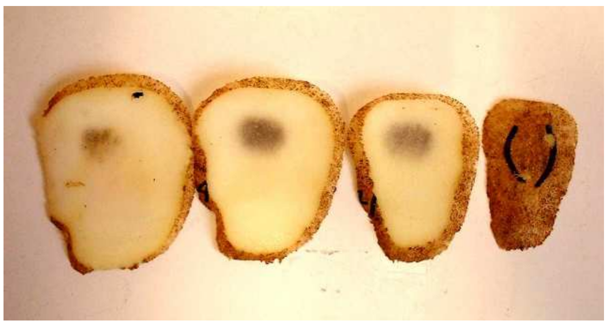
Bruising in a Commercial Environment (BRUCE)

Factors associated with internal damage and bruising in potato tubers

Final Report
Amended for BPC
on 18 June 2004

1 March 2001 to 31 May 2004



1. Title

Bruising in a Commercial Environment (BRUCE) – Factors associated with internal damage and bruising in potato tubers

1.1 Reporting period

Years 1 – 3   1 March 2001 to 31 May 2004

1.2 Contents

1.3 List of tables

1.4 List of figures

2. Summary for growers

2.1 Project aims

The aim of this project is to determine important factors influencing bruising using the variability experienced in commerce.

2.2 Work undertaken

During 2001, 2002 and 2003 samples of tubers from 187 commercial crops were bruised using a pendulum, and tuber dry matter content and mineral nutrient content were measured. The varieties Cara, Marfona and Maris Piper were used. Maris Piper crops were supplied as either Maris Piper grown for prepacking or for processing. Records of the history of 184 of these crops were supplied by growers. Relationships between bruising susceptibility, tuber characters and features of crop production were explored.

2.3 Key findings and conclusions

- Data analyses have suggested that several factors have no significant influence on susceptibility to bruising
- Bruising susceptibility varied considerably between crops of the same variety
- Bruising susceptibility in Marfona varied with soil type with sandy soils being associated with increased susceptibility to bruising and loams with decreased susceptibility
- Dry soil conditions at burning off were associated with greater susceptibility to bruising in Marfona, Cara and Maris Piper
- In Marfona and in Maris Piper, the time between defoliation and lifting was associated with susceptibility to bruising
- In Cara and in Maris Piper a higher tuber dry matter percentage was associated with greater susceptibility to bruising
- In Marfona there was no relationship between tuber dry matter percentage and susceptibility to bruising
- The influence of K and Mg appears complex and varies with variety
- Levels of applied K above 300 kg/ha and Mg above 100 kg/ha were associated with increased susceptibility to bruising in Marfona
- In general for Cara and for Maris Piper higher soil and tuber tissue levels of K and Mg were associated with reduced susceptibility to bruising
- Higher tuber tissue levels of K and Mg were not associated with the levels of K and Mg which had been applied

3. Experimental section

3.1 Introduction

The UK potato industry has an annual marketable output of about £1 billion and, while recent estimates of losses due to bruising are not available, overall damage averages about 9%, with considerable year to year variation. Internal damage and bruising are undesirable in potatoes which have been pre-packed because of consumer rejection, while in potatoes for processing damaged and discoloured tissue has to be removed and is a particular problem on tuber ends, where it leads to a reduction in fry length. For potato suppliers bruising reduces the value of their produce and can lead to a worthless crop.

Although much is done to ensure that handling equipment minimizes damage and bruising there is still considerable variability in the susceptibility to bruising of tubers from different sources. There is ample evidence that crop production history and other environmental factors influence susceptibility to bruising but much of this is conflicting and its relevance under commercial circumstances has not been established. What is needed now is information about the factors during crop growth which predispose crops to develop *susceptibility* or *resistance* to damage and bruising. Knowledge of these will aid decisions on the cultivation, management, handling and marketing of crops and will reduce damage and bruising levels.

This work aims to identify important factors in commercial practice which may or may not be associated with susceptibility to bruising. These may suggest areas for further, more detailed analysis in the future.

3.2 Materials and methods

3.2.1 Tubers

2001

Samples of 200 tubers from commercial crops were hand dug, carefully packed to minimize damage, and transported to Solanum at Yaxley, where they were stored at 8-10 ^{o}C prior to collection by HRI. Sixty-six samples were supplied as shown in Table 1.

Table 1. Number of samples in all three years by variety and supplier

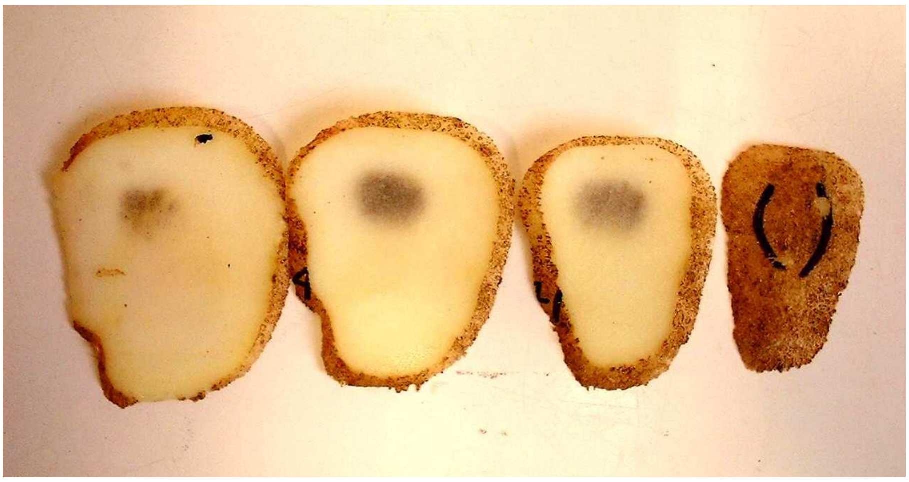
Variety	Number of samples in			
	2001	2002	2003	Total
Marfona	23	25	14	62
Cara	13	21	14	48
Maris Piper Pre-pack	10	14	10	34
Maris Piper Processing	20	13	10	43
Total	**66**	**73**	**48**	**187**

Supplier	Number of samples in			
	2001	2002	2003	Total
Branston	13	13	10	36
Greenvale	12	10	6	28
MBM	13	13	7	33
McCains	11	10	8	29
QV Foods	8	13	9	30
Solanum	9	14	8	31
Total	**66**	**73**	**48**	**187**

The samples of tubers were collected every Friday from 10 August to 26 October and brought by road to HRI Wellesbourne. Tubers were put on a wire mesh, washed with a jet of water to remove traces of soil and then placed in plastic crates and stored at 10^{o}C over the weekend. At all stages care was taken to avoid damaging the tubers. Three samples were handled on the following Monday and three on the Tuesday. Fifty tubers of the correct weight range (100 to 250 g) were selected from each sample and numbered, whilst still in the cold room. To minimize increase in tuber temperature, batches of 5 tubers at a time were brought into the laboratory for impacting and sampling. Tubers were cut in two with a diagonal longitudinal cut. One half was then used for bruise assessment while the other half was sampled for determinations of dry matter, nutrient content and total oxidative potential.

On one tuber 'half' at a point on the flat side of the tuber near to, but not on, the point of stolon attachment an impact was applied with the HRI Pendulum using an impact energy of 0.5 Joules. The point of impact was marked, and impacted tuber halves were incubated in a deep-sided tray enclosed in a polyethylene bag at laboratory temperature for 48 to 50 hours. Bruise development was assessed by removing layers of tissue from the point of impact with a potato peeler until a bruise was revealed (Fig. 1). If a bruise was not found after 5 or 6 strokes of the peeler, the tuber-half was cut in two with a knife to see if there was a bruise deeper in the tuber, but this was found never to be the case. Where a bruise was found, layers of tissue were removed and those showing bruising were laid out, in order of removal, on a white background. The longest length of the bruise and the widest width (usually, but not always, on the same layer) were measured with callipers to 0.1 mm. The intensity of the bruise in the layer with the darkest mark was scored on a 5-point scale using a Dulux Definitions colour strip number 119 (0005-B10G to 8010-B10G) as a guide (Fig. 2). Then the layers were 'rebuilt' to enable the thickness of the bruise to be measured, also to 0.1 mm. Records of these measurements were made against the number of the tuber, together with a record of the thickness of the tuber-half at the point of impact, and any comment about impact damage (e.g. whether a cavity had been produced in the tissue).

Fig. 1 Illustration of bruising assessment procedure

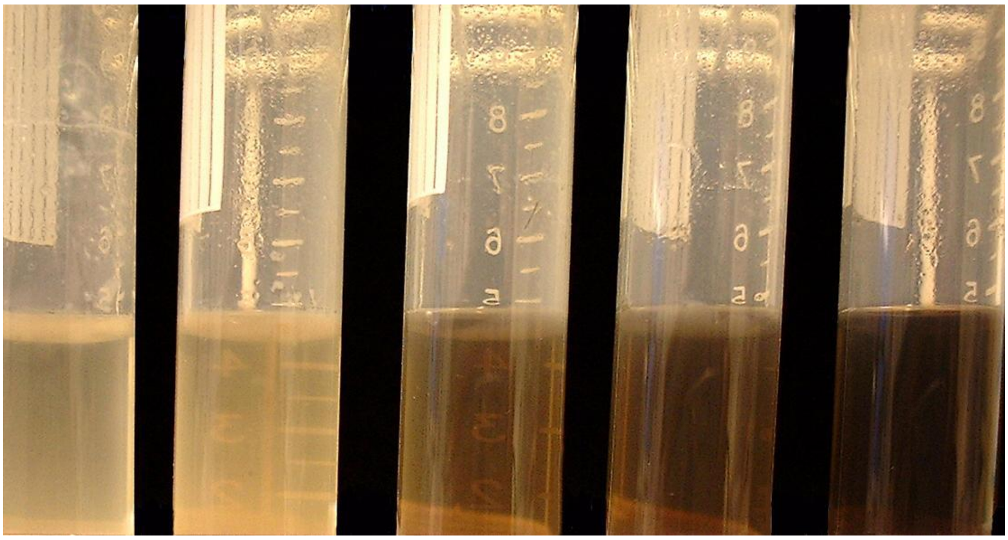


The second 'half' of each tuber was used for sampling tissue for determinations of dry matter, nutrient content and total oxidative potential (TOP). For dry matter, a 10 mm internal diameter cork borer was used to take a core and those from all 50 tubers were bulked. Weights, before and after drying in an oven at 90 °C for 3 to 4 days, were recorded and used to calculate dry matter percentage. The dried tissue was reduced to powder in a mill and, in mid-November, passed to the analytical laboratory for mineral analysis for Organic N, K, Na, Ca, Mg, P and Mn.

Fig. 2 Bruise intensity scoring

For TOP, another core was taken from the second ‘half’ of each tuber using a cork borer with 18 mm internal diameter, and a transverse slice 3 mm thick was removed from a point in the core a mm or two below the skin, roughly corresponding to the position in which bruises develop in the entire tuber. The resulting disc of tissue was immediately frozen in liquid nitrogen and discs from all 50 tubers were bulked and stored in a freezer until needed. Samples were freeze-dried and milled to a fine powder. A small sample of the powder was taken up in 0.05 M phosphate buffer at a ratio of 1 ml to 0.1g powder, allowed to stand overnight at 20 ^{o}C, and the liquid was cleared of solids by centrifuging. The optical density of the clear solution (Fig. 3) was read at wavelengths of 450 and 490 nm. The higher the reading of optical density, the greater was the Total Oxidative Potential of the tissue.

Fig. 3 TOP analysis of two Maris Piper (left) and three Marfona samples (right)



2002

In 2002 the sample number was reduced to 150 tubers. Seventy-three samples were supplied as shown in Table 1.

The samples of tubers were collected every Friday from 9 August to 18 October and brought by road to HRI Wellesbourne. Fifty tubers of the correct weight range (150 to 300 g) were selected from each sample and numbered. The weight range used was increased from the 100 to 250 g used in 2001, at the request of growers, in order to make their sampling easier.

All handling and impacting methods were the same as carried out in the previous year except that sampling and analyses to determine TOP were no longer carried out (see section 3.3.2). The assessment of bruise development was modified from that used in 2001 after agreement reached at a meeting of the consortium held on 29 May 2002. Where a bruise was found, the intensity of the bruise was scored as in the previous year but the length, width and thickness of the bruise were not measured. Neither was the thickness of the tuber-half at the point of impact measured.

2003

In 2003, 47 samples of 150 tubers were supplied as shown in Table 1.

The samples of tubers were collected every Friday from 8 August to 17 October and brought by road to HRI Wellesbourne. All handling, impacting and assessment methods were the same as carried out in the previous year.

An additional meeting was held on 14 August 2003 when the first assessments of samples for the 2003 season were made. This meeting had been convened to confirm that the damage recorded as bruising was, in fact, bruising. At this meeting, Roy Drew assessed two of the samples collected on 8 August 2003. Notes and photographs were taken and the participants were all in agreement with the results of the assessments. The notes and photographs are included here in Appendix I.

3.2.2 Soil

2001

Samples of the topsoil (0 to 30 cm) and subsoil (30 to 60 cm) from each crop site were put in aluminium foil trays 195 x 195 x 30 mm deep (Fig. 4) and left to air-dry in a warm, well-ventilated room. After 7 days, they were transferred to labelled bags and stored until required. In mid-November, they were reduced to fine particles of 2 mm or less in a soil mill. Sandy soils went through this process in a matter of minutes or less, but cloddy clay soils took much longer. After grinding, the samples were passed to the analytical laboratory for determination of K and Mg content.

2002 and 2003

In the following two years, samples were taken of the topsoil (0 to 30 cm) only. These samples were processed and analysed as in 2001.

3.2.3 Crop history

Survey sheets detailing the crop history of each sample, originally devised in 2001, were slightly modified following the consortium meeting at HRI on 29 May 2002 and a blank copy is shown in Table 2. It must be noted that some of the crop history data are fairly crude subjective measures. For instance, soil tilth and compaction at planting are categorised by a simple 3-point scale, and soil moisture conditions at both burning-off and at lifting by a 4-point scale. Tuber temperature at lifting was recorded as a spot reading when the sample was hand dug. Of all the samples dug, crop histories were provided for 66, 71 and 47 crops for 2001, 2002 and 2003 respectively.

In 2001 limited weather records for 3 weeks before defoliation to lifting were also supplied. There were no data for more than half the crop samples supplied, and at the meeting of the consortium held on 29 May 2002 it was agreed that analyses of weather data should be dropped from the project.

Table 2. Recording sheet for crop history survey

Code	

Grower		**Location of the crop**	
Date lifted		**Grid Reference**	
Date delivered			

Variety	

Sprouting Regime

Chitted	
NOT chitted	

Seed Source

Dutch	
English	
Scottish	

Date planted	

Soil Tilth at planting

Fine	
Medium	
Cloddy	

Soil compaction at planting

Absent	
Moderate	
Severe	

Defoliated?

Yes	
No	

Date of first defoliation	

Defoliation Method

Mechanical first ONLY	
Chemical first ONLY	
Mechanical first followed by chemical second	
Chemical first followed by chemical second	

	First Defoliation	**Second Defoliation**
Which chemical defoliant?		
% ground cover at defoliation		
% senescence (as yellowing)		

Soil moisture conditions at burning-off

Dry	
Moist	
Wet	
Very wet	

Table 2. Recording sheet for crop history survey contd.

Code ______

Time of day lifted

Before 6am	
6am - 9am	
9am - 12 noon	
12 noon - 3pm	
3pm - 6pm	
After 6pm	

Soil moisture conditions at lifting

Dry	
Moist	
Wet	
Very wet	

Tuber temperature at lifting (^oC) ______

SOIL sample taken at lifting? Tick to confirm

0 - 30 cm	

Previous crop ______

Initial soil K mg/kg ______

APPLICATIONS - express as ELEMENTAL N, P, K, Mg & S

	Autumn 2001	Spring 2002
Nitrogen rate (kg/ha)		
Phosphorus rate (kg/ha)		
Potassium rate (kg/ha)		
Magnesium rate (kg/ha)		
Sulphur rate (kg/ha)		

Soil Type

Organic/peat	
Sand	
Silt	
Sandy loam	
Medium loam	
Other	

Commercial internal damage assessment of mechanically lifted crop

Slight	
Moderate	
Severe	

Any further comments about crop history or the sample ?

3.2.4 Data analysis and Statistical Methods

Samples were taken for the varieties Marfona, Cara and Maris Piper, with the Maris Piper samples coming from crops grown for both prepacking and for processing. The original intention in this project was to treat these Maris Piper crops as separate groupings. However, at a meeting held on 4 May 2004, the consortium decided that analyses of all the Maris Piper crops aggregated together should be included in this final report. It was agreed that the main differences in crop husbandry would have been in the irrigation strategies which would be planned to mitigate the effects of scab in crops grown for prepacking.

All data analysis was carried out using the GenStat language (GENSTAT COMMITTEE, 2000). The significance of linear correlations was assessed by testing the correlation coefficient.

Investigating associations between susceptibility to bruising and pre-harvest crop history

Information on the history of each crop was examined and the data were tabulated according to groupings based on the percentages of tubers showing bruising and on the crop history data. Where appropriate, Chi-squared tests were used to compare the group of crops with higher susceptibility to bruising with the group with lower susceptibility (Pearson, 1900). The analyses are intended to flag up associations of interest. Caution in the interpretation of the contingency tables must be taken. For instance, an association with the site of crop production will be intrinsically linked with many other factors such as soil type, rainfall or height above sea level. Any one factor, or a combination of factors, might be associated with susceptibility to bruising. In this instance, the association with the production site might just be coincidental.

The statistical technique was used by Wurr et al. (1992) to investigate the environmental factors influencing head density of crisp lettuce. It has subsequently been used in several commercial contracted studies and in an European Union funded FairCraft project. Studies have investigated pre-harvest and processing conditions and their associations with taste and aroma in cooked brussels sprouts and post-harvest discolouration of various processed salad crops. A similar type of approach was used by Wurr et al. (1993) to examine the impact of some agronomic factors on the variability of tuber size distribution. Consequently the technique is known to be robust and suited to this study.

3.3 Results

3.3.1 Bruising susceptibility

Initial data summaries (Table 3) show selected characters from all samples sorted by the proportion of tubers which were bruised. The data for 2001 and 2002 have been reported before but for completeness in this final report on the project, they are repeated here.

Figure 4 shows the distributions of bruising for all samples in 2001, 2002 and 2003. The percentage bruised ranged from 1 to 98% in Marfona and was well distributed across the range. For Cara and Maris Piper, the majority of the samples showed fewer than half bruised, with a few more susceptible samples.

Fig. 4 Frequency distributions of all bruising in all three years

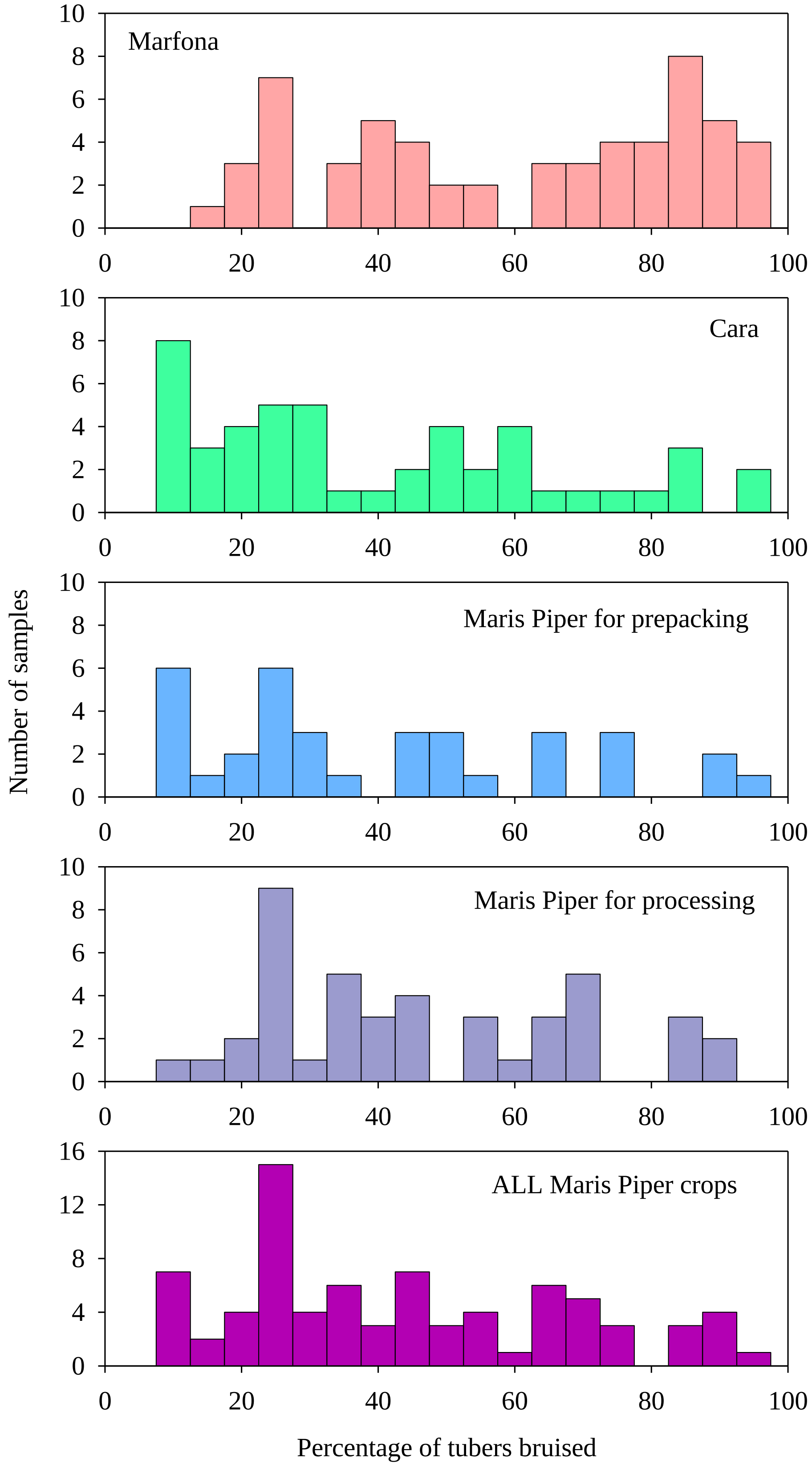


Table 3. Selected characters from all samples - 2001

Delivered	Variety	Supplier	Percentage bruised	Dry Matter %	% K in tuber tissue	Soil K µg/ml dry weight 0-30 cm	Soil Group
4 Sep	PiperPRE	MBM	0	20	2.9	408	Silt
9 Oct	Cara	Greenvale	2	19	2.6	169	Loam
18 Oct	PiperPRO	Greenvale	2	21	2.7	1158	Organic
12 Sep	PiperPRE	MBM	4	22	2.6	176	Organic
18 Oct	Cara	Branston	8	21	2.3	449	Silt
5 Oct	Cara	MBM	8	18	2.9	617	Organic
5 Oct	Cara	Solanum	8	19	2.4	320	Silt
20 Sep	PiperPRE	QV Foods	10	20	2.8	520	Silt
22 Aug	PiperPRO	McCains	12	21	2.7	536	Loam
9 Oct	Cara	MBM	12	19	2.7	158	Loam
12 Oct	Cara	Solanum	14	19	2.6	244	Silt
28 Sep	Cara	Greenvale	16	19	2.5	200	Loam
17 Aug	PiperPRO	MBM	16	21	2.5	220	Organic
21 Sep	PiperPRE	Solanum	16	21	2.4	139	Loam
9 Aug	Marfona	Greenvale	18	14	2.5	182	Sand
18 Oct	Cara	MBM	18	19	2.2	121	Loam
9 Aug	Marfona	Branston	20	19	2.1	350	Loam
28 Aug	Marfona	Branston	20	16	2.2	115	Loam
15 Aug	PiperPRO	McCains	20	21	2.1	84	Loam
23 Oct	PiperPRO	MBM	20	24	2.4	191	Organic
11 Oct	Cara	QV Foods	20	20	2.4	434	Silt
4 Oct	PiperPRE	Branston	22	22	2.4	228	Silt
9 Aug	Marfona	Branston	22	14	2.9	302	Loam
18 Oct	PiperPRO	Greenvale	22	20	2.0	137	Loam
27 Oct	PiperPRO	McCains	22	20	2.7	374	Loam
16 Aug	Marfona	Greenvale	24	17	2.2	137	Loam
15 Aug	Marfona	Greenvale	24	16	2.4	210	Loam
20 Sep	PiperPRE	Greenvale	24	21	1.9	*	Loam
11 Sep	PiperPRO	McCains	24	25	1.9	146	Loam
16 Oct	PiperPRO	McCains	24	17	3.0	318	Loam
24 Oct	PiperPRO	McCains	24	19	2.8	222	Loam
11 Oct	Cara	QV Foods	26	20	2.4	221	Silt
27 Sep	PiperPRE	QV Foods	26	23	2.6	460	Silt
4 Oct	Cara	Branston	28	21	2.0	208	Loam
20 Sep	PiperPRE	Branston	28	17	3.0	540	Organic
4 Oct	Cara	Greenvale	28	21	2.3	120	Sand
6 Sep	Marfona	Branston	30	15	2.5	412	Silt
11 Oct	PiperPRO	Greenvale	30	23	2.3	135	Loam
9 Aug	Marfona	Greenvale	32	16	2.5	96	Loam
15 Aug	PiperPRO	McCains	32	21	2.4	195	Loam
29 Aug	PiperPRO	McCains	32	21	2.7	195	Sand
12 Sep	PiperPRO	MBM	34	22	3.0	504	Organic
4 Oct	Cara	Branston	38	21	1.8	237	Loam
27 Sep	Marfona	Branston	38	18	2.2	186	Loam
27 Sep	Marfona	Branston	38	16	2.3	146	Loam
4 Oct	PiperPRO	McCains	38	25	1.8	213	Loam
6 Sep	PiperPRO	McCains	38	21	2.8	173	Sand
9 Aug	Marfona	Branston	40	14	3.1	359	Silt
23 Oct	PiperPRO	MBM	40	24	2.6	1010	Organic
24 Oct	PiperPRO	McCains	44	21	2.6	180	Silt
20 Sep	PiperPRE	Branston	48	22	2.5	249	Loam
20 Sep	Marfona	QV Foods	54	16	2.7	491	Silt
31 Aug	PiperPRE	Solanum	60	23	2.3	83	Loam
31 Aug	Marfona	Solanum	62	17	2.2	95	Sand
19 Sep	Marfona	QV Foods	64	14	3.0	437	Silt
23 Oct	PiperPRO	MBM	66	25	2.4	396	Organic
17 Aug	Marfona	MBM	68	14	2.8	246	Sand
6 Sep	Marfona	QV Foods	70	17	2.6	610	Silt
24 Aug	Marfona	Solanum	76	17	2.1	158	Sand
9 Aug	Marfona	Greenvale	78	14	2.6	*	Loam
6 Sep	Marfona	QV Foods	78	16	2.8	244	Loam
24 Aug	Marfona	MBM	80	15	3.0	258	Sand
25 Aug	Marfona	Solanum	80	17	2.6	116	Sand
28 Sep	PiperPRO	Solanum	84	24	1.9	99	Loam
5 Sep	Marfona	MBM	88	13	3.1	219	Sand
24 Aug	Marfona	Solanum	88	17	2.1	116	Sand

Table 3. Selected characters from all samples – 2002

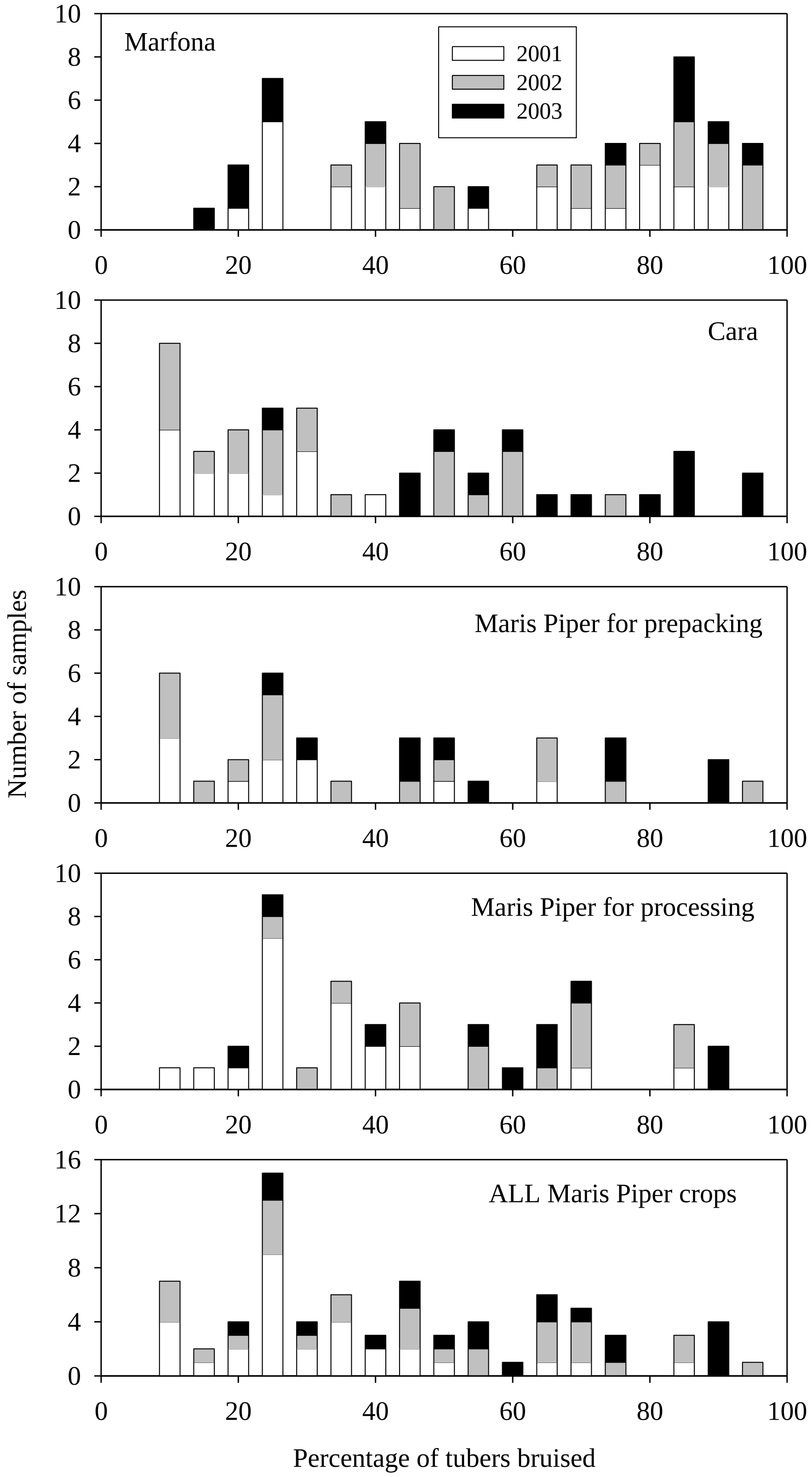
Delivered	Variety	Supplier	Percentage bruised	Dry Matter %	% K in tuber tissue	Soil K µg/ml dry weight 0-30 cm	Soil Group
10 Oct	Cara	QV Foods	2	17	1.9	202	Silt
15 Aug	PiperPRE	Branston	4	15	2.3	153	sandy loam
3 Oct	Cara	QV Foods	4	16	1.8	182	Silt
25 Sep	Cara	MBM	6	20	2.1	167	organic peat
20 Sep	PiperPRE	Solanum	6	18	2.0	291	organic peat
27 Sep	Cara	Branston	10	17	1.8	145	medium loam
30 Aug	PiperPRE	Branston	10	17	2.1	177	organic peat
4 Sep	PiperPRE	MBM	12	20	2.0	108	organic peat
17 Oct	Cara	QV Foods	14	18	1.6	125	Silt
25 Sep	Cara	MBM	16	18	2.2	442	organic peat
30 Aug	PiperPRE	Solanum	16	17	2.2	261	Silt
4 Oct	Cara	Branston	18	17	1.9	168	sandy loam
3 Oct	Cara	QV Foods	20	20	1.7	211	Silt
12 Sep	PiperPRE	QV Foods	20	18	1.9	333	Silt
13 Sep	PiperPRE	Branston	22	18	2.0	157	Silt
17 Oct	Cara	Greenvale	22	19	1.7	50	Sand
25 Sep	PiperPRO	McCains	22	18	1.9	102	medium loam
26 Sep	Cara	QV Foods	22	17	1.6	154	Silt
13 Sep	PiperPRE	Solanum	24	18	2.1	446	silty loam
19 Sep	PiperPRO	McCains	26	19	1.9	215	Silt
11 Oct	Cara	Branston	28	20	1.7	198	sandy loam
17 Oct	Cara	Greenvale	28	18	1.7	93	medium loam
15 Aug	Marfona	Greenvale	30	14	2.3	206	sandy loam
23 Aug	PiperPRE	Branston	32	19	1.6	116	medium loam
25 Sep	PiperPRO	McCains	34	19	1.8	92	medium loam
1 Oct	Cara	MBM	34	17	2.1	163	Sand
22 Aug	Marfona	Greenvale	36	14	2.2	159	sandy loam
29 Aug	Marfona	QV Foods	36	16	1.9	218	Silt
3 Oct	PiperPRO	Greenvale	42	20	1.6	65	sandy loam
11 Sep	PiperPRO	McCains	42	20	1.7	106	sandy loam
9 Aug	Marfona	Branston	44	13	2.0	141	medium loam
16 Aug	Marfona	Branston	44	13	2.2	201	sandy loam
10 Oct	PiperPRE	Greenvale	44	19	1.8	210	sandy loam
22 Aug	Marfona	QV Foods	44	15	2.0	192	Silt
16 Oct	Cara	MBM	46	20	1.7	71	medium loam
10 Oct	Cara	QV Foods	46	18	1.6	85	Silt
9 Oct	Cara	Solanum	46	21	1.6	291	Silt
4 Sep	PiperPRE	MBM	48	22	1.5	68	organic peat
9 Aug	Marfona	Solanum	48	13	2.2	206	Sand
23 Aug	Marfona	Solanum	48	15	2.1	143	sandy loam
3 Oct	PiperPRO	McCains	50	20	1.7	132	sandy loam
11 Sep	PiperPRO	McCains	52	21	1.6	112	sandy loam
17 Oct	Cara	QV Foods	52	20	1.4	112	Silt
18 Oct	Cara	Branston	56	21	1.4	131	Silt
10 Oct	Cara	MBM	58	20	1.5	86	sandy loam
18 Oct	Cara	Solanum	58	20	1.4	115	medium loam
26 Sep	PiperPRO	Greenvale	60	21	1.6	67	sandy loam
7 Aug	Marfona	MBM	62	14	2.1	126	Sand
11 Sep	PiperPRE	QV Foods	62	20	1.5	95	Silt
19 Sep	PiperPRE	QV Foods	62	20	1.7	153	Silt
9 Aug	Marfona	Branston	66	12	2.4	213	Sand
17 Oct	PiperPRO	McCains	66	21	1.7	134	sandy loam
19 Sep	PiperPRO	McCains	66	22	1.5	84	Sand
30 Aug	Marfona	Solanum	66	17	1.7	168	Silt
3 Oct	PiperPRO	Greenvale	68	21	1.6	72	medium loam
10 Oct	Cara	Greenvale	70	20	1.5	50	medium loam
9 Aug	Marfona	Solanum	70	16	1.7	57	sandy loam
23 Aug	Marfona	Branston	72	14	1.8	85	medium loam
26 Sep	PiperPRE	Greenvale	72	21	1.5	61	sandy loam
15 Aug	Marfona	QV Foods	76	14	1.9	202	Silt
30 Aug	Marfona	Branston	82	14	2.2	195	sandy loam
8 Oct	PiperPRO	McCains	82	21	1.7	190	sandy loam
7 Aug	Marfona	MBM	82	15	2.0	110	Sand
23 Aug	Marfona	Solanum	82	17	1.9	187	Sand
3 Oct	PiperPRO	McCains	84	21	1.6	221	sandy loam
13 Aug	Marfona	MBM	86	14	2.2	249	Sand
28 Aug	Marfona	MBM	90	15	2.1	156	sandy loam
16 Aug	PiperPRE	Solanum	92	23	1.4	107	sandy loam
20 Aug	Marfona	MBM	94	16	2.0	86	Sand
28 Aug	Marfona	MBM	94	15	2.0	132	Sand
16 Aug	Marfona	Solanum	98	15	2.0	125	sandy loam

Table 3. Selected characters from all samples – 2003

Delivered	Variety	Supplier	Percentage bruised	Dry Matter %	% K in tuber tissue	Soil K µg/ml dry weight 0-30 cm	Soil Group
8 Aug	Marfona	Branston	14	30	2.7	458	medium loam
8 Aug	Marfona	Solanum	16	227	2.9	577	sand
29 Aug	Marfona	Branston	18	224	2.0	236	sandy loam
25 Sep	PiperPRO	McCains	18	191	2.8	205	sandy loam
15 Aug	Marfona	Branston	22	225	2.6	388	silt
7 Aug	Marfona	MBM	22	236	1.6	122	sandy loam
25 Sep	PiperPRO	McCains	24	207	3.1	279	sandy loam
24 Sep	Caraa	MBM	24	195	2.8	187	organic peat
29 Aug	PiperPRE	Solanum	24	239	2.3	487	organic peat
29 Aug	PiperPRE	Branston	26	255	2.0	200	sandy loam
8 Aug	Marfona	Branston	36	30	2.3	137	sandy loam
8 Oct	PiperPRO	McCains	38	229	2.9	403	sand
25 Sep	PiperPRE	QV Foods	40	263	2.3	249	sandy loam
10 Oct	Cara	Solanum	42	210	2.8	557	organic peat
3 Sep	PiperPRE	MBM	44	238	2.2	359	organic peat
17 Oct	Cara	Solanum	44	213	2.4	370	silt
9 Oct	PiperPRE	Greenvale	48	251	2.3	152	medium loam
9 Oct	Cara	QV Foods	48	191	2.5	319	silt
5 Sep	Marfona	Branston	52	221	2.5	511	silt
8 Oct	PiperPRO	McCains	52	244	2.6	334	sand
5 Sep	PiperPRE	Branston	54	233	2.4	384	silt
9 Oct	Cara	MBM	54	217	2.6	138	sandy loam
14 Oct	PiperPRO	McCains	56	282	2.2	275	sand
2 Oct	Cara	MBM	56	215	2.1	112	sandy loam
14 Oct	PiperPRO	McCains	60	224	2.2	350	sand
16 Oct	Cara	MBM	62	199	2.6	526	organic peat
3 Oct	PiperPRO	Greenvale	64	229	2.3	129	medium loam
1 Oct	PiperPRO	McCains	68	221	2.0	144	medium loam
2 Oct	Cara	MBM	68	220	2.3	195	sandy loam
4 Sep	Marfona	QV Foods	70	226	2.4	464	silt
11 Sep	PiperPRE	QV Foods	70	258	2.4	173	sand
12 Sep	PiperPRE	Solanum	74	251	2.3	378	silt
9 Oct	Cara	QV Foods	76	226	2.1	165	silt
9 Oct	Cara	Greenvale	80	215	2.7	218	medium loam
28 Aug	Marfona	QV Foods	80	231	1.7	251	silt
5 Sep	Marfona	Solanum	82	220	1.9	73	sand
15 Aug	Marfona	Branston	84	226	1.8	213	sandy loam
17 Oct	Cara	Greenvale	84	230	2.0	444	chalkyloam
16 Oct	Cara	QV Foods	84	198	2.0	199	silt
12 Sep	Marfona	Branston	86	239	2.4	475	silt
12 Sep	PiperPRE	Branston	86	239	2.1	254	silt
3 Oct	PiperPRO	Greenvale	86	210	2.0	126	sandy loam
1 Oct	PiperPRO	McCains	88	198	2.1	282	medium loam
15 Aug	PiperPRE	Solanum	88	243	1.7	142	sandy loam
2 Oct	Cara	QV Foods	92	234	2.1	278	silt
14 Aug	Marfona	QV Foods	92	231	1.9	153	silt
17 Oct	Cara	Greenvale	94	204	1.6	87	medium loam

Figure 5 shows the same distributions indicating the number of samples for each of the three years. Susceptibility to bruising was worse during the 2003 season for Cara and for Maris Piper, but was no worse than the other two years for Marfona samples.

Fig. 5 Frequency distributions of all bruising for individual years



Relationship between intensity score and proportion of tubers bruised

Figure 6 shows how the mean colour intensity score increases with the proportion of tubers bruised. This confirms earlier evidence suggesting that samples which show severe bruise discolouration exhibit bruising on a high proportion of tubers.

Fig. 6 Relationship between bruising and mean colour intensity score of crops from 2001, 2002 and 2003 seasons

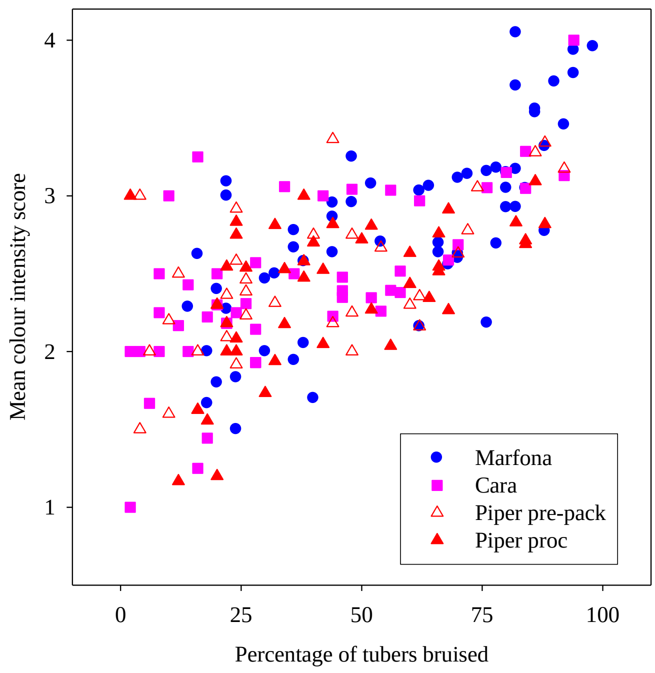
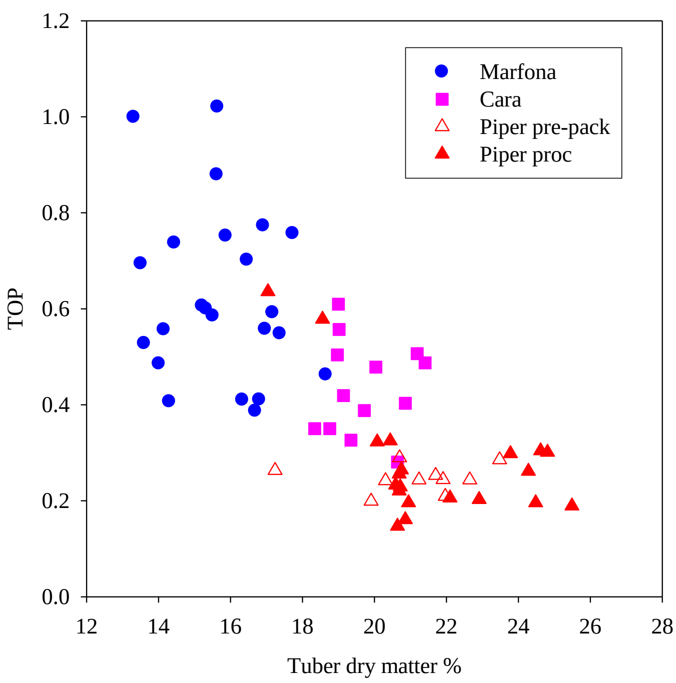


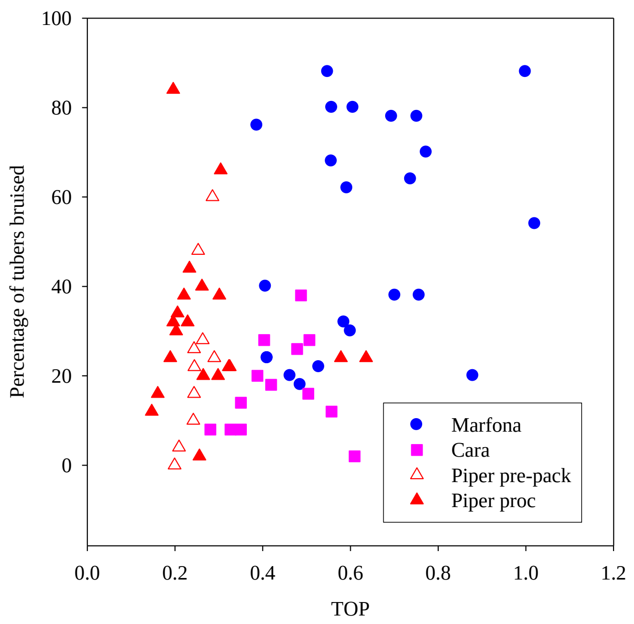
Fig. 7 Total oxidative potential plotted against tuber dry matter percentage for all crops in 2001 only



3.3.2 Measurement of total oxidative potential in 2001 only

These results have already been reported at the end of 2001, but are repeated here in this report for completion. Pooled data from all the crops in 2001 show a highly significant negative correlation of -0.746 between total oxidative potential and dry matter % (Fig. 7) and a significant positive correlation of 0.386 between percentage bruised tubers and total oxidative potential (Fig. 8). However, both these relationships were due to varietal pooling of the data simply suggesting that varieties with a higher total oxidative potential are likely to have a lower dry matter percentage and a higher susceptibility to bruising. Within any one variety there were no significant correlations between the percentage of tubers bruised and total oxidative potential suggesting that total oxidative potential is unlikely to be a useful indicator of bruising susceptibility.

Fig. 8 Percentage tubers bruised plotted against total oxidative potential for all crops in 2001 only



3.3.3 Correlations with bruising

Examination of correlation matrices for all sets and subsets of data identified relationships of interest, each of which are indicated below. The correlation coefficients are shown on the plots.

Marfona

There was no relationship between dry matter percentage and percentage bruising (Fig. 9a). There were also no relationships between percentage bruising and Mg in the tuber tissue, or with K, either in the tuber tissue or in the soil as is evident in Figs 9b, c and d.

Cara

Fig. 10a shows that, in contrast to Marfona, the percentage of tubers bruised increased with increase in tuber dry matter percentage. Figures 10b, c and d respectively show that lower susceptibility to bruising is associated with increases in % Mg in tuber tissue but there was no relationship between susceptibility and K in tuber tissue or K in the soil from 0 to 30 cm.

Fig. 9 Scatter plots of various characters against the percentage of tubers bruised in Marfona

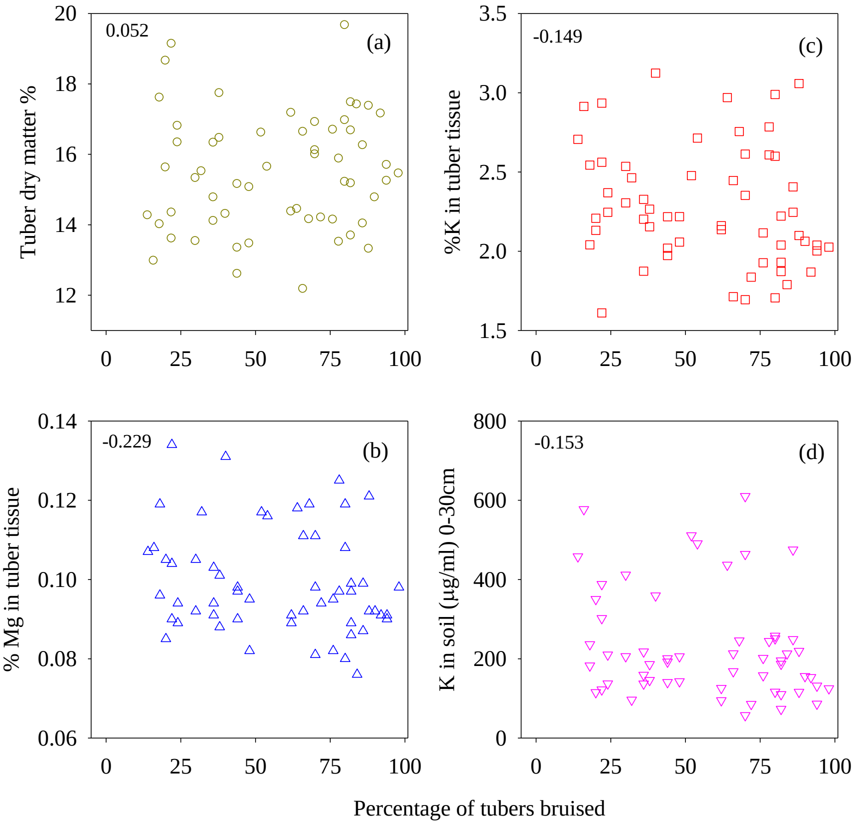
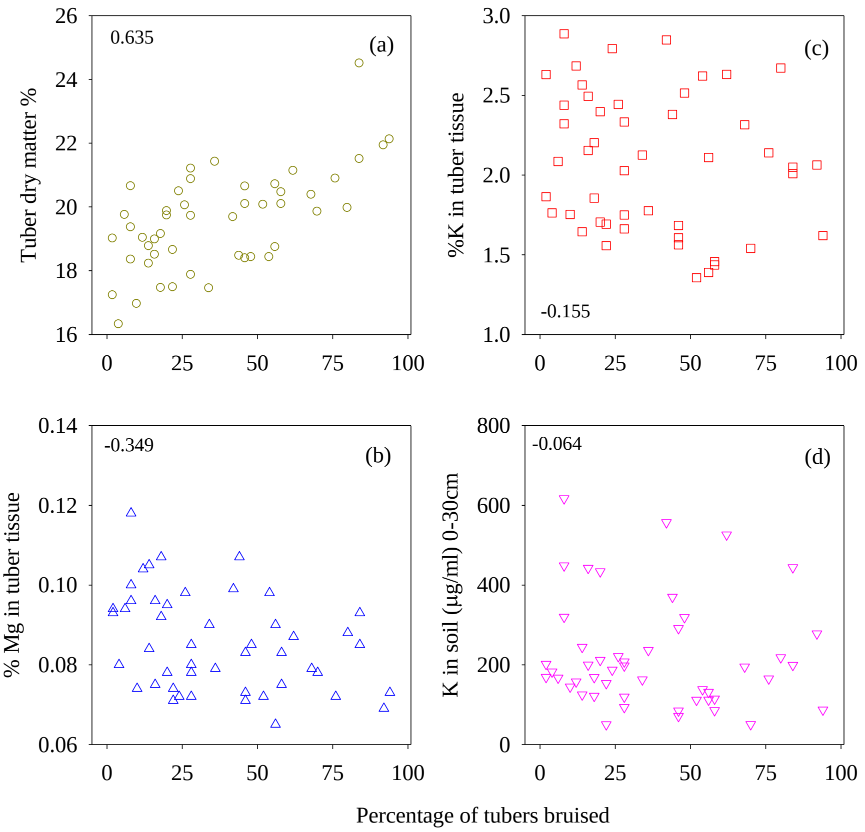


Fig. 10 Scatter plots of various characters against the percentage of tubers bruised in Cara



Maris Piper for prepacking

Figure 11a shows that as dry matter increased so did susceptibility to bruising. Figures 11b and c show an association between reduced bruising susceptibility and increased tuber tissue levels of Mg and K. Figure 11d shows that there was also a slight relationship between increasing K in the top soil and reduced susceptibility to bruising.

Fig. 11 Scatter plots of various characters against the percentage of tubers bruised in Maris Piper for prepacking

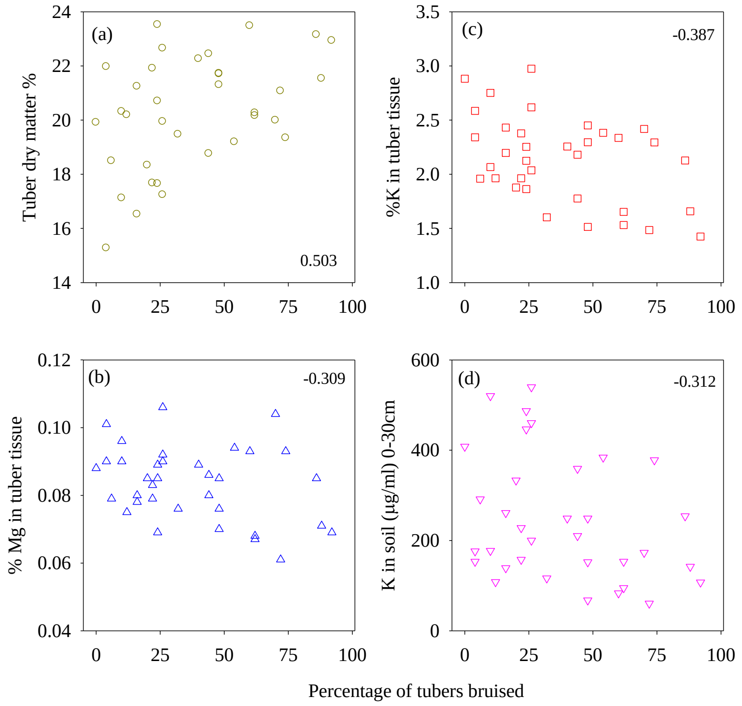
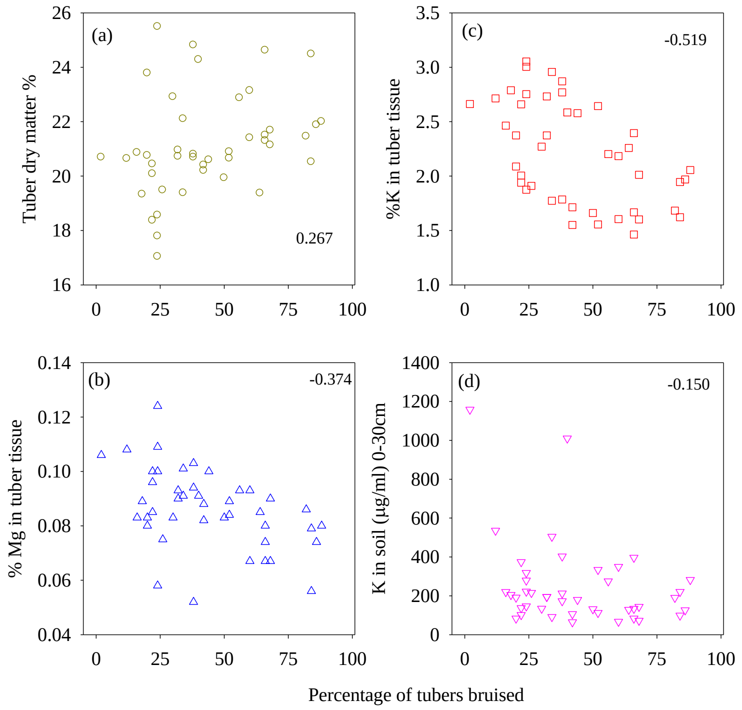


Fig. 12 Scatter plots of various characters against the percentage of tubers bruised in Maris Piper for processing



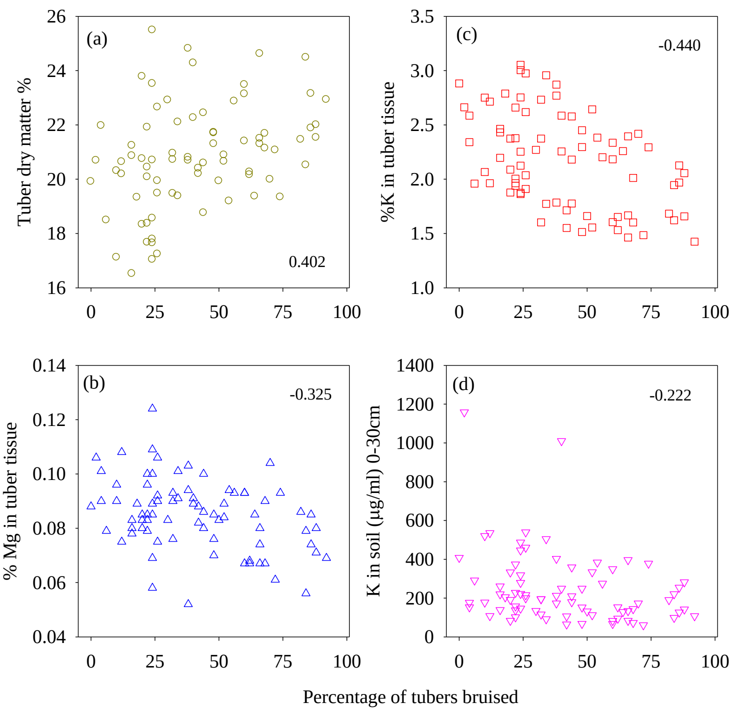
Maris Piper for processing

There was no association between susceptibility to bruising and tuber dry matter percentage (Fig 12a). Lower susceptibility to bruising was associated with increases in the %Mg and % K in tuber tissue (Figs 12b and c). However there was no relationship with K in the top soil (Fig 12d).

ALL the Maris Piper crops

When all the Maris Piper crop data were combined, as dry matter increased so did susceptibility to bruising (Fig 13a). Figures 13b and c show an association between reduced bruising susceptibility and increased tuber tissue levels of Mg and K. There was no relationship between increasing K in the top soil and reduced susceptibility to bruising (Fig 13d).

Fig. 13 Scatter plots of various characters against the percentage of tubers bruised in all Maris Piper crops



3.3.4 Relationships between susceptibility to bruising and the time of lifting and the time interval between defoliation and the time when the tubers were dug

Figure 14 is a scatter plot showing the percentage of tubers bruised plotted against the time when the tubers were dug. There were no trends evident for any of the varieties.

Figure 15 shows the relationship between the percentage of tubers bruised and the time interval between the first defoliation and the day when the tubers were dug. For Cara and for Maris Piper there was no relationship, but for Marfona there was a significant positive trend with increasing time between defoliation and the time when the tubers were dug leading to increasing susceptibility to bruising with a correlation coefficient of 0.462 (d.f.= 52).

Fig. 14 Scatter plot showing the percentage of tubers bruised plotted against the time when the tubers were dug

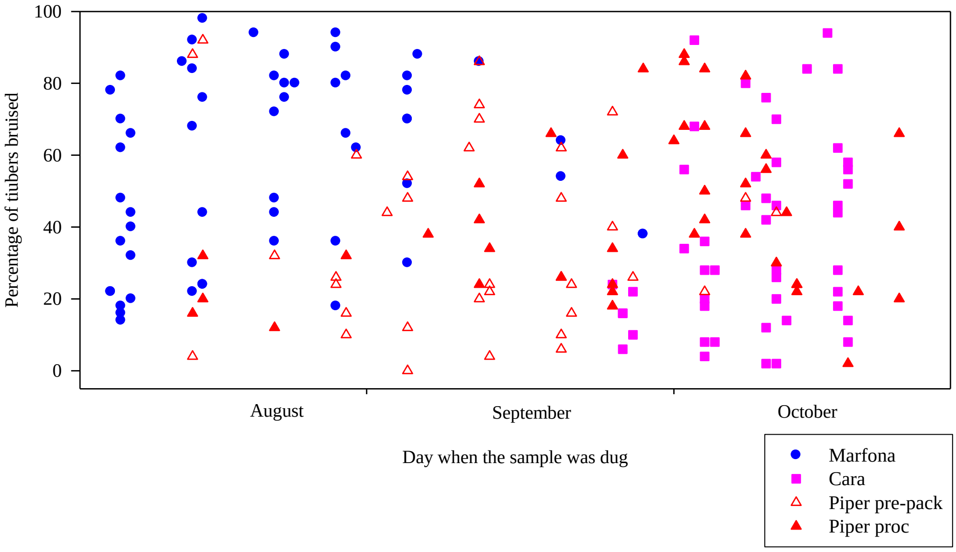
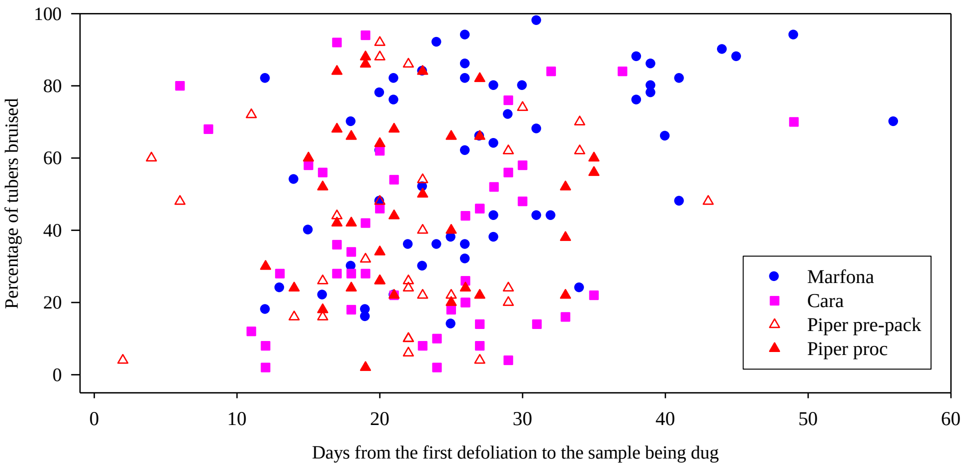


Fig. 15 Scatter plot showing the percentage of tubers bruised plotted against the number of days between the first defoliation and the day when the tubers were dug

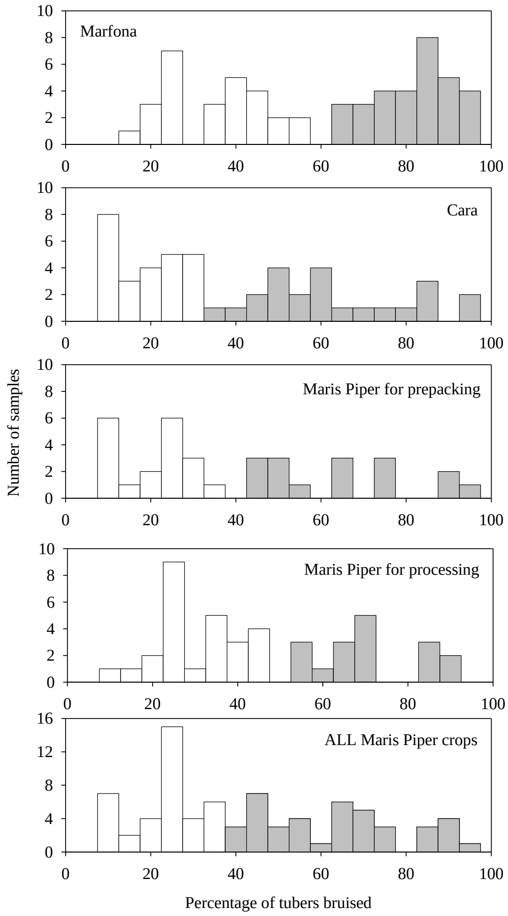


3.3.5 Contingency tables showing associations between susceptibility to bruising and pre-harvest crop history

In order to appreciate the range and scope of the data recorded in the crop history survey over all three years, Figures 16 a-w, included as Appendix II, show the minimum and maximum values of the observed data characters and the number of values observed overall. Tables 4 a-m, included as Appendix III, show the number of observations in different categories where the data recorded were subjective.

Data from all three years have been analysed and where interesting and significant are presented for each variety and, in the case of both Maris Piper products, separately. The crops were split into two groups according to the percentage bruised in order to give approximately similar numbers in each group. The split was drawn for Marfona above and below 60%, for Cara above and below 30%, for Maris Piper prepacked crops above and below 35% and for Maris Piper processed crops above and below 45% susceptibility to bruising. When all the Maris Piper crops were aggregated together, the division was drawn at above and below 35%. Figure 17 repeats the frequency distributions for each, showing how the data were split. The subsequent contingency tables are shown to indicate associations between bruising and other pre-harvest factors. The tables show the observed number of crops in each group, the total numbers and the deviation of the observed number from the expected number. Where crop history data observations are missing, the total numbers may not always agree with the number of crops within the survey. Significance levels in the Chi-squared test analyses were tested at P = 0.05. Where the test was significant, that row within the table is shaded in grey to highlight the association.

Fig. 17 Frequency distributions of all bruising in 2001, 2002 and 2003 with the crops with greater susceptibility to bruising indicated in grey



To further explain the statistical technique, let us look at one contingency table in detail, Table 5a, which shows associations between the soil type on which crops were grown and susceptibility to bruising for Marfona. The crops of Marfona were grouped into those *<60%* and those *>60%* in susceptibility to bruising. For instance, Table 5a shows that there were 18 crops in total grown on sand soils. Of these, 3 crops were classed as *<60%* with 15 crops *>60%*. In total, over the three years of production on all soil types, there were 58 crops of Marfona, with 27 crops *<60%* and 31 crops *>60%* in their susceptibility to bruising. In this case, we would expect the ratio of the 18 crops grown on sand soils to remain the same as the ratio of all 58 crops, ie 27 to 31. So you would expect to see the following data:

27/58 * 18 = 8.4 crops in the group *<60%*
31/58 * 18 = 9.6 crops in the group *>60%*

In actual fact, there were only 3 crops in the group <60%, that is 5.4 fewer than expected, and 15 crops in the group >60%, 5.4 more than expected. Deviations between observed and expected values were then tested for significance, using a Chi-squared test and in the case of Table 5a, there were significantly more crops grown on sand soils with higher susceptibility to bruising than would be expected. Table 5a also shows that there was an association of similar significance with the 25 crops grown on loam soils, but here in contrast, there were 5.4 more crops with lower susceptibility to bruising than would be expected on this soil type.

Marfona

Tables 5a to f indicate that there were associations with soil type, total K and Mg applied, spring Mg applied, soil moisture conditions at burning off and at lifting. Increased bruising susceptibility was associated with sandy soils, high levels of applied K and Mg and with dry soil conditions at burning off and at lifting. Reduced susceptibility was associated with crops grown on soils classified as loams.

Table 5. Contingency tables indicating possible associations with susceptibility to bruising in Marfona

Table 5a Marfona

Soil type	Grouping by susceptibility to bruising				Total number observed
	<60% bruised		*>60% bruised*		
	Number observed	Deviation from number expected	Number observed	Deviation from number expected	
Sand	3	-5.4	15	5.4	18
Silt	7	0.0	8	0.0	15
Loam	17	5.4	8	-5.4	25
Total number observed	27		31		58

Table 5b Marfona

Total K applied (kg/ha)	Grouping by susceptibility to bruising				Total number observed
	<60% bruised		*>60% bruised*		
	Number observed	Deviation from number expected	Number observed	Deviation from number expected	
≤ 240	7	-0.3	9	0.3	16
240 – 300	8	2.5	4	-2.5	12
300 – 360	8	3.5	2	-3.5	10
>360	2	-5.7	15	5.7	17
Total number observed	25		30		55

Table 5c Marfona

Total Mg applied (kg/ha)	Grouping by susceptibility to bruising				Total number observed
	<60% bruised		*>60% bruised*		
	Number observed	Deviation from number expected	Number observed	Deviation from number expected	
None	7	-0.8	10	0.8	17
≤ 50	8	3.4	2	-3.4	10
50 – 100	8	1.5	6	-1.5	14
> 100	1	-4.1	10	4.1	11
Total number observed	24		28		52

Table 5d Marfona

Spring Mg (kg/ha)	Grouping by susceptibility to bruising				Total number observed
	<60% bruised		*>60% bruised*		
	Number observed	Deviation from number expected	Number observed	Deviation from number expected	
None	10	0.8	10	-0.8	20
≤ 50	7	2.8	2	-2.8	9
50 - 100	6	0.5	6	-0.5	12
> 100	1	-4.1	10	4.1	11
Total number observed	24		28		52

Table 5e Marfona

Soil moisture conditions at burning off	Grouping by susceptibility to bruising				Total number observed
	<60% bruised		*>60% bruised*		
	Number observed	Deviation from number expected	Number observed	Deviation from number expected	
Dry	1	-3.5	9	3.5	10
Moist	17	0.9	19	-0.9	36
Wet	7	2.5	3	-2.5	10
Very wet	0	0.0	0	0.0	0
Total number observed	25		31		56

Table 5f Marfona

Soil moisture conditions at lifting	Grouping by susceptibility to bruising				Total number observed
	<60% bruised		*>60% bruised*		
	Number observed	**Deviation from number expected**	**Number observed**	**Deviation from number expected**	
Dry	2	-3.5	10	3.5	12
Moist	20	2.2	19	-2.2	39
Wet	3	0.7	2	-0.7	5
Very wet	1	0.5	0	-0.5	1
Total number observed	26		31		57

Cara

Tables 6a and b show that in Cara there was an association with soil moisture conditions at burning off and with the year of production. Reduced susceptibility to bruising was associated with wetter soil conditions at burning off. In 2001 crops were less susceptible to bruising than expected, while in 2003 the opposite was the case.

Table 6. Contingency tables indicating possible associations with susceptibility to bruising in Cara

Table 6a Cara

Soil moisture conditions at burning off	**Grouping by susceptibility to bruising**				**Total number observed**
	<30% bruised		***>30% bruised***		
	Number observed	**Deviation from number expected**	**Number observed**	**Deviation from number expected**	
Dry	6	-4.3	15	4.3	21
Moist	11	1.7	8	-1.7	19
Wet	4	2.0	0	-2.0	4
Very wet	1	0.5	0	-0.5	1
Total number observed	22		23		45

Table 6b Cara

Year of production	**Grouping by susceptibility to bruising**				**Total number observed**
	<30% bruised		***>30% bruised***		
	Number observed	**Deviation from number expected**	**Number observed**	**Deviation from number expected**	
2001	12	5.2	1	-5.2	13
2002	12	1.1	9	-1.1	21
2003	1	-6.3	13	6.3	14
Total number observed	25		23		48

Maris Piper for prepacking

Tables 7 a and b show that there was an association with soil moisture conditions at burning off and with the year of crop production. Increased susceptibility to bruising was again associated with dry soil conditions at burning off. In 2003 crops were more susceptible to bruising than expected.

Table 7. Contingency tables indicating possible associations with susceptibility to bruising in Maris Piper for prepacking

Table 7a Maris Piper for prepacking

Soil moisture conditions at burning off	**Grouping by susceptibility to bruising**				**Total number observed**
	<35% bruised		***>35% bruised***		
	Number observed	**Deviation from number expected**	**Number observed**	**Deviation from number expected**	
Dry	1	-3.1	7	3.1	8
Moist	10	1.2	7	-1.2	17
Wet	3	0.9	1	-0.9	4
Very wet	2	1.0	0	-1.0	2
Total number observed	16		15		31

Table 7b Maris Piper for prepacking

Year of production	**Grouping by susceptibility to bruising**				**Total number observed**
	<35% bruised		***>35% bruised***		
	Number observed	**Deviation from number expected**	**Number observed**	**Deviation from number expected**	
2001	8	2.6	2	-2.6	10
2002	9	0.9	6	-0.9	15
2003	2	-3.4	8	3.4	10
Total number observed	19		16		35

Maris Piper for processing

Table 8 shows that in Maris Piper for processing there was only an association with the year of production. As also seen in Cara, in 2001 crops were less susceptible to bruising than expected while in 2003 the opposite was the case.

Table 8. Contingency table indicating possible associations with susceptibility to bruising in Maris Piper for processing

Year of production	**Grouping by susceptibility to bruising**				**Total number observed**
	<45% bruised		***>45% bruised***		
	Number observed	**Deviation from number expected**	**Number observed**	**Deviation from number expected**	
2001	18	5.9	2	-5.9	20
2002	5	-2.9	8	2.9	13
2003	3	-3.0	7	3.0	10
Total number observed	26		17		43

ALL Maris Piper crops

When all the Maris Piper crop data were combined Tables 9a to e indicate that there were associations with burning off and with soil moisture conditions at burning off, time of lifting, growth period and the year of production. There was an association between crops lifted without being defoliated and susceptibility to bruising, with more crops than expected in the lower grouping for bruising. However, it is important to note that there were only 13 crops over the three years which were not defoliated.

Increased bruising susceptibility was associated with dry soil conditions at burning off, crops lifted later in the season and longer grower period. Reduced susceptibility was associated with crops lifted earlier in the season and shorter growing period, though the shorter growing period is linked with the crops being lifted without defoliation. As stated previously, in 2001 crops were less susceptible to bruising than expected while in 2003 the opposite was the case.

Table 9. Contingency tables indicating possible associations with susceptibility to bruising in all Maris Piper crops

Table 9a **ALL Maris Piper crops**

Was the crop defoliated?	**Grouping by susceptibility to bruising**				**Total number observed**
	<35% bruised		***>35% bruised***		
	Number observed	**Deviation from number expected**	**Number observed**	**Deviation from number expected**	
Yes	28	-3.7	37	3.7	65
No	**10**	**3.7**	**3**	**-3.7**	**13**
Total number observed	38		40		78

Table 9b **ALL Maris Piper crops**

Soil moisture conditions at burning off	**Grouping by susceptibility to bruising**				**Total number observed**
	<35% bruised		***>35% bruised***		
	Number observed	**Deviation from number expected**	**Number observed**	**Deviation from number expected**	
Dry	**2**	**-7.9**	**21**	**7.9**	**23**
Moist	17	4.5	12	-4.5	29
Wet	6	1.7	4	-1.7	10
Very wet	**3**	**1.7**	**0**	**-1.7**	**3**
Total number observed	28		37		65

Table 9c **ALL Maris Piper crops**

Time of lifting	**Grouping by susceptibility to bruising**				**Total number observed**
	<35% bruised		***>35% bruised***		
	Number observed	**Deviation from number expected**	**Number observed**	**Deviation from number expected**	
Late Aug	11	4.2	3	-4.2	14
Early Sept	8	-0.8	10	0.8	18
Late Sept	11	1.7	8	-1.7	19
Early Oct	5	-5.7	17	5.7	22
Late Oct	3	0.6	2	-0.6	5
Total number observed	38		40		78

Table 9d **ALL Maris Piper crops**

Time from planting to lifting in days	**Grouping by susceptibility to bruising**				**Total number observed**
	<35% bruised		***>35% bruised***		
	Number observed	**Deviation from number expected**	**Number observed**	**Deviation from number expected**	
≤ 150	**14**	**5.1**	**5**	**-5.1**	**19**
150 - 170	17	3.0	13	-3.0	30
> 170	**4**	**-8.1**	**22**	**8.1**	**26**
Total number observed	35		40		75

Table 9e **ALL Maris Piper crops**

Year of production	**Grouping by susceptibility to bruising**				**Total number observed**
	<35% bruised		***>35% bruised***		
	Number observed	**Deviation from number expected**	**Number observed**	**Deviation from number expected**	
2001	**22**	**7.4**	**8**	**-7.4**	**30**
2002	12	-1.6	16	1.6	28
2003	**4**	**-5.7**	**16**	**5.7**	**20**
Total number observed	38		40		78

3.4 Discussion

It is important to remember that this work has investigated inherent susceptibility to bruising and not the actual incidence of bruising, which is a combination of susceptibility and what happens in practice during harvesting and handling. Susceptibility to bruising was determined by the number of tubers which showed discolouration in the tissue, after impact testing was applied under controlled laboratory conditions.

While this work cannot determine specific causes of bruising it has identified factors, which do **not** appear to be associated with susceptibility to bruising and which therefore can be eliminated when developing any protocol designed to minimize bruising. These factors are listed in Table 10. It appears that in all varieties, initial soil K, applied P, the day of planting, soil tilth and compaction at planting and both the method and day of defoliation had no effect on susceptibility to bruising. The tuber temperature at lifting also seemed to show no association.

Table 10. Pre-harvest factors which do not appear to be associated with susceptibility to bruising

Factor	**How were these data collected?** *See also Table 2* *Recording sheet for crop history data*
Initial soil K	Supplied by the grower in mg/kg
All P applied	Supplied by the grower in kg/ha
Day of planting	Supplied by the grower
Soil tilth at planting	Allocated to one of three categories by the grower
Soil compaction at planting	Allocated to one of three categories by the grower
Method of defoliation	Recorded as one of four methods by the grower
Day of defoliation	Supplied by the grower
Tuber temperature when the sample was dug	Recorded as a spot measurement in ^{o}C when the sample of tubers was dug

A test using total oxidative potential was found unlikely to be a useful indicator of bruising susceptibility because, within any one variety, there were no significant correlations between the percentage of tubers bruised and total oxidative potential measured.

McGarry *et al*. (1996), surveying the literature, thought that it was not possible to conclude that genotypic effects on bruising susceptibility existed. However, our results indicate clear varietal differences. On average, bruising was highest in Marfona and lowest in Cara but the range of bruising was considerable in both Marfona (18 to 98%) and Cara (2 to 70%) showing that susceptibility to bruising varies enormously from one crop to another. Consequently it is important to identify the factors which influence susceptibility to bruising in a particular variety, to allow potentially susceptible crops to be pin-pointed, so that production and handling can be modified to minimize its incidence.

Kunkel and Gardner (1965) suggested that the decrease in tuber dry matter content was related to decreased bruise susceptibility and our results certainly confirm this for Cara and Maris Piper but not in Marfona, which in any case has a much lower dry matter percentage than either Cara or Maris Piper. Marfona behaves quite differently to Cara and Maris Piper. Unfortunately, it is not possible to tell from our work to what extent changes in dry matter percentage are attributable to differences in starch and sugar content, tissue turgor or to other physiological conditions.

It is evident that K and Mg nutrition is important, although their precise effects are not clear. McGarry *et al*. (1996) considered that there was fairly compelling evidence to show that bruising susceptibility reduced with increasing rates of K application but our results find no evidence for this in the season of application. Nevertheless, in general for Maris Piper, higher soil and tuber tissue levels of K and Mg were associated with reduced susceptibility to bruising. The problem therefore is how to increase tissue levels of K and Mg since there were no significant correlations between applied K and Mg and levels of K and Mg in tuber tissue. This suggests that applications in the season of production may not be effective in influencing tuber tissue levels and raises a question about the development of fertilizer regimes for the longer term, at least with respect to the susceptibility of crops to bruising.

The possible influence of K and Mg appears however to be variety-dependent. In Marfona higher levels of K and Mg in the tuber tissue or in the top soil do not appear to affect susceptibility to bruising. In Cara this was also the case with K in the tuber tissue and in the top soil, and with Mg in the top soil.

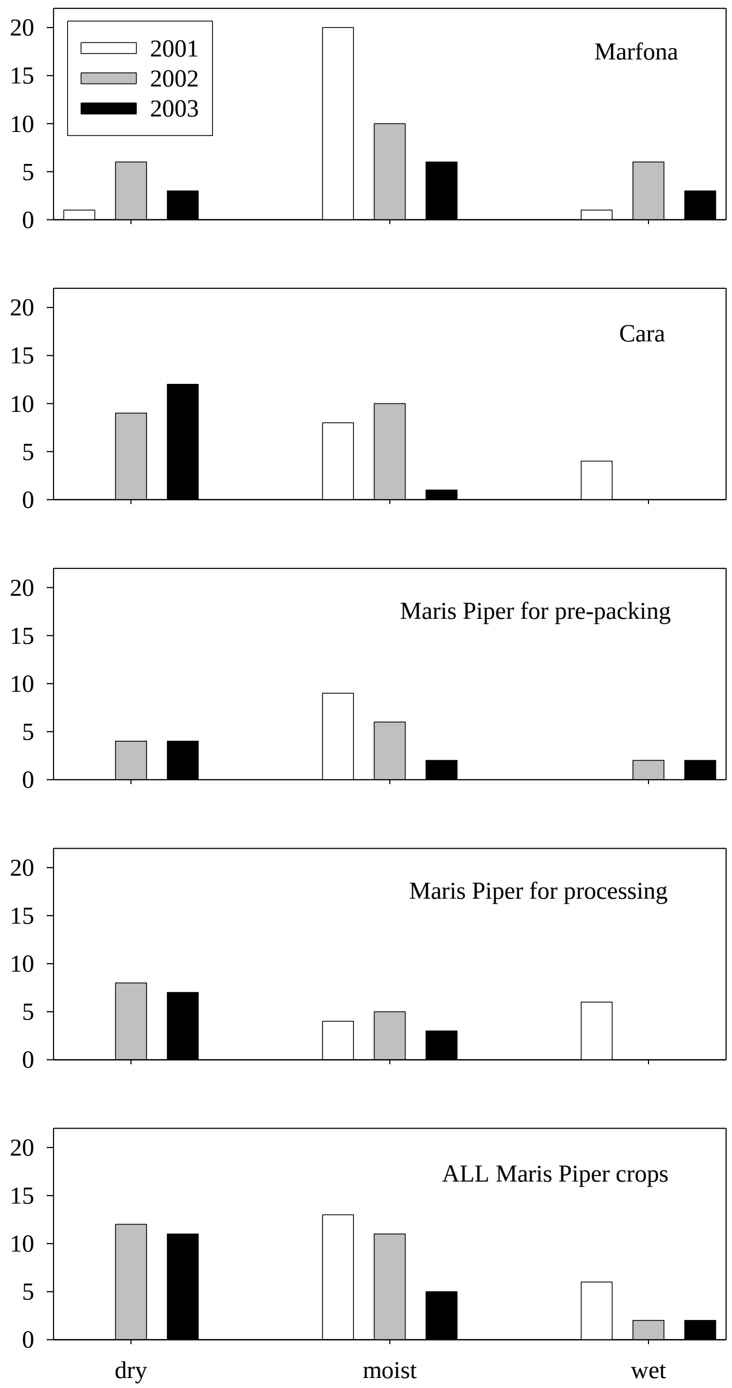
What is clear, is that the issue of how to influence tuber tissue content of K and Mg needs to be better understood. It may be that only one of them is important because, in this work, tuber tissue levels of K and Mg were correlated in all varieties.

Perhaps the most interesting and useful association identified is that between susceptibility to bruising and the soil moisture conditions at the time of burning off. Figure 18 shows the numbers of crops defined at each level of soil moisture at burning off for each year. McGarry *et al*. (1996) pointed out that tuber hydration has been the subject of relatively few investigations and a large amount of speculation. This still seems to be the case eight years later. There is much anecdotal evidence that the water status of the tubers around the time of haulm destruction is of significance to tuber physiology post harvest. It is very unfortunate that recordings of environmental variables were dropped from the project after the first year. The differences in susceptibility are, no doubt, confounded by the unusually warm and dry weather that crops experienced in 2003. The data for Cara and for Maris Piper show that susceptibility to bruising varied with year and although some environmental spot measurements were recorded at lifting, there are indications that weather records for each crop could identify additional and contributory factors influencing susceptibility to bruising.

Examination of the interval between burning-off and lifting, revealed a trend of increased susceptibility to bruising with increasing time interval for Marfona, but there was no trend evident with the other varieties as Figure 15 showed. However, once all the Maris Piper crops were combined, the chi-squared analyses identified an association between susceptibility to bruising and the time between planting and lifting. Where Maris Piper crops were harvested without defoliation there were also less crops showing severe bruising than would have been expected. These indications relate to previous evidence that younger tubers are less susceptible to bruising than older ones, as discussed by McGarry *et al*. (1996).

Another interesting, but very obvious, question raised by the work is why some tubers show no discolouration at all, while others of the same size from the same crop under controlled laboratory conditions show severe blackening, with a range of discolouration in the rest of the tubers. Is it something to do with the position of the tuber in the ridge or the derivation on the stem of the stolon bearing that tuber?

Fig. 18 Histogram showing the number of crops at different soil moisture conditions at burning off



3.5 Conclusions

- Data analyses have suggested that several factors have no significant influence on susceptibility to bruising
- A test using total oxidative potential is unlikely to be a useful indicator of bruising susceptibility
- Bruising susceptibility varied considerably between crops of the same variety
- Bruising susceptibility in Marfona varied with soil type with sandy soils being associated with increased susceptibility to bruising and loams with decreased susceptibility
- Dry soil conditions at burning off were associated with greater susceptibility to bruising in Marfona, Cara and Maris Piper
- In Marfona and in Maris Piper, the time between defoliation and lifting was associated with susceptibility to bruising
- In Cara and in Maris Piper a higher tuber dry matter percentage was associated with greater susceptibility to bruising
- In Marfona there was no relationship between tuber dry matter percentage and susceptibility to bruising
- The influence of K and Mg appears complex and varies with variety
- Higher levels of applied K and Mg were associated with increased susceptibility to bruising in Marfona
- In general for Cara and for Maris Piper higher soil and tuber tissue levels of K and Mg were associated with reduced susceptibility to bruising
- Higher tuber tissue levels of K and Mg were not associated with the levels of K and Mg which had been applied

3.6 Challenges for future work

There is great scope for future work to investigate the understanding of susceptibility to bruising. Future work in the areas indicated below may further our knowledge. The relevant conclusions from this study are shown in italics above each of the outlined challenges.

- *Conclusion - Dry soil conditions at burning off were associated with greater susceptibility to bruising in Marfona, Cara and Maris Piper*

- *Conclusion - In Marfona and in Maris Piper, the time between defoliation and lifting was associated with susceptibility to bruising*

    - Investigation of defoliation, the degree of foliage senescence and the maturity of tubers, and soil moisture status throughout the entire growing season, giving a fuller and continuous picture of the water status of the tubers

- *Conclusion - The influence of K and Mg appears complex and varies with variety*

- *Conclusion - Higher levels of applied K and Mg were associated with increased susceptibility to bruising in Marfona*

- *Conclusion - In general for Cara and for Maris Piper higher soil and tuber tissue levels of K and Mg were associated with reduced susceptibility to bruising*

- *Conclusion - Higher tuber tissue levels of K and Mg were not associated with the levels of K and Mg which had been applied*

    - Investigation of the influence of K and Mg on the physiology of tubers and both short-term and long-term fertilisation strategies

    - Investigation of the causes of the variation from tuber to tuber in susceptibility to bruising

It should be noted that any, or indeed, all of the factors suggested above for further study may interact with one another.

3.7 References

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4. Achievement of milestones

Year 1

Mar 2001	Initial project meeting to finalise sampling plans and logistics	**11-04-01**
Oct 2001	Complete collection of 50 tuber samples	**Yes**
Nov 2001	Crop production details for 50 samples put into spreadsheets	**Yes**
Nov 2001	Complete bruising susceptibility testing on 50 samples.	**Yes**
Feb 2002	Complete biochemical and nutrient analyses on 50 samples	**Yes**
Mar 2002	Preliminary discriminatory analyses completed on 50 samples	**Yes**
Mar 2002	Review of project progress	
May 2002	Annual report produced	**Yes**

Year 2

Mar 2002	Review of project progress	**Yes**
May 2002	Annual report produced	**Yes**
June 2002	Technology transfer meeting	**29-05-02**
Oct 2002	Complete collection of 50 tuber samples	**Yes**
Nov 2002	Crop production details for 50 samples put into spreadsheets	**Yes**
Nov 2002	Complete bruising susceptibility testing on 50 samples.	**Yes**
Dec 2002	Present preliminary findings to BPC technology transfer meeting	**01-05-02**
Feb 2003	Complete biochemical and nutrient analyses on 50 samples	**Yes**
Mar 2003	Discriminatory analyses updated to include 100 samples	**Yes**
May 2003	Annual report produced	**Yes**

Year 3

Mar 2003	Review of project progress	**Yes**
June 2003	Technology transfer meeting	**05-06-03**
Oct 2003	Complete collection of 50 tuber samples	**Yes**
Nov 2003	Crop production details for 50 samples put into spreadsheets	**Yes**
Nov 2003	Complete bruising susceptibility testing on 50 samples.	**Yes**
Dec 2003	Present preliminary findings to BPC technology transfer meeting	**No***
Feb 2004	Complete biochemical and nutrient analyses on 50 samples	**Yes**
Mar 2004	Discriminatory analyses updated to include 100 samples	**Yes**
May 2004	Final report produced	**Yes**

***** This was agreed between Dr David Wurr and Dr Ewen Brierley

5. Summary of technology transfer and project deliverables

Article in Eye Witness Issue 16 October 2001
Poster at BPC Potato Storage Event on 1 May 2002
Article in Eye Witness Issue 20 August 2002
Article in Crops Potato supplement Autumn 2002
Poster at BPC Potato Storage Event on 20 May 2004
Paper at HRIA meeting on 10 June 2004

6. Acknowledgements

We thank the consortium members listed below for providing sample material and crop history data and, in the case of Solanum Ltd, storage facilities as well.

- Branston Ltd
- Greenvale AP plc
- MBM Produce Ltd
- McCain Foods (GB) Ltd
- QV Foods Ltd
- Solanum Ltd

This work was originally proposed by Dr Chris Hole, who retired before the start of the project. Dr David Wurr and Mr Roy Drew both retired in September 2003 after two seasons' work had been completed. This report has been written by Ms Jane Fellows. She would like to thank Mrs Jayne Akehurst and Mr Howard Hilton for their invaluable technical assistance and Dr Richard Napier for most helpful discussions.

7. **Appendix I**

Notes taken at a meeting of the BRUCE BPC potato bruising consortium held on Thursday 14 August 2003 at 14.00 at HRI, Wellesbourne

Present: Tim Berry, MBM Produce Ltd (TB), Ewen Brierley, BPC (EB), Roy Drew, HRI (RD), Jane Fellows, HRI (JF), Martin Stothard, Branston Potatoes (MS), David Wurr, HRI (DW)

- The meeting had been convened to take place on the day when the first assessments of samples for the 2003 season were made. RD assessed two of the samples collected on 8 August 2003.

- MS said he carries out damage assessments for Branston at Lincoln. For assessments made from the damage barrel, size determines whether damage would be classed as major or minor damage. Anything major would be rejected on the lines and for minor, it is assumed that half would be rejected. So the score is based on all major plus 50% minor. So far, there did not appear to be great incidence of bruising this season.

- There was a discussion on dry matter. TB had recently sampled two non-irrigated crops by SG and found 26% dry matter in Pentland Dell and 25% in Maris Piper. Did dry matter vary within the ridge, within the plant and within the tuber? TB pointed out that McDonalds particularly like Russet Burbank because the dry matter is consistent across the tubers. EB cited recent Dutch literature. TB suggested that position in the ridge was important. There was wide temperature variation within a ridge.

- Everyone agreed that moisture status at the time of defoliation was of major importance.

- Two crops of Marfona were assessed. Where bruises were observed, notes and photographs were taken.

B070803MAR1 had been irrigated right up to defoliation, by 2 acid applications about 21 days ago. The crop was very green before burn-off.

Tuber 12

Score 1

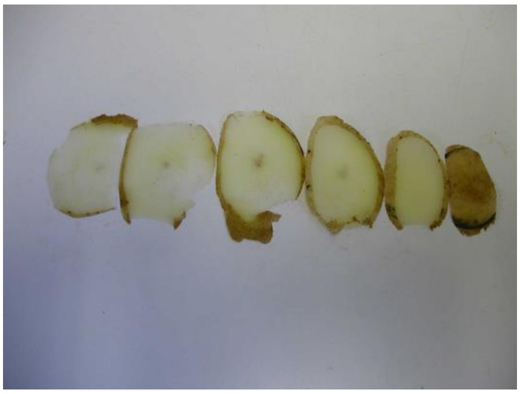
No sign of surface damage

MS said that this would not be picked up commercially

Tuber 19

Score 3

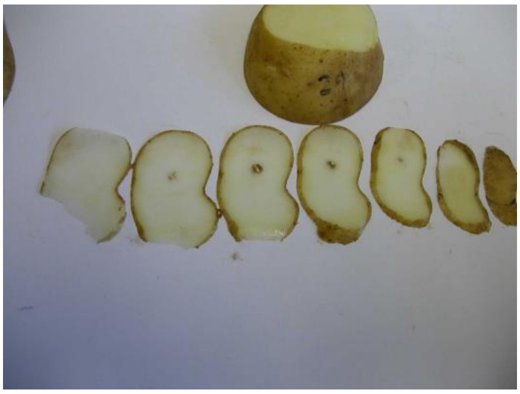
No shatter damage on skin
Cell necrosis around the bruise



Tuber 21

Score 2

No skin damage



Tuber 29

Score 4

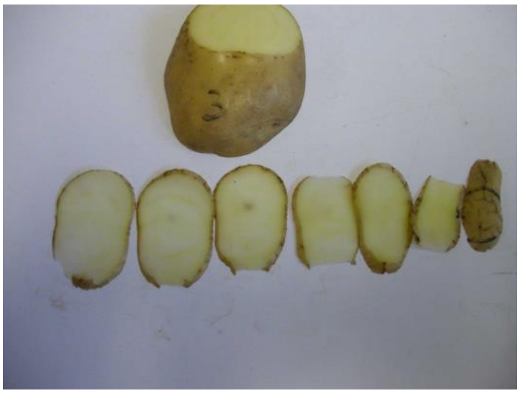
No shatter damage on skin
Cell necrosis
Cavity present

Tuber 42

Score 4

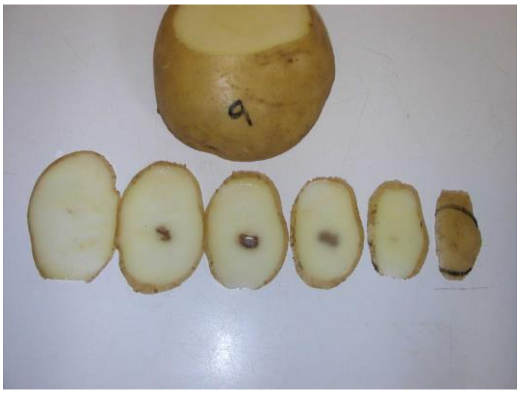
Cavity present

MB060803MAR1 came from a sandy loam and had not been defoliated. The crop was about 70% senesced when lifted.



Tuber 3

Score 2



Tuber 9
CLASSIC BRUISE
Score 4

Skin not broken

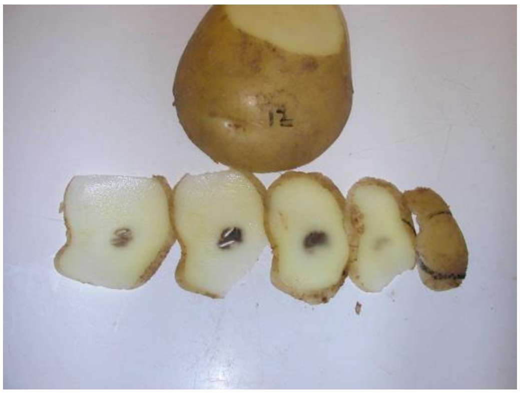
Cavity which had nothing to do with shattering

Tuber 11

Score 5

No skin damage

Cavity

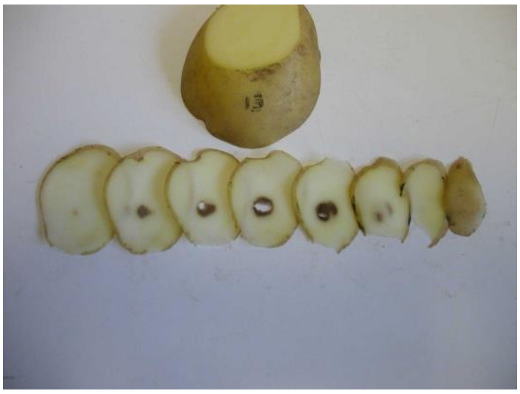


Tuber 12

Score 5

Skin not broken

Cavity



Tuber 13

Score 4

No skin damage

Big cavity

Tuber 35

Score 3

No skin damage

Tuber 39

Score 5

Slight skin damage but not over the area where the bruise was

Small cavity

Tuber 43

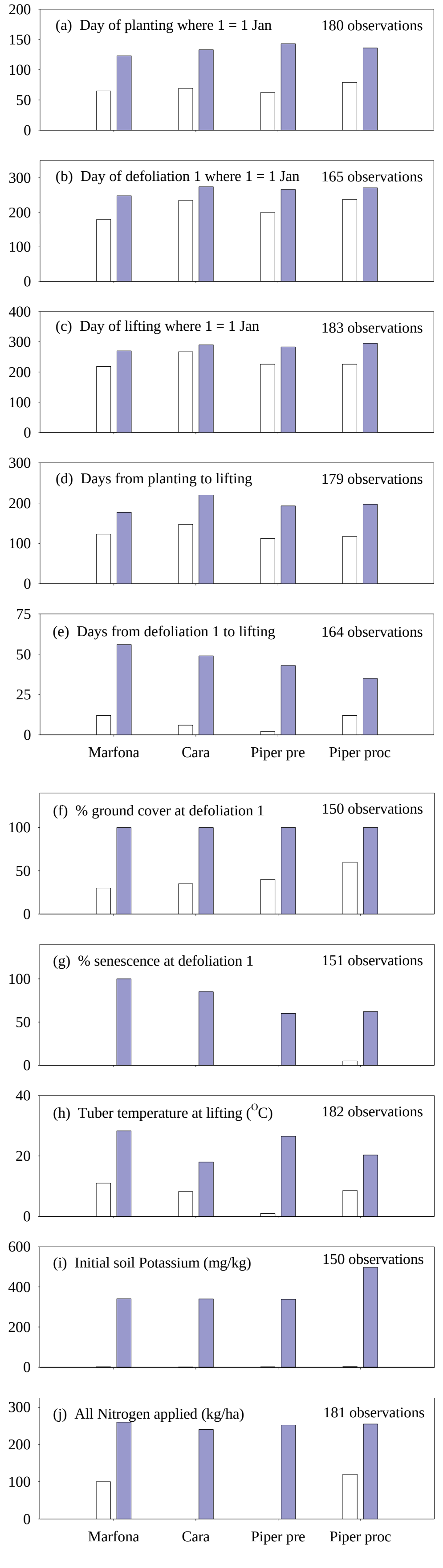
Score 2

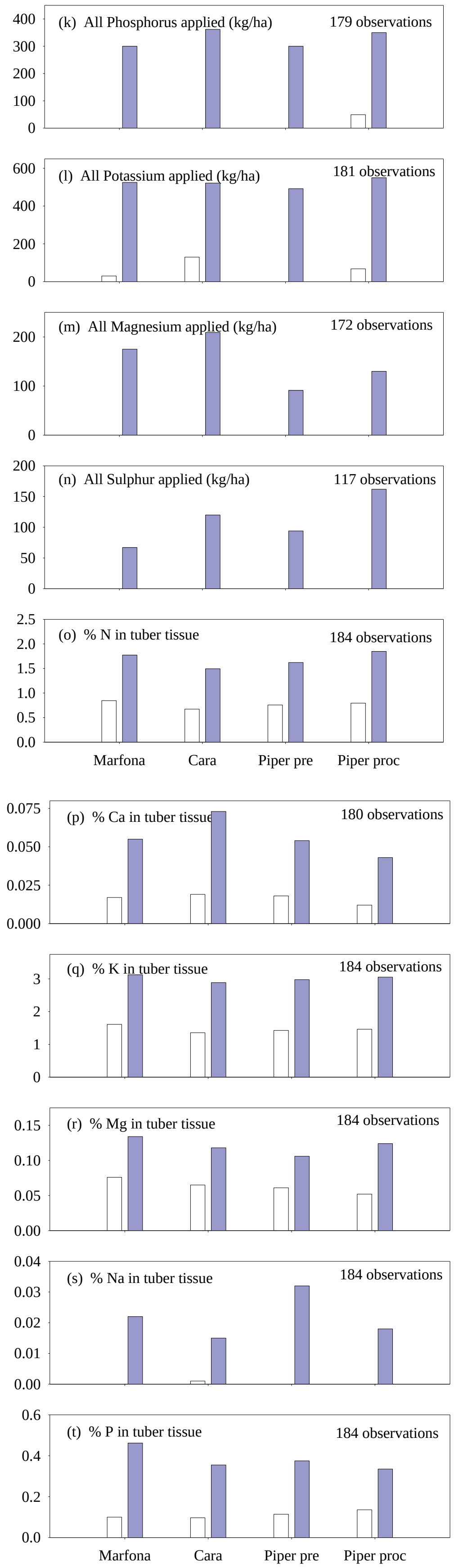
No skin damage

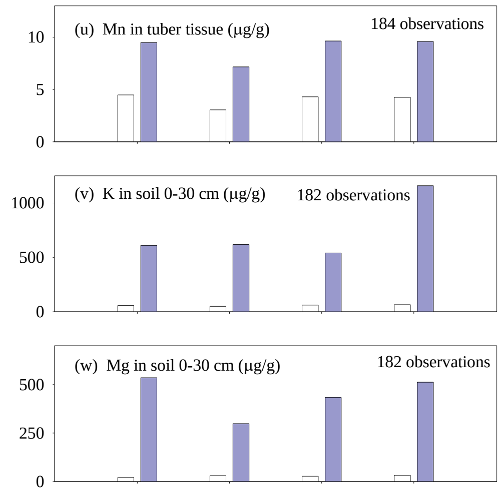
Everyone agreed that the assessments were recording bruising, not impact or shatter damage.

Appendix II

Fig. 16 Bar charts showing the minimum (white bar) and maximum (blue bar) data values recorded over all three years of the crop history survey




(k) All Phosphorus applied (kg/ha)
179 observations
400
300
200
100
0
(l) All Potassium applied (kg/ha)
181 observations
600
400
200
0
(m) All Magnesium applied (kg/ha)
172 observations
200
100
0
(n) All Sulphur applied (kg/ha)
117 observations
200
150
100
50
0
(o) % N in tuber tissue
184 observations
2.5
2.0
1.5
1.0
0.5
0.0
Marfona
Cara
Piper pre
Piper proc
(p) % Ca in tuber tissue
180 observations
0.075
0.050
0.025
0.000
(q) % K in tuber tissue
184 observations
3
2
1
0
(r) % Mg in tuber tissue
184 observations
0.15
0.10
0.05
0.00
(s) % Na in tuber tissue
184 observations
0.04
0.03
0.02
0.01
0.00
(t) % P in tuber tissue
184 observations
0.6
0.4
0.2
0.0
Marfona
Cara
Piper pre
Piper proc


(u) Mn in tuber tissue (µg/g)
184 observations
10
5
0
(v) K in soil 0-30 cm (µg/g)
182 observations
1000
500
0
(w) Mg in soil 0-30 cm (µg/g)
182 observations
500
250
0

Appendix III

Table 4. Number of observations in different categories in the crop history survey

Table 4a Sprouting regime

Sprouting	Marfona	Cara	Maris Piper Pre-pack	Maris Piper Processing	Total
Chitted	47	32	22	17	118
Not chitted	11	16	13	26	66
Total	58	48	35	43	184

Table 4b Seed source

Seed source	Marfona	Cara	Maris Piper Pre-pack	Maris Piper Processing	Total
Dutch	21	0	0	0	21
English	31	28	11	8	78
Scottish	6	20	24	35	85
Total	58	48	35	43	184

Table 4c Soil tilth at planting

Soil tilth	Marfona	Cara	Maris Piper Pre-pack	Maris Piper Processing	Total
Fine	35	33	23	29	120
Medium	23	14	11	10	58
Cloddy	0	1	1	4	6
Total	58	48	35	43	184

Table 4d Soil compaction at planting

Compaction	Marfona	Cara	Maris Piper Pre-pack	Maris Piper Processing	Total
Absent	42	36	24	28	130
Moderate	16	12	11	14	53
Severe	0	0	0	1	1
Total	58	48	35	43	184

Table 4e Previous crop on the land

Previous crop	Marfona	Cara	Maris Piper Pre-pack	Maris Piper Processing	Total
Wheat	31	22	19	16	88
Barley	8	11	2	17	38
Legumes	7	9	5	1	22
Vegetables	4	4	3	0	11
Sugarbeet	2	1	4	2	9
Other	5	1	2	7	15
Total	57	48	35	43	183

Table 4f Soil type

Soil type	Marfona	Cara	Maris Piper Pre-pack	Maris Piper Processing	Total
Organic	0	6	7	4	17
Sand	18	3	1	9	31
Silt	15	19	12	2	48
Loam	25	20	15	28	88
Total	58	48	35	43	184

Table 4g Was the crop defoliated?

Defoliated?	Marfona	Cara	Maris Piper Pre-pack	Maris Piper Processing	Total
Yes	56	45	31	34	166
No	2	3	4	9	18
Total	58	48	35	43	184

Table 4h Defoliation method

Defoliation method	Marfona	Cara	Maris Piper Pre-pack	Maris Piper Processing	Total
single mechanical	1	0	0	0	1
single chemical	12	4	3	8	27
mechanical then chemical	6	2	3	1	12
chemical then chemical	37	39	24	25	125
Total	56	45	30	34	165

Table 4i First Defoliation - Which chemical defoliant?

Chemical defoliant	Marfona	Cara	Maris Piper Pre-pack	Maris Piper Processing	Total
Acid	38	30	20	21	109
Reglone	12	8	6	7	33
Mechanical	1	0	1	1	3
Glyphosate	2	5	3	5	15
Triazolinone	0	0	0	0	0
Total	53	43	30	34	160

Table 4j Second Defoliation - Which chemical defoliant?

Chemical defoliant	Marfona	Cara	Maris Piper Pre-pack	Maris Piper Processing	Total
Acid	37	35	24	19	115
Reglone	3	4	2	5	14
Mechanical	0	0	0	0	0
Glyphosate	0	1	1	2	4
Triazolinone	0	1	0	0	1
Total	40	41	27	26	134

Table 4k Soil moisture conditions at burning-off

Soil moisture conditions	Marfona	Cara	Maris Piper Pre-pack	Maris Piper Processing	Total
Dry	10	21	8	15	54
Moist	36	19	17	12	84
Wet	10	4	4	6	24
Very wet	0	1	2	1	4
Total	56	45	31	34	166

Table 4l Time of day lifted

Time of day lifted	Marfona	Cara	Maris Piper Pre-pack	Maris Piper Processing	Total
Before 6 am	0	0	0	0	0
6 to 9 am	6	5	3	6	20
9 to 12 am	18	18	15	18	69
12 to 3 pm	21	19	10	15	65
3 to 6 pm	13	6	6	4	29
After 6 pm	0	0	1	0	1
Total	58	48	35	43	184

Table 4m Soil moisture conditions at lifting

Soil moisture conditions	Marfona	Cara	Maris Piper Pre-pack	Maris Piper Processing	Total
Dry	12	19	8	15	54
Moist	39	18	22	19	98
Wet	5	8	3	8	24
Very wet	1	3	2	1	7
Total	57	48	35	43	183