Science and management of blackspot bruising

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Bruising risk assessment advice sheet - 1

Variety

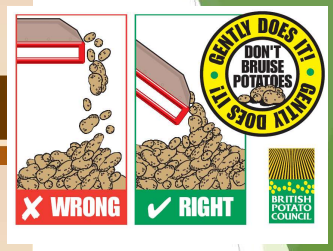
Varieties differ in their susceptibility to bruising. BPC Independent Variety Trials score varieties for their susceptibility to bruising on a 1 to 9 scale (1 = susceptible, 9 = resistant). The table to the right gives some examples, for other varieties see the BPC seed variety

Resistant

Cara	8
Fianna	7
Nadine	7
Sante	7
Saxon	7
Estima	6
Hermes	6

BPC National Bruising Survey
94% of respondents recognised variety as a major influence on crop bruising susceptibility.

ACTION



Bruising risk assessment advice sheet - 11

Soil moisture at burn-off

In the BPC funded BRUCE study, soil moisture at burn-off showed a consistent correlation with tuber susceptibility to bruising. Dry soils were also associated with greater susceptibility. These results support speculation about the water status of tubers around the time of haulm destruction having an influence over bruising levels. Tubers in dry soils could be dehydrated and hence more susceptible to bruising.

Further BPC funded work examining the effects of soil moisture at haulm destruction with that of bruising levels at harvest is being carried out on crops in 2004. The project will determine if a grower has any control on the sensitivity to bruising at harvest through manipulation of soil moisture. The findings of the project should allow guidance on crop management at burn-off.

BRUCE study - how soil moisture at burn-off affects Maris Piper

Soil moisture conditions at burning off	<33% bruised	>33% bruised	Total
Dry	0	8	8
Moist	6	3	9
Wet	3	3	6
Very wet	1	0	1
Total	10	14	24

BRUCE study: Tubers were hand lifted and then subjected to a standard impact. Bruise susceptibility was then correlated with crop history data. The point of separation (e.g. 33% bruised) was chosen to show the biggest difference between treatments. In this case, more crops are bruised where soil moisture at burn-off was lower than under other conditions.

Results from the BRUCE study suggest growers should avoid dry soil conditions at burn-off.

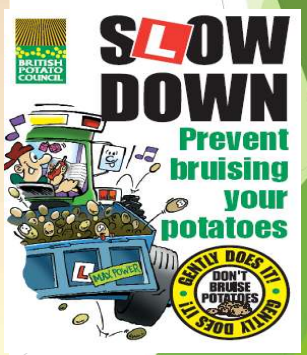
For further information on the BPC funded BRUCE project, BPC Ref. 807/227, and Bruising sensitivity at harvest BPC Ref. 252, see www.potato.org.uk or telephone BPC Publications on 01865 782222.

BPC National Bruising Survey
33% of respondents recognised soil moisture at burn-off as having a major or very major influence on bruising. Furthermore, 38% said they would consider irrigating just prior to burn-off to raise soil moisture levels in a dry season if shown proof that it could make a real difference.

ACTION
- Monitor soil moisture prior to burn-off
- At burn-off, make an assessment as to whether soils are wet/moist/dry. If soils are dry at harvest treat with extra caution
- Register your interest to receive results of BPC funded research on bruising sensitivity at harvest

Potatoes are more likely to bruise.....
.....when soils are dry at burn-off.

Potatoes are less likely to bruise.....
.....when soils are moist at burn-off.



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Factor affecting bruising	Priority 2007	Priority 2025
Crop maturity and dry matter	19	15
Harvester operation	16	14
Variety	16	8
Energy (drop height)	15	8
Soil moisture at burn-off	11	10
Temperature	10	4
Soil moisture at harvest	9	8
Irrigation	4	6
Soil preparation	4	6
Season	2	6
Site selection	1	3
Soil type	1	4
Turgor	1	3
Windrowing time	1	0
Crop nutrition	0	6
Haulm destruction	0	1

3

Shatter cracking

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Blackspot bruising

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Blackspot sensitivity

- Blackspot susceptibility varies between potato varieties and is determined by two tuber qualities:
  - Sensitivity to subcellular decompartmention
  - The biochemical potential to synthesize blackspot pigments
- Sensitivity to subcellular decompartmentation depends on various factors:
  - Specific gravity
  - Dry matter content
  - Number and size of starch granules
  - Cell turgor
  - Mineral content
- The biochemical potential to synthesize blackspot pigments is dependent on both an enzyme, polyphenol oxidase (PPO), and its substrates
- PPO catalyzes the oxidation of phenols to form compounds called quinones
- The quinones can then polymerize to form dark pigments called melanins
- The physical interaction between PPO and its substrates occurs when PPO is released from its subcellular compartment (i.e. vesicles inside the amyloplasts) upon cell disintegration

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Blackspot bruising – simple chemistry

- Integrity (strength and permeability) of membranes between PPO (contained in plastid membranes including the amyloplast) and the substrate (mainly tyrosine, contained in the vacuole) is crucial to prevent contact and thereby colorimetric reaction
- Intensity of colour development is more to do with the number of cells crushed rather than the concentration of tyrosine in each cell
- Deterioration of intracellular membranes may occur for some time after initial impact
- Permeability increases as cells age: may be a cause of blackspot increasing during season (and storage with no additional impact)

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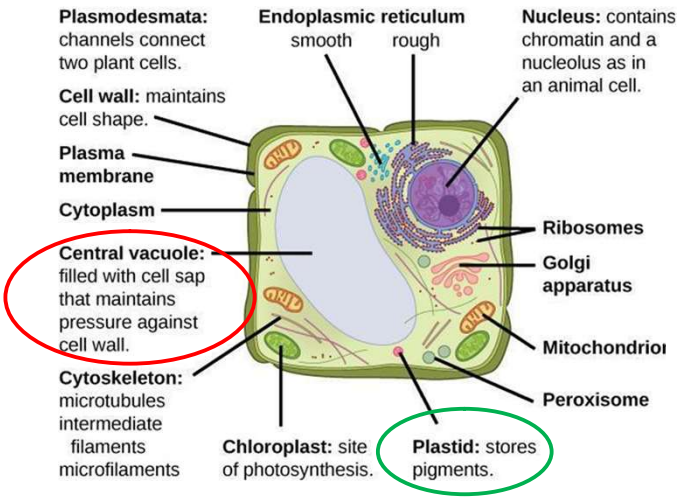
Potato cells



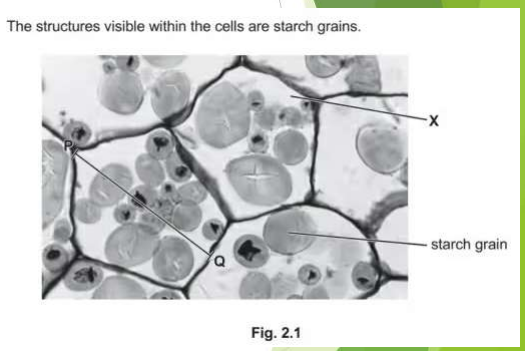


Fig. 2.1

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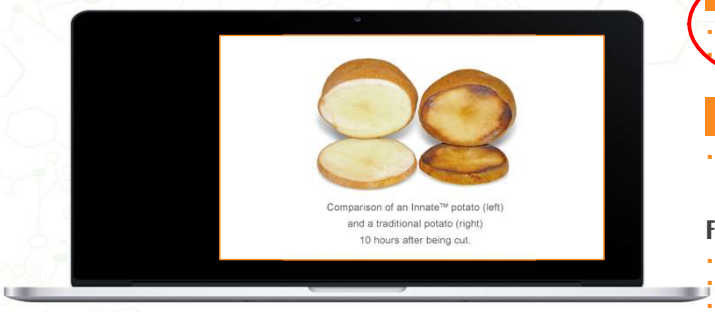
Silencing or downregulating PPO
INNATE™ 1.0 POTATOES



TWO IMPORTANT TRAITS

SILENCED PPO (ENZYME)

- Non-browning when cut
- Reduced black spot bruise

REDUCED ASPARAGINE (AMINO ACID)

- Yields a 50-80% reduction in Acrylamide when baked or fried

FOUR IMPROVED VARIETIES

- Russet Burbank
- Ranger Russet
- Atlantic
- Snowden

No effect on taste, texture, or performance

INNATE

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Mechanisms for PPO

- Low Bruise/non-Browning: PPO5
  - Silenced the 5'UTR or trailer. Specific enough that we don't silence PPO 1-4.
  - Tuber specific silencing
  - Other crops have silenced all PPO genes

Comparison of an Innate™ potato (left)
and a traditional potato (right)
10 hours after being cut.

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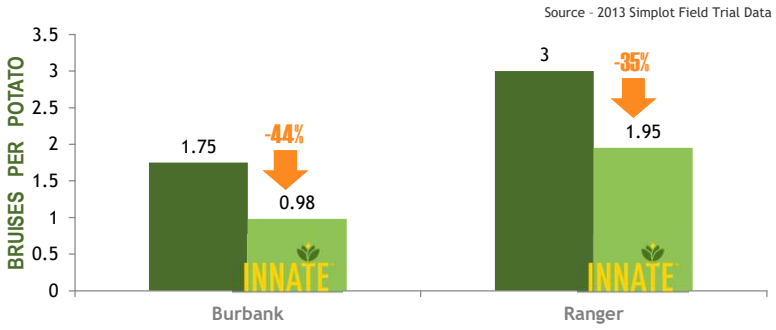
Less bruising



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But what about 'Whitespot' damage?

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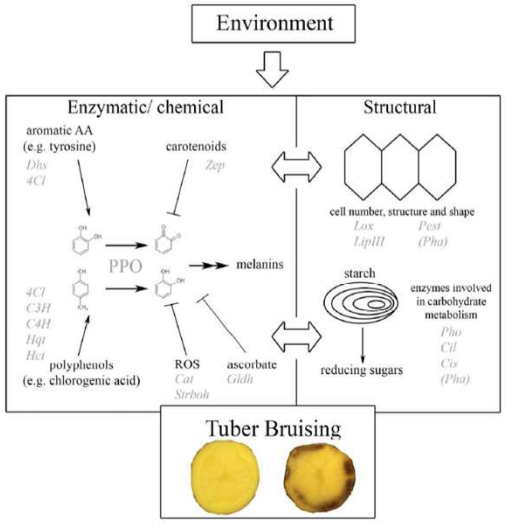
Figure 1 Simplified metabolic scheme of potato tuber bruising and the candidate genes used in the association experiment. Shown are the enzymatic/chemical, structural and environmental components and the involved genes with their corresponding abbreviations. The abbreviations are: AA = Amino acid; ROS = reactive oxygen species PPO = Polyphenoloxidase, 4Cl = 4-coumarate:CoA ligase, C3H = p-coumarate 3-hydroxylase, C4H = Cinnamic acid 4-hydroxylase; Cil = ATP citrate lyase, Cis = Mitochondrial citrate synthase, Cat = Catalase, Dhs = 3-deoxy-7-phosphoheptulonate synthase, Gldh = L-galactono-1,4-lactone dehydrogenase, Hct = Hydroxycinnamoyl transferase, Hqt = Hydroxycinnamoyl CoA quinate transferase, LipII = Triacylglycerol lipase II, Lox = Lipoxygenase, Pest = pectin methyl esterase, Pha = plasma memebrane ATPase; proton pump, Pho = α-glucan phosphorylase L-type, Strboh = *Solanum tuberosum* respiratory burst oxidase homologue, Zep = zeaxanthin epoxidase.



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Tyrosine (Corsini, Pavek & Dean 1992)

- Blackspot index was highly correlated with the tyrosine content of the tubers
- Tubers with free tyrosine levels below 4 µmole/g DW consistently showed a resistant blackspot response
- Bud end samples of each of the clones had lower tyrosine content and a corresponding reduction in blackspot compared with stolon ends
- Phenols, other than tyrosine, showed no consistent relationship to the blackspot reaction

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Scharf et al. (2016)

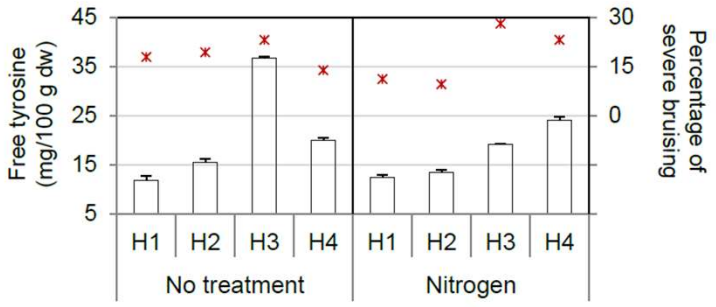

Figure 4.55 Effect of variety, harvest and storage time on free tyrosine of lyophilized cortex (mg/100 g dw) (bars) and percentage of severe bruising (scatter) from crops harvested in September and October, stored until January (S1), March (S2) and May (S3), field trial 2. Value bars show means (n=3), error bars are SE and scatter shows incidence of severe bruising (n=>21).

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Goyer & Pelle (2018)

- Seven russet potato varieties were stored for eight months at 8.8 °C and then were subjected to mechanical impact
- A **blackspot susceptibility index** was calculated for each variety by determining an index for the percentage of the tuber cortex area that was covered with blackspot, and an index for the intensity of blackspot discoloration
- Concentrations of tyrosine, chlorogenic acid, phenylalanine, and ascorbic acid, and **blackspot biochemical potential** of tubers to synthesize pigments were measured in the tuber cortex
- Blackspot indices, metabolites concentrations and blackspot biochemical potential varied significantly between varieties
- **Tyrosine** concentrations strongly, significantly, and positively correlated with **blackspot biochemical potential**
- **Phenylalanine concentrations** showed good, significant, and positive correlation with **blackspot biochemical potential** and discoloration index
- **None of the analyzed metabolites correlated with blackspot susceptibility**

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Summary: “We have a problem Houston!”

- Blackspot biochemical potential is not a good indicator of blackspot susceptibility
- Varieties with low biochemical potential can still be susceptible to blackspot (e.g. Clearwater Russet)
- Varieties with high biochemical potential can show low susceptibility to blackspot (e.g. Alpine Russet)
- In addition to the biochemical potential of the tuber, the sensitivity to cellular breakage that leads to the release of PPO and phenolic substrates from their respective storage subcellular compartments is a crucial determinant of blackspot susceptibility
- Prediction of blackspot susceptibility should therefore include those two tuber qualities

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ROS and antioxidants

- A high degree of electron flux occurs in PPO-catalysed reactions with tyrosine
- Electron flux produces transient ‘free radical’ compounds (ROS) to be produced. These are highly reactive and damaging.
- ROS compounds are used by plants as a defense mechanism against pathogen invasion
- Croy & Johnson (2002) detected correlation between ROS concentration and bruising
- Followed identification of a suitable dye to detect the rate of increase in ROS following an impact, they developed a test (Blackspot Protect)

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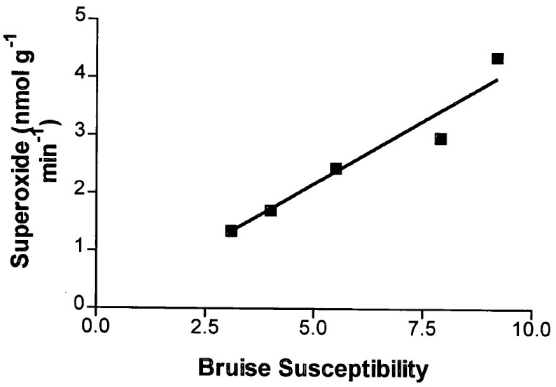
Correlation between maximum superoxide production following impact and tuber bruise susceptibility.
Varieties: Russet Burbank, Saturna, Cara, King Edward, Maris Piper



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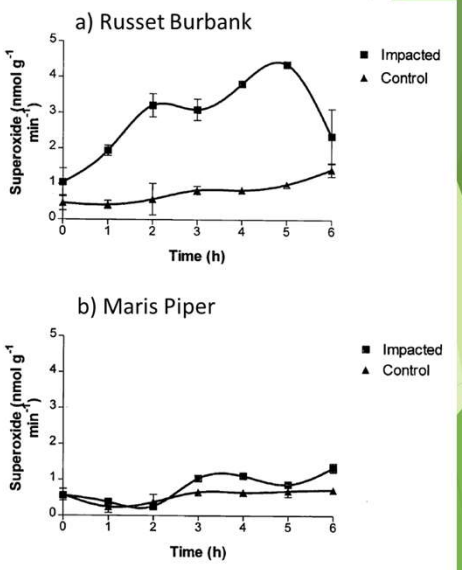
Blackspot Protect bruise kits



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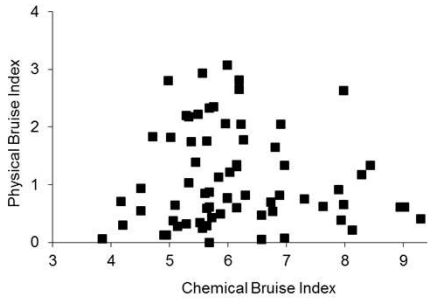
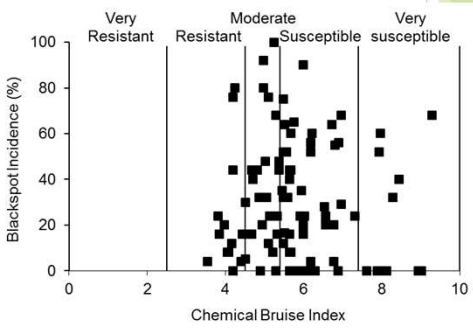
In reality, there was difficulty correlating the differences in bruising…





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ROS

- We should not forget about their role in bruising
- Stress response: whatever may cause that
- Complicated area: no one has come up with a solution yet

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BPC Project R263 Final Report 2004-7

Management of tuber water status to reduce bruising

Mark Stalham

UNIVERSITY OF CAMBRIDGE

Cambridge University Farm

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The equation formulated by Gary Hyde's group in Washington

$$h \approx 7600\ \sigma_f\ \varepsilon_f^{4}\ R^3/(mg)$$

h = potato tuber bruise threshold (drop height)

σ_f = tissue failure stress ("strength")

ε_f = tissue failure strain ("elasticity" or ability to deform before failing)

R = radius of curvature at point of impact

m = specimen mass

g = acceleration due to gravity

Summary:

Small changes in elasticity of tissue have a very large influence on bruising

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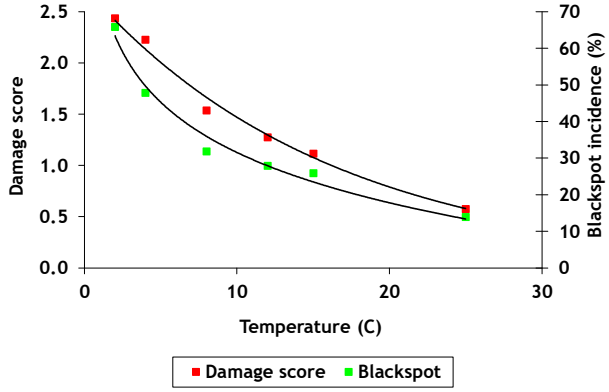
The lower the temperature the worse the bruising: reduced tissue elasticity

Crucial temperature is 8°C: typically occurs around 25th October in eastern England



Low temperatures reduce both the elasticity and strength of tissue

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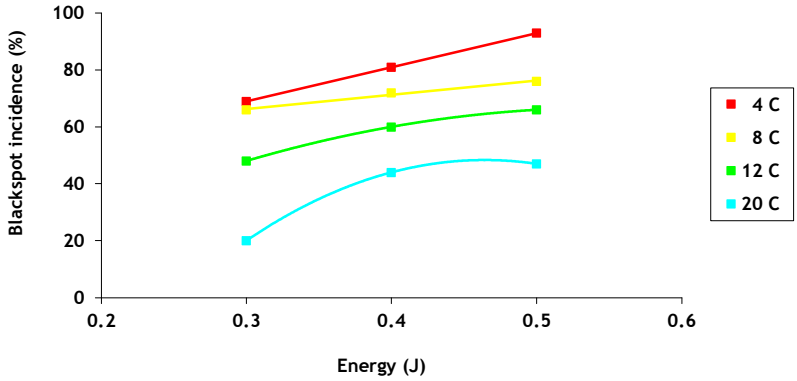
The higher the impact energy, the worse the damage, but it is still temperature dependent



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Summary of temperature and energy

- Harvesting at 8 °C vs 20 °C increases the incidence of BS from 44 to 72% and the volume of each bruise from 111 to 166 mm^3
- This reduction in temperature is the equivalent to decreasing the allowable drop height of a 50-60 mm tuber from 43 cm to 18 cm!

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Where did we look?

Finding out how the hydration status of tubers affects bruising susceptibility, achieved through altering:

- Tissue strength (failure stress)
- Tissue stiffness (elasticity)

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Bruising hypotheses

- Changes in tuber turgor, not [DM], influence tissue strength/elasticity which affects bruising
- Sufficient changes in physical parameters can occur during short periods of drying, not just after prolonged drought stress
- Large changes in tuber turgor induced by prolonged drying take time to correct
- Tubers may not possess the biochemical apparatus (low enzyme or tyrosine) for blackspot bruising until later in the season irrespective of tuber physical properties

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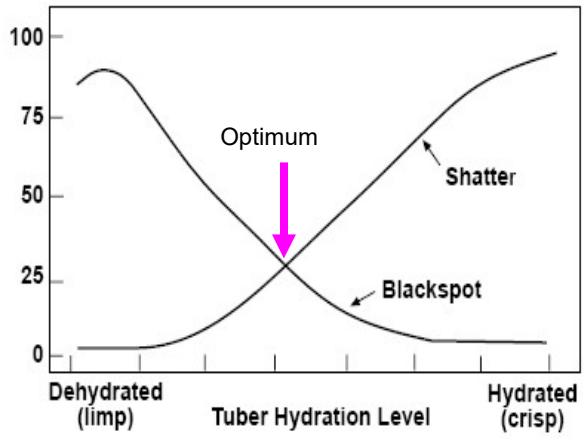
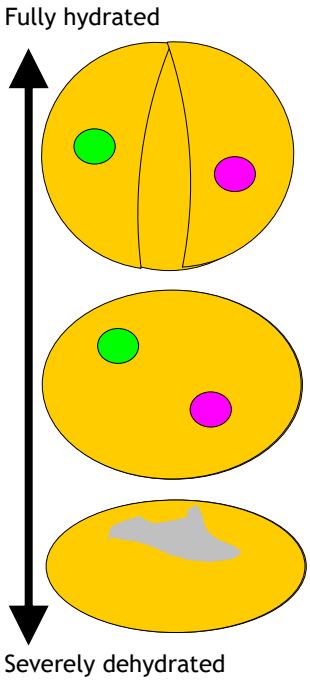
Where the turgor story starts



Source: Thornton, Smittle & Petterson (1973)

But they never produced any data to support their hypothesis!

30



Tissues fully inflated, shock wave transmission very rapid, tissue splits along planes of weakness between cell walls

Tissues partially dehydrated, shock wave dissipates more sideways, cells deform slightly, thereby 'cushioning' contents from force

Tissues severely dehydrated, shock wave transmission slow, more lateral spread of energy, internal membranes rupture causing intimate mixing of PPO and tyrosine

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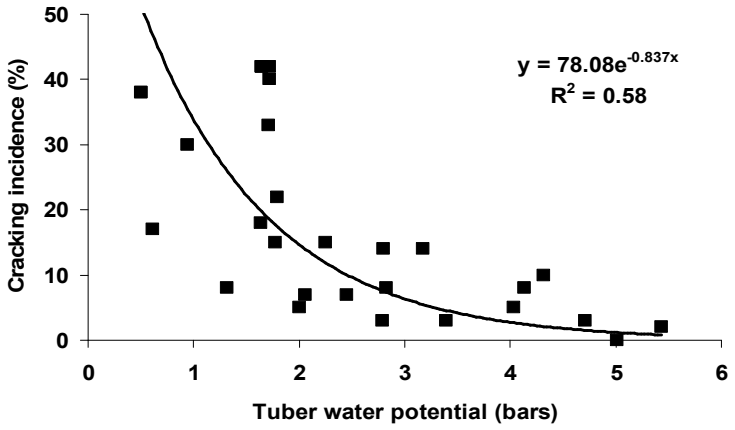
In varieties which exhibit cracking, as tubers become more turgid, cracking increases (Smith's Comet, 2005)



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So can we influence blackspot bruising by manipulating tuber turgor in the opposite direction to that which results in external cracking?

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Tuber water potential (≈ turgor) measurement

- Tuber sealed inside pressure bomb chamber with stolon protruding
- Chamber pressurized using compressed air at a slow rate until a film of xylem sap just visible on the cut surface of the stolon

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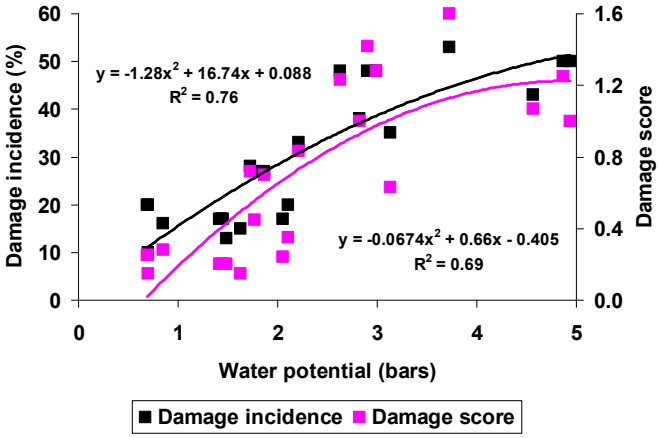
Can we predict internal damage from turgor?



Reasonably well for Lady Rosetta, it seems

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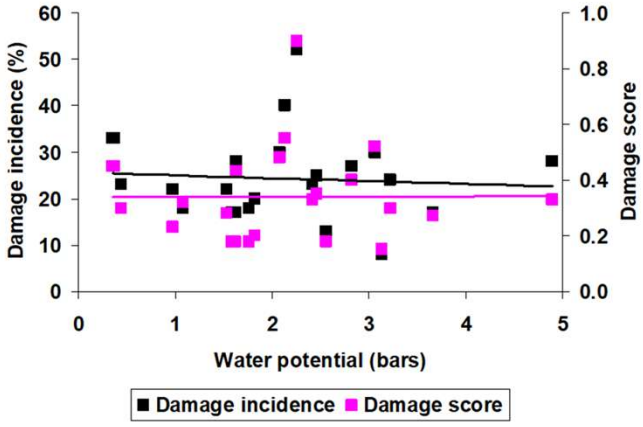

Maris Piper: no relationship?

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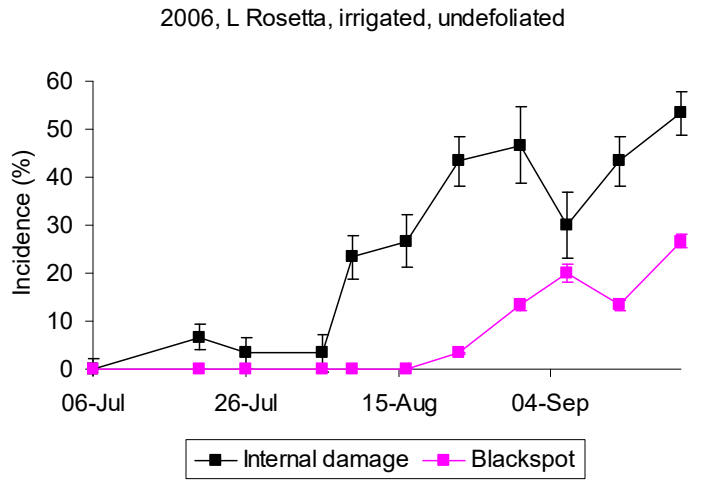
Biochemically, tubers may not blackspot bruise early in the season (partly PPO presence, partly build up of tyrosine)



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Final harvest bruising, Lady Rosetta, 2004-2007

Year	Irrig	Final water potential (bars)	Blackspot incidence (%)	Severity Score
2004	-I	2.38	13	1.03
	+I	1.89	13	1.83
2005	-I	2.99	20	1.15
	+I	2.90	19	0.85
2006	-I	0.97	28	0.81
	+I	0.35	46	1.18
2007	-I	1.21	74	3.10
	+I	1.01	75	3.35

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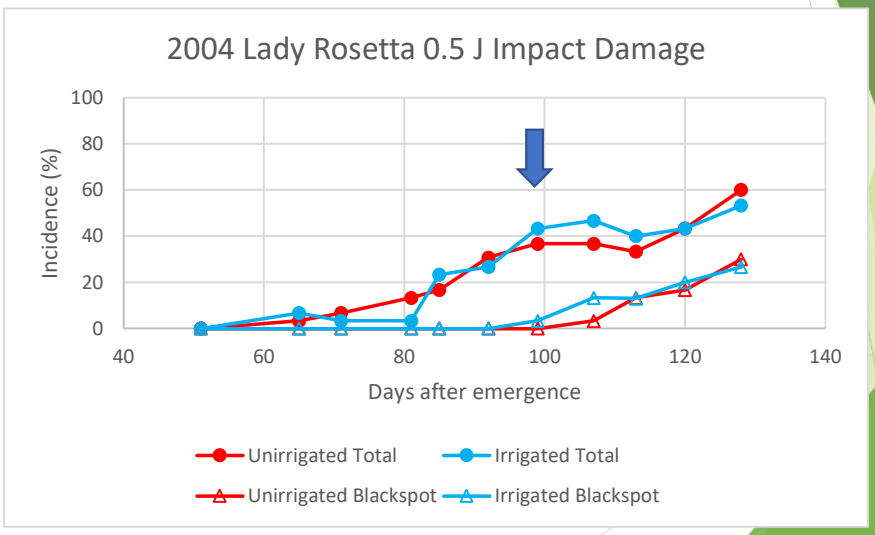
Blackspot: 98 DAE



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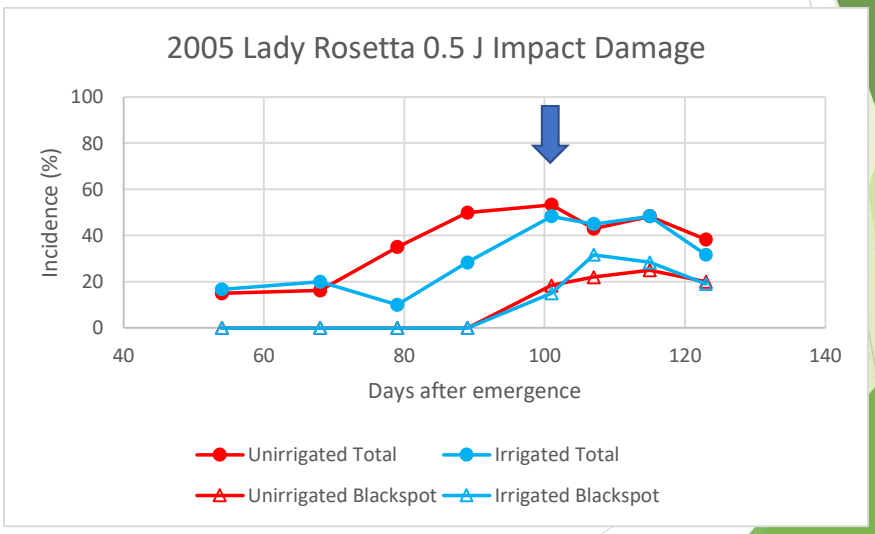
Blackspot: 102 DAE



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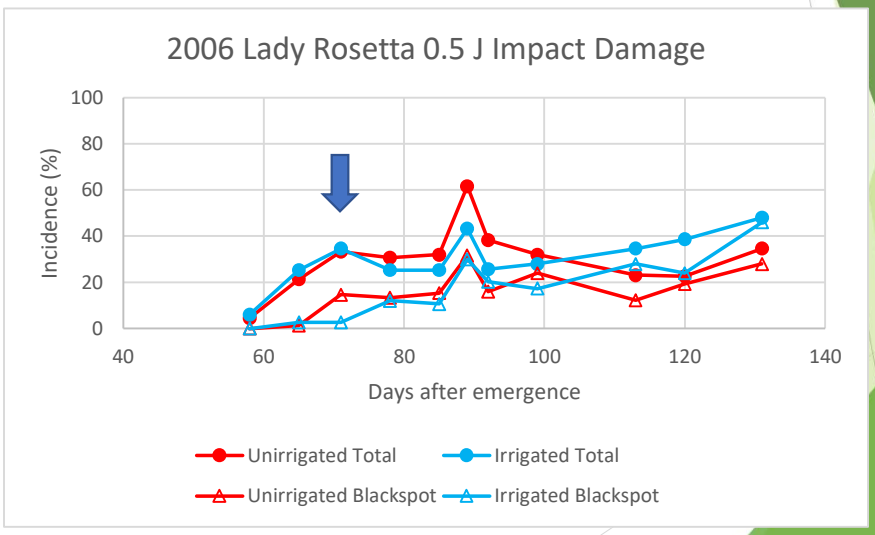
Blackspot: 71 DAE



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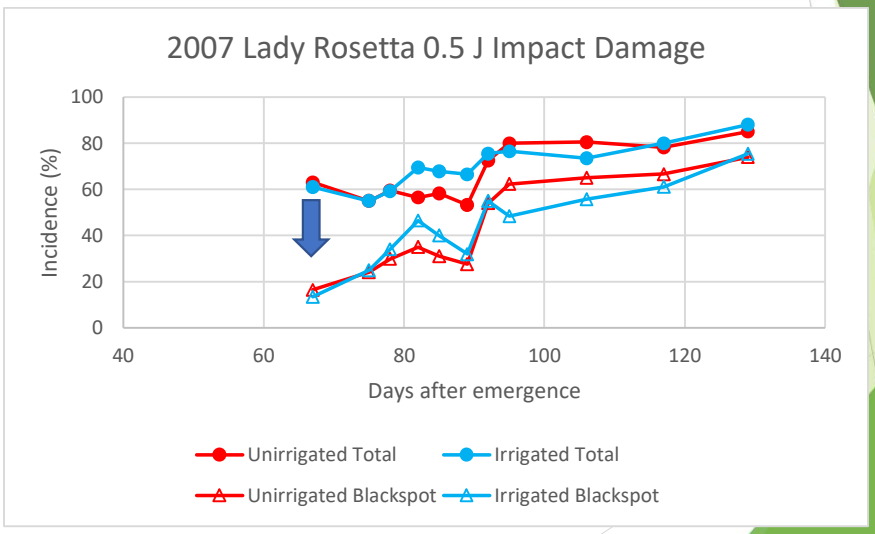
Blackspot: 66 DAE



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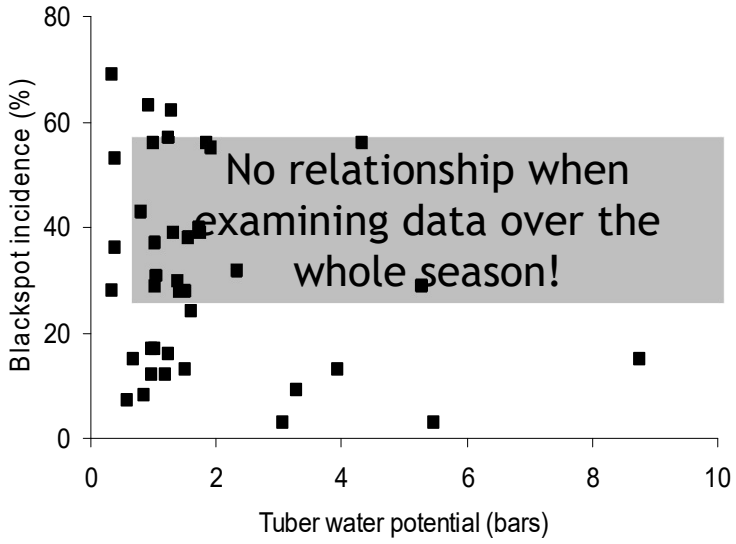
Relationship between blackspot and water potential (L Rosetta, 2006)



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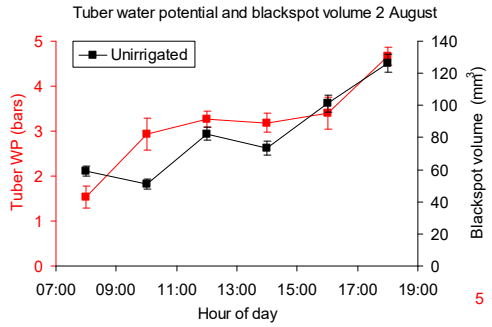
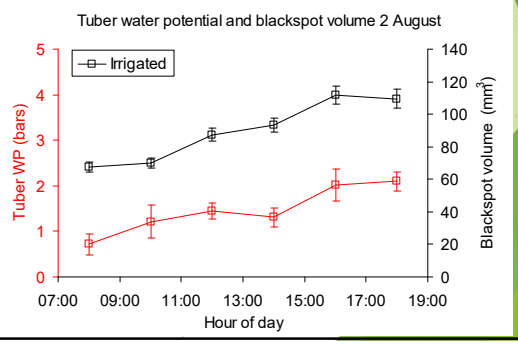
Water potential and blackspot bruising: 2 August 2007





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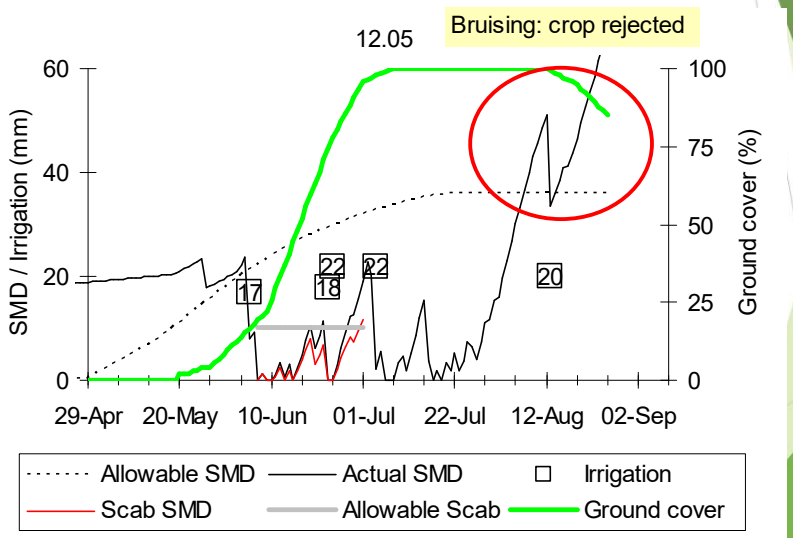
Late-season soil water stress



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So, can we predict bruising from turgor?

- We cannot measure the water potential of a tuber and predict exactly how it will bruise at that moment in time or in the future but clearly turgidity plays a major role in blackspot bruising
- Large varietal differences – less clear relationships in Maris Piper or Smiths Comet
- Difficult to manipulate turgor controllably without yield penalty
- Fully irrigated crops had the highest water potential throughout the season yet still bruised
- Unirrigated crops did not bruise worse at full senescence but did on occasions during each season

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Tuber re-hydration depends on:

- Stage of crop growth – slow or no rehydration if crop moderately-severely senesced
- Tubers may not fully re-hydrate if exposed to high evaporative stress around onset of senescence
- Crops seem to reach a (moderate) equilibrium water potential during September
- Absolute SMD and evaporative demand early in the season as well as at time of re-wetting
- It takes more than one 15-18 mm irrigation event to re-hydrate tubers in such a state!

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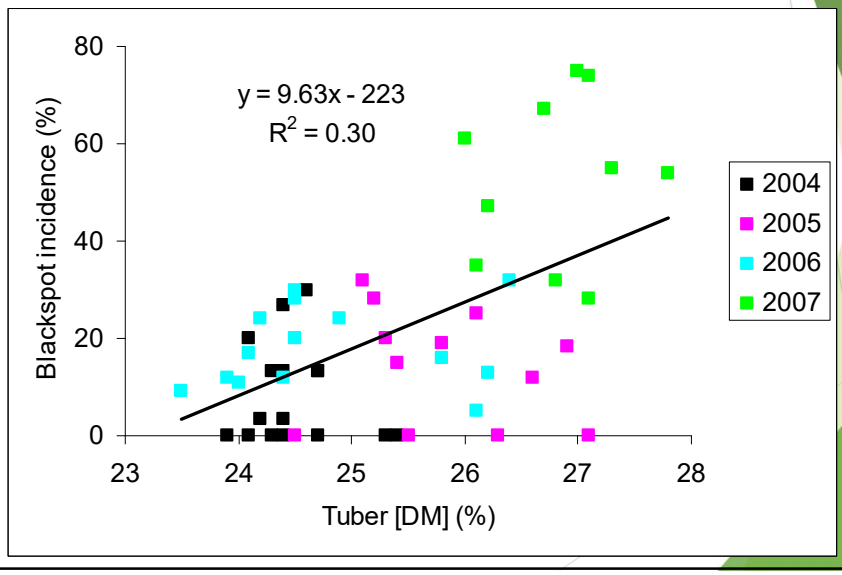
Blackspot bruising vs tuber dry matter concentration: Lady Rosetta 2004-2007



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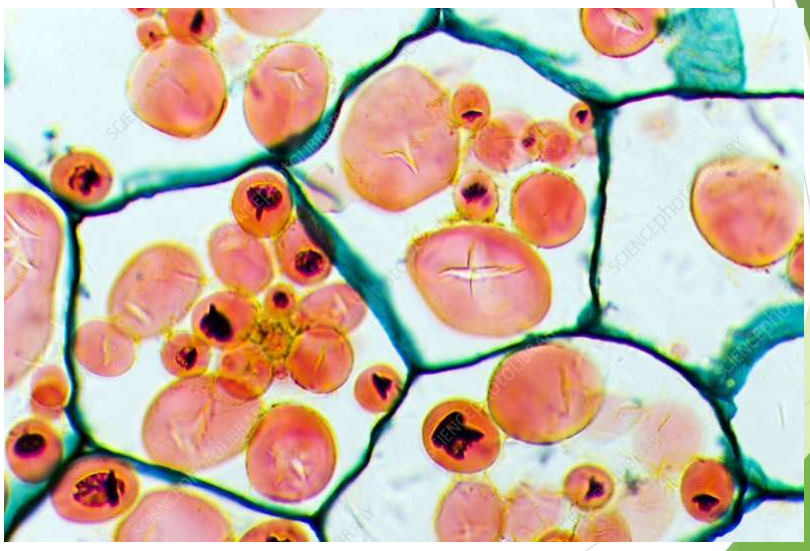
Starch grain density: 1084 vs 1094 SpG?



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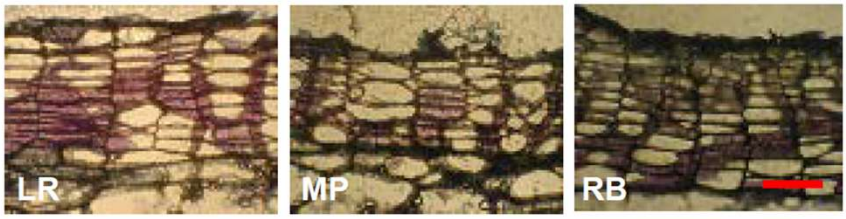
Scharf et al. (2015)



- On the skin, Russet Burbank presented suberized cells stacked with adjacent cells compressed together whereas Lady Rosetta and Maris Piper presented a “ragged” appearance
- The “ragged” organisation may act to prevent transmission and dissipation of forces throughout the potato, leading to more energy to be absorbed at the point of impact rather than transmitting and distributing it to the rest of the tuber
- Comparing the structural characteristics with the results from the energy to break the skin tissue, Lady Rosetta and Maris Piper required, respectively, 25.5 and 33.3% more energy than Russet Burbank to break the skin

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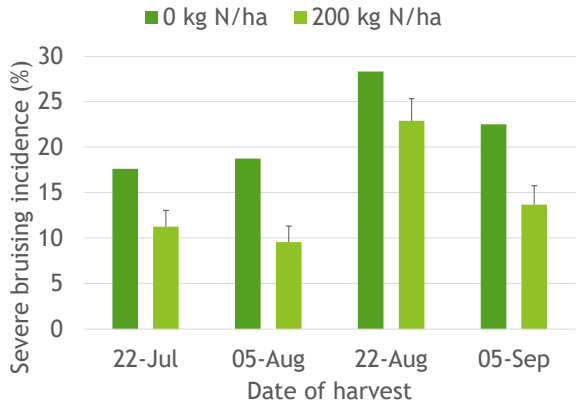
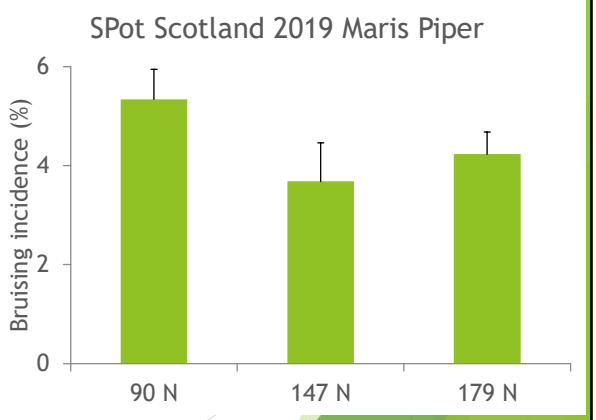
Nitrogen rate, date of harvest & bruising Scharf *et al.* (2014) vs reality





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Bruising: concluding comments on turgor

- Turgity is important. However, relationships between bruising and water potential differ over time and between irrigation regimes so no overall relationship exists.
- Crops can dehydrate sufficiently to increase bruising over the course of a few hours or days. The response to drying can be greater in fully irrigated crops than in droughted. Tubers act as a supply of water to leaves, so they dehydrate.
- Maintaining wet soils at defoliation does not appear to consistently reduce bruising but defoliating crops with a vigorous canopy and high SMD or on hot days can result in greater bruising than leaving the crop to senesce naturally.
- Fully irrigated crops are more prone to cracking in a susceptible variety – can be reduced by maintaining a brief period of higher SMDs close to harvest.

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Defoliation when crops are actively growing and SMDs are high can increase bruising at final harvest (L Rosetta, 2004)

Irrigation	Defoliation	Damage Score	Blackspot incidence (%)
None	No	1.03	30.0
None	Flailed	1.83	66.7
Full	No	0.87	26.7
Full	Flailed	1.27	33.3
	SE (12 DF)	0.191	7.77

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Potassium influences physics and biochemistry of bruising?

Source: McNabnay *et al.* (1999)

- 0, 10, 100% K in fertigation solution
- Reducing K increased tyrosine concentration x2
- Reducing K to 0% increased [PPO] significantly
- Lower K increased tissue elasticity (turgor effect)
- Lower K reduced tissue strength
- But 10% K = soil solution required for max yield: additional K no effect

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Old, newer and vigorous methods of impacating to mimic harvesting

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Factor affecting bruising	Priority 2007	Priority 2025
Crop maturity and dry matter	19	15
Harvester operation	16	14
Variety	16	8
Energy (drop height)	15	8
Soil moisture at burn-off	11	10
Temperature	10	4
Soil moisture at harvest	9	8
Irrigation	4	6
Soil preparation	4	6
Season	2	6
Site selection	1	3
Soil type	1	4
Turgor	1	3
Windrowing time	1	0
Crop nutrition	0	6
Haulm destruction	0	1

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Minimising damage

https://projectbluearchive.blob.core.windows.net/media/Default/Potato%20knowledge%20library/Minimising%20Damage%202013.pdf

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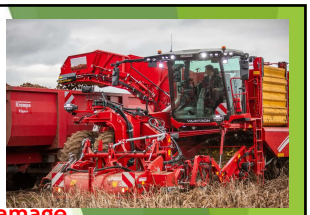
Harvester set-up



- Haulm: not long, not short, not living. Flail height set to avoid scalping tubers: **damage**
- Don't flail in wet soil, otherwise clods will form: **damage**
- Match share width to bed width to avoid crowding tubers: **damage**
- Avoid wheel damage to tubers by aligning correct-width tyres in centre of furrows: **damage**
- Avoid high pressure on diablo rollers. Direct pressure and slicing by discs: **damage**
- Correct disc width and alignment. Too wide brings in excessive stone and clod, too narrow results in slicing: **damage**
- Share: too shallow results in slicing, too deep in excess soil entry: **damage**
- Share to primary web gap is a potential pinch point: **damage**
- Primary web speed. 1.5:1 on wet, clay soils to 0.7:1 on sandy soils. No roll back and soil coverage to end of web
- Web agitators: only when soil load excessive: **damage**

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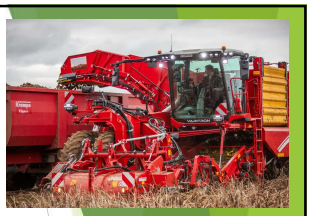
Harvester set-up



- Replace damaged rods, joining links and web attachment plates: **damage**
- Keep guide rollers tight onto webs to prevent sideways web movement: **damage**
- Haulm rakes/fingers positioned too low will contact tubers: **damage**
- Use clod breakers only in extreme conditions: **DAMAGE!**
- Haulm fingers should be rubber-coated and raised when haulm is profuse: **damage**
- Haulm rollers should only extract <70% of the haulm at this stage, not anything else: **damage**
- Second web: similar to primary web. Optimum is 85% full with tubers. Too slow and a layer of tubers will be caught by haulm rollers. Too fast and increased energy on impact: **damage**
- Cleaning units. Settings are always a compromise.
  - Mid-range speed
  - Large diameter rollers for small tubers, less cleaning, less damage and in dry conditions
  - Small rollers: **DAMAGE**

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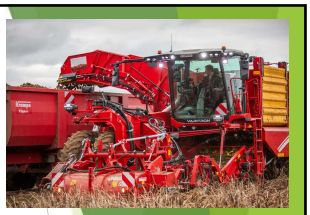
Harvester set-up



- Distorted spirals: **damage**
- Heights of rollers. Too high results in more cleaning but more **damage**
- Angle of unit: increasing steepness reduces cleaning
- Picking tables. Avoid drops and changes in direction. Use web covers and foam padding. Beware of side gaps: **damage**
- Elevator. On-feed drops heights as small as possible. Speed affects damage at both on-feed and discharge ends of elevator. Flights 75% full.
- Harvester to trailer discharge: **DAMAGE**
  - Skilled harvester AND trailer drivers required
  - Typical drop heights 1-2 m!!! Too much going on to focus on elevator discharge height
  - Increase visibility where possible
  - Use trailer mats, fall breakers, elevator height control devices
- **Good operator = low damage**

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Science and management of blackspot bruising

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