Tuber-Machine Interaction and Conditioning to Reduce Impact Bruising

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Abstract
This article discusses the effects of temperature and turgor on bruising in potato tubers and gives a new method of predicting bruise threshold from these variables. In addition, it discusses effects of radius of curvature and tuber size on bruising, and the importance of tuber-machine interaction in reducing bruising.

Why bruises occur

Impact bruises occur when the impact-induced stress (stress = force/area) in a tuber exceeds its tissue failure stress (i.e., tissue strength), causing that tissue to fail. The kind of bruise that results depends to great extent on the tuber condition (warm or cold, turgid or flaccid) and the impact velocity (how far the tuber falls and the amount of cushioning involved). For example, Mathew et al. (1997) found when dropping tubers from the same lot from different heights, that while blackspot bruises occurred at the lower drop heights, as drop height increased, less blackspot and more shatter bruises and cracking occurred. For colder tubers (50°F), no blackspot occurred at the higher drop heights.

One measure of bruise susceptibility is tuber 'bruise threshold,' the drop height at which bruising just begins to occur for a given tuber size, radius of curvature at the point of impact, and impact surface character (such as stiffness or hardness and radius of curvature). Thus, bruise threshold is the drop height at which the impact-induced stress in the tuber just begins to exceed tuber tissue failure stress. So if you want to know how far you can drop a tuber without bruising it, the answer depends upon: tuber size, radius at point of impact, tuber tissue strength and stiffness, and the impact surface onto which it is being dropped. This article discusses how to use these factors to predict bruise threshold and how to modify tissue strength and stiffness to improve bruise threshold.

Reducing bruising

We can reduce impact bruising by:

1. improving cushioning,
2. reducing effective drop heights through better machine design and/or operation,
3. redesigning drops so that tubers don't land on-end where radius of curvature is small,
4. conditioning the commodity to:
   - increase failure stress (σ_f, strength),
   - increase failure strain (ε_f, deformation/initial length) to increase 'self cushioning',
   - or both.

A word about self-cushioning (Figure 1) A tuber that is less stiff (softer) will distribute a given impact force over a larger area, resulting in less stress induced by that force and so less likelihood of a bruise occurring. So making the tissue less stiff can reduce bruising, up to a point. (More on that point later.)

Temperature & turgor conditioning

Figure 2 shows how strain rate, turgor, and temperature affect potato tuber tissue, as well as the tissues of apples and 'Bartlett' pears. The graph is stress (σ) on the vertical axis and strain (ε) on the horizontal axis. The peak of the curve is where the tissue fails and shows failure stress and failure strain (σ_f and ε_f). Stiffness, $E = \sigma_f / \varepsilon_f$, so stiffness is the slope of the curve near the failure point. A steeper curve means stiffer tissue.

Notice in Figure 2 that as temperature increases, the tuber tissue failure point moves to the right and very slightly upward. That means that warming the tuber makes the tissue slightly stronger, but makes it have a much greater failure strain; i.e., that is deforms further before the tissue fails. The result is that the tissue becomes both stronger and less stiff, so that the tuber self-cushions better and is less likely to be bruised. Similarly, if we decrease tissue turgor, the failure point moves to the right and slightly upward; so slight decreases in turgor will reduce bruising up to a point.

A new prediction tool

Our research indicates that all of the variables discussed above (tuber mass, radius of curvature, failure stress, and failure strain) can be used to predict bruise threshold in the following equation:

$$h = 7600\,(\sigma_f)\,(\varepsilon_f)^4\,R^3/(mg) \qquad (1)$$

where: h = bruise threshold (mm)
σ_f = failure stress (MPa)
ε_f = failure strain
R = radius of curvature (m)
m = tuber mass
g = acceleration due to Earth's gravity (9.81 m/s^2)

Notice that failure strain and radius of curvature are to the 4th and 3rd power, respectively. Those powers mean that these two factors are much more important in determining bruise threshold than are failure stress and tuber mass.

Applications

Tuber radius & machine interaction

This example shows the effect of radius of curvature (Figure 3). A typical 8 oz. Russet Burbank tuber has a radius of curvature R = 9/16 inch (15 mm) at the end and R = 1-3/4 inch (45 mm) on the flattest side. The corresponding bruise thresholds (Figure 3) are 2 and 48 inches (50 and 1220 mm), respectively.

Figure 4 shows a machine that takes advantage of radius of curvature effects. In this machine tubers drop about 9 inches onto the shoulder of a steel drum. Tuber separation from stones and soil clods is based on the principle that the tubers bounce further off the steel drum. Figure 3 indicates that if the tubers landed on their ends on the drum, most of them would be bruised. However, note in Figure 4 that the tubers seem to be landing on their sides. Figure 3 indicates that a 9-inch drop onto the side of the tuber is not likely to bruise many tubers, because the bruise threshold on the sides of the tuber is much higher than 9 inches.

Tuber size effects

Figure 5 shows the effect of tuber mass on bruise threshold, using a radius of curvature of R = 9/16 inch, since the small radius of curvature at the end of a Russet Burbank tuber doesn't change very much with tuber size. While small tuber bruise threshold was about 8 inches, the threshold for large tubers was only 2-3 inches, confirming that large tubers bruise more easily than small ones, especially if they land on their small radius of curvature.

Turgor conditioning

Figure 6 plots failure stress and failure strain for Russet Burbank and Atlantic cultivars by relative turgor (assessed by % weight loss) and by temperature. Looking first at turgor effects, note that for Russet Burbank, as percent mass loss goes from 0-1.5% to 1.5-3%, both failure stress and strain increase, with failure strain increasing considerably. However, further mass loss up to 3-4.5% actually decreased failure stress with only slight increase in failure strain. When we use these values to estimate bruise threshold with equation (1), we get the graph of Figure 7, which shows that mass loss to 1.5-3% improved bruise threshold by 1.67 times, but further mass loss was not helpful.

Temperature conditioning

Figure 8 resulted from using the temperature effects data from Figure 6 to estimate bruise with equation (1). Increasing temperature from 5 to 15°C (41 to 59°F) nearly doubled bruise threshold (1.91 times) for 8-oz. Russet Burbank tubers.

The problem with too much water loss

As we slightly dehydrate tubers to make them slightly softer, the peak impact-induced stress moves deeper into the tuber. That stress can move from the cortex tissue down to the vascular ring and into the perimedulary tissue. As Figure 9 shows, our preliminary data indicates that perimedulary tissue is stiffer than cortex tissue, primarily because it has lower failure strain. The result can be an increase in blackspot bruise susceptibility and effectively a decrease in bruise threshold. There will be more work on this in the future.

Conclusion

We now have results that show how temperature and turgor conditioning affect tuber tissue failure properties; and we have a tool, an equation, for predicting bruise threshold based on tuber mass, radius of curvature at the point of impact, and those failure properties. The equation is not yet a precision tool, but it can predict trends in bruise threshold with changes in tuber properties. We can use this tool to help design handling equipment, to evaluate cultural practices, to help in conditioning tubers to minimize damage, to predict the cost/benefit ratios of doing such conditioning, and to help in evaluating cultivars for bruise susceptibility.

References

Mathew, R. and G. M. Hyde. 1997. Potato Impact Damage Thresholds *ASAE Trans.* 40(3): 705-709.

For more information, go to Dr. Hyde's web site at:
http://www.wsu.edu/~gmhyde/ImpactProperties.html

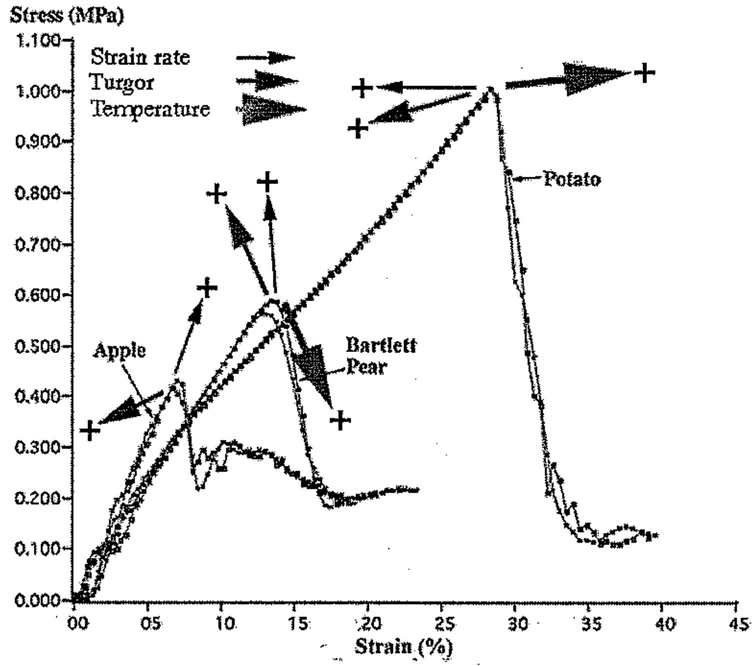

Figure 1. *A resilient sphere impacting a flat, rigid surface. A less-stiff sphere will deform more for a given force, spreading the load over a greater area, and resulting in lower stress in the sphere tissue.*

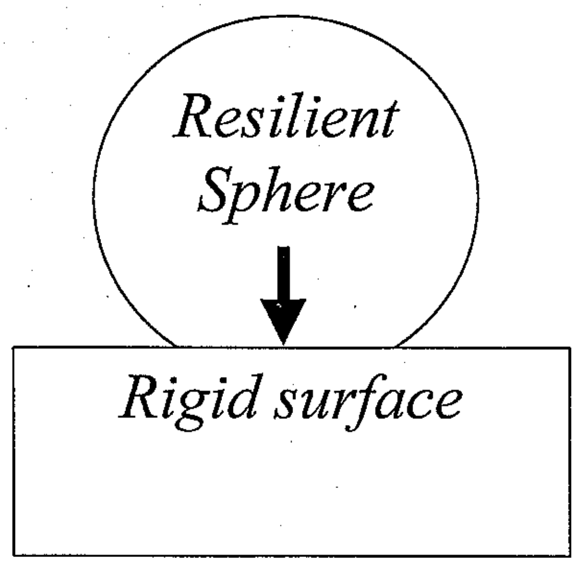

Figure 2. *Stress – strain profiles under impact loading for apples, 'Bartlett' pears and potato tubers, showing movement of the failure point with increasing (+) strain rate, turgor, and temperature.*

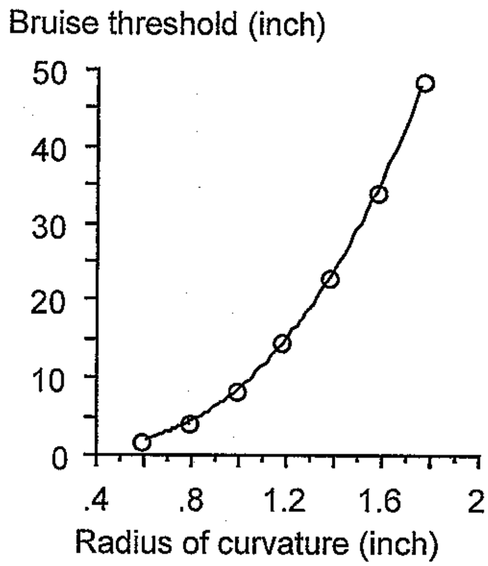

Figure 3*. Bruise threshold variation with radius of curvature. (Bruise threshold calculated using equation 1.)*

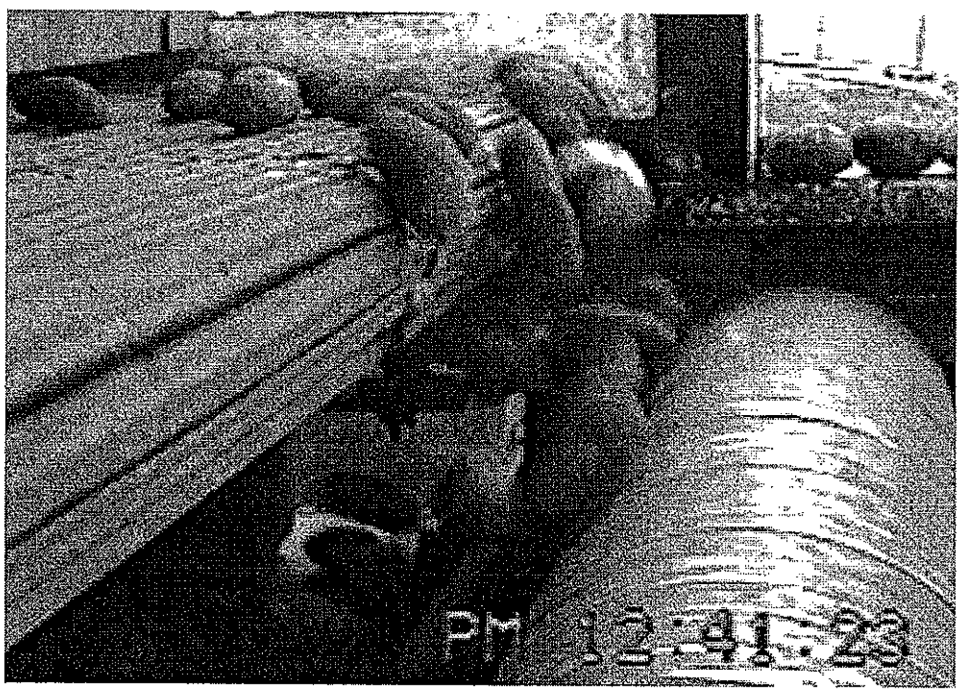

Figure 4*. Machine apparently avoids dropping most tubers on end.*

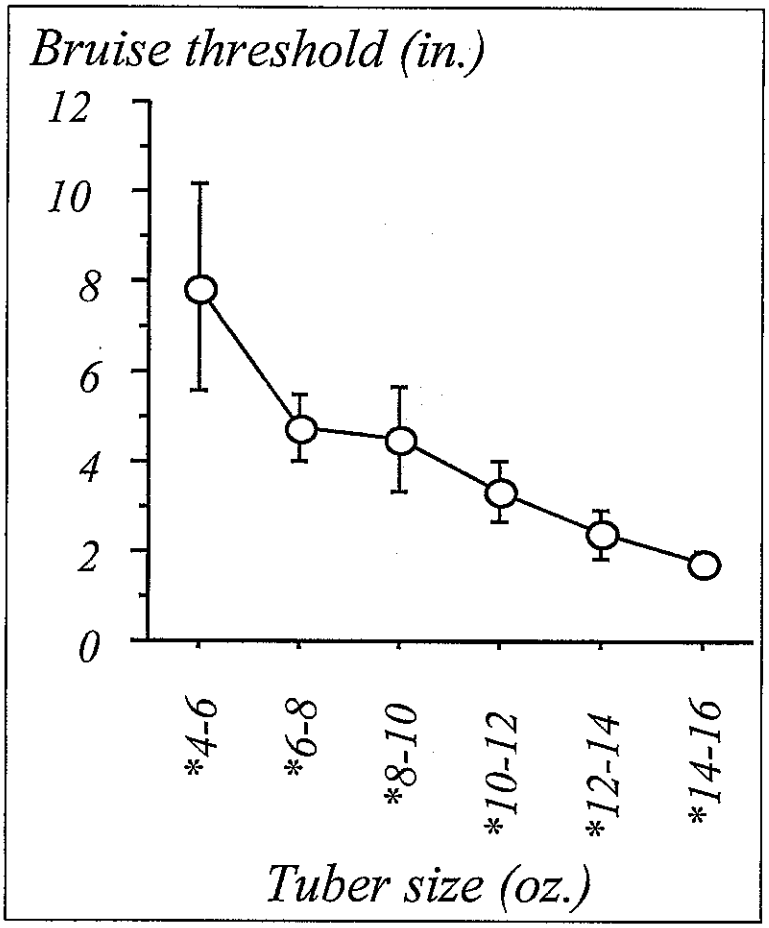

Figure 5. *Effect of tuber size on bruise threshold (with 95% confidence intervals).*

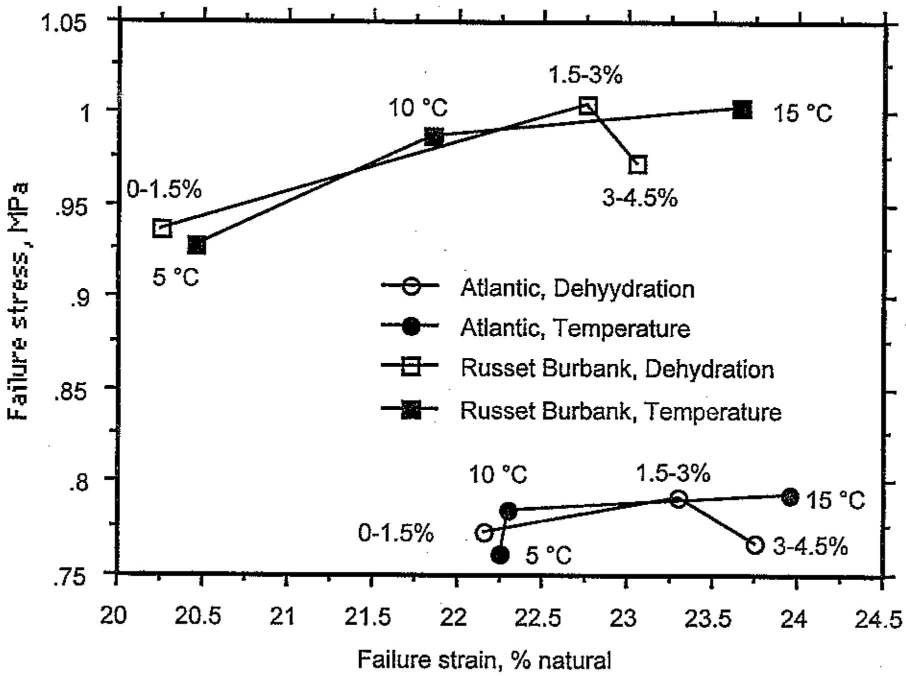

***Figure 6**. Failure stress and strain values for two potato cultivars by temperature and relative turgor (assessed by percent mass loss).*

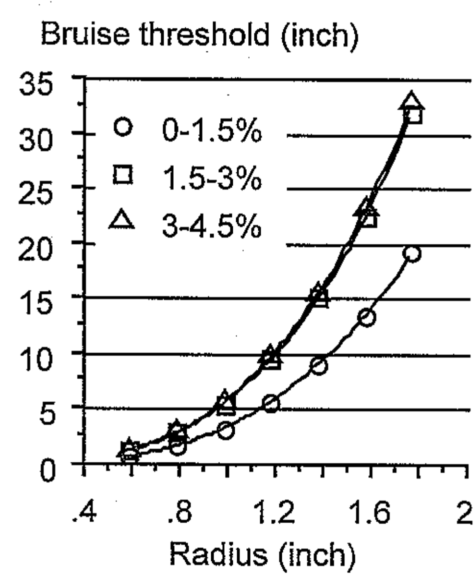

***Figure 7**. Bruise threshold vs. turgor (assessed by mass loss).*

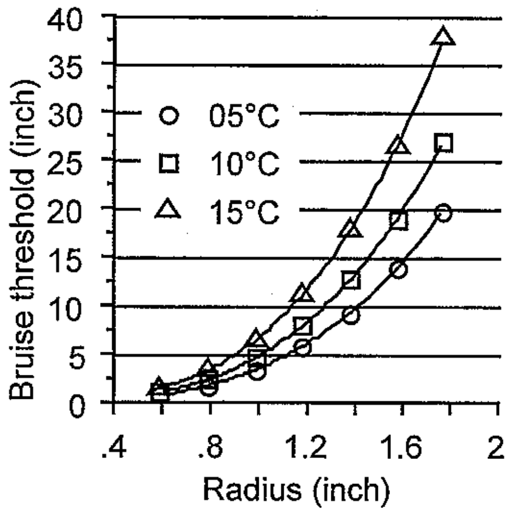

Figure 8. Bruise threshold vs. temperature.

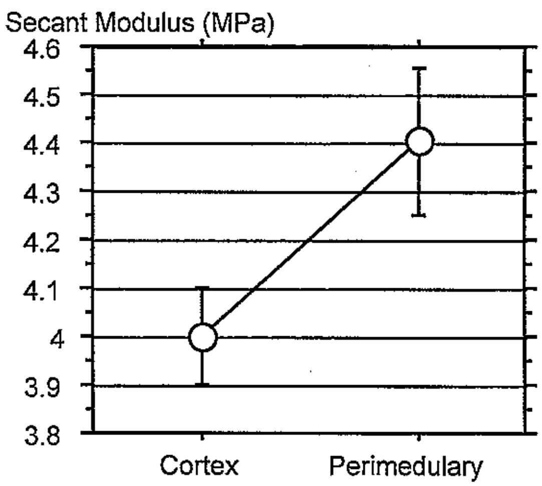

Figure 9. Cortex and perimedulary stiffness.