar.) Resulting high stres concentrations lead to very localized crushing under impact loads.	
5) Internal Shatter	Has distinct failure planes where the tissue has sheared; generall indicates more brittle tissue failure than crush bruise. Normall occurs in the perimedulary tissue; but occasionally one failur plane will extend into or through the cortex to the outside tube surface. Both cell debonding (distinct planes) and damage to th cells (resulting in the discoloration) are found. These bruises occu in tubers at lower tuber temperatures, higher drop heights (Mathe and Hyde, 1997) and in tubers that are more hydrated (Thornton e *al*., 1974).	
6) External Shatter	Distinct failure planes are found in external shatter bruises however at least two failure planes extend through the cortex to th skin, unlike internal shatter. External Shatter bruises tend to hav a brownish rather than the characteristic blue black color o previous examples, probably because of air entering the crack an drying the tissue before complete oxidation can occur.	
7) External Cracking	Characterized by little or no tissue discoloration because failure i mostly by cell debonding. The cracks are often long and narro through the tuber parallel to the direction of impact. This bruis type is rare but occurred occasionally in tubers dropped up t 500mm on a rigid surface (Mathew and Hyde, 1997). Externa cracks indicate serious problems in handling systems.	---

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