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Soil nutrition effects on kumara root yield and quality

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Copy 1 of 15

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Contents

1 Executive summary 1

2 Introduction 1

3 Materials and methods 2

4 Results 4

4.1 Brown centre incidence 5

4.2 Storage root yield 6

4.3 Storage root dry matter content 6

5 Discussion 7

5.1 Current research findings 7

5.2 Proposed research 8

6 Acknowledgements 9

7 References 9

Appendices 13

Appendix 1 14

Appendix II 15

Appendix II 16

1 Executive summary

A physiological root disorder known as brown centre (BC) has been recorded by the New Zealand kumara or sweetpotato industry since 1955. Roots that are harvested with the disorder contain various degrees of brown necrotic tissue and are inedible. There are no external symptoms that would enable detection of affected roots. The first research project examining the disorder, initiated in 1964, determined that the disorder was physiological rather than pathological. The second investigation, conducted from 1979, confirmed that the disorder occurred regularly in roots harvested after mid-April. The third study, conducted in 1999, demonstrated that soil nitrogen levels modified the incidence of BC. The current study is directed at understanding the mechanism by which BC is induced, so that the disorder can be more accurately predicted and controlled. This is the first part of a two-part study, which confirmed that soil nitrogen is involved in the disorder, but that BC occurs independently of boron or calcium levels. Soil nitrogen levels also have significant effects on root yield and various aspects of quality. Next season's trials will focus on the role of nitrogen and carbohydrate partitioning effects on root yield and quality.

2 Introduction

The New Zealand kumara or sweetpotato industry is dominated by the cv. Owairaka Red, which was released as a commercial cultivar in 1954 (Lewthwaite 1998). The release of Owairaka Red allowed the crop's rapid development into the present sweetpotato industry (Coleman 1969). The storage root disorder brown centre (BC) was first recorded in New Zealand in 1955 when it was described as 'brown heart' (Gillard 1955). It was noted that the disorder was not a disease, but occurred particularly in sweetpotato crops from heavy, wet soils where harvesting had been delayed. The flesh of affected roots turned brown, beginning from the centre but sometimes extending throughout the root, rendering it inedible. It was recommended that harvesting should be completed by the end of April in order to avoid the problem. The disorder occurred in the field prior to harvest and had no external symptoms.

Research into BC was first conducted in 1964 when root samples from a crop with the disorder were examined over a 5-month storage period without showing any increase in symptoms (Nielsen & Harrow 1966). Samples of root tissue with BC were grafted into unaffected roots to test the pathology of the disorder, but failed to transmit the symptoms. These researchers described BC as an internal necrosis, with tan to light brown tissue occurring in the pith region, but not in the cortical phloem tissue. They also observed one root in which the necrotic tissue had disintegrated, leaving a cavity. The cause of the disorder was not determined, but it was concluded that internal cork virus was not involved.

BC continued to be a problem and in 1979 a 3-year field study was initiated at Pukekohe (Wood & Schappi 1984). The disorder was then described as a light to dark brown internal staining, evident if the storage roots were cut open. The disorder was present at harvest and sound roots did not develop the disorder in storage. The degree of BC in plants produced from sound nursery material was the same as that produced from BC-affected parent roots. Even if only a small part of the root showed BC symptoms, the whole root could be 'woody' when cooked and developed objectionable flavours. There was no evidence of a relationship between the occurrence of BC and plant yield components. No specific cause of the BC disorder could be identified, but it was recommended that harvesting be completed by mid-April.

The BC disorder was especially severe within the 1996/97 commercial sweetpotato crop harvested from the Dargaville-Ruawai district, so the disorder was again studied in the 1998/99 season (Lewthwaite et al. 1999). A careful study of the relationship between temperature and the severity of chilling injury within storage roots indicated that chilling injury was not the cause of the disorder. Although the symptoms of BC and those from chilling injury were similar, they could be distinguished. A field trial was conducted at Pukekohe to compare BC incidence under different levels of supplemental nitrogen and boron. Nitrogen was watered-in by overhead irrigation, and boron was applied to the foliage. The addition of boron did not have a significant effect on the incidence of BC (P=0.77), nor was there a significant nitrogen x boron interaction (P=0.95). However, the addition of nitrogen in that trial effectively doubled the incidence of BC (P<0.001). The nitrogen response was consistent with growers' field observations.

The current project examines the mechanism by which nitrogen influences the incidence of BC. Nitrogen levels also influence crop yield and aspects of root quality, so these effects are also investigated. This report covers the first season of a two-season project, examining the relationship between BC incidence and additions of supplementary nitrogen, boron and calcium to the soil.

3 Materials and methods

A Pukekohe Research Centre inclined field site, consisting of Patumahoe clay loam soil, was tested for base nutrient levels (Appendix I) on 4 November 2005. The site was then prepared by broadcasting and incorporating fertiliser (N: 0.00, P: 10.25, K: 22.60, S: 5.10, Mg: 0.00, Ca: 7.00) at 0.85 t ha^{-1} prior to moulding. The experimental treatments consisted of the presence/absence of three nutrient supplements: nitrogen (N), boron (B) and calcium (Ca), in all combinations (Table 1). This gave a total of eight treatments, and the trial was arranged in an 8 x 8 Latin square design. Each of the eight treatment combinations were effectively replicated eight times in the trial array.

Table 1: Supplementary nutrient treatment combinations (present +, absent -) used in the 2005/06 sweetpotato brown centre trial.

Nitrogen	Boron	Calcium
+	+	+
+	+	-
+	-	+
+	-	-
-	+	+
-	+	-
-	-	+
-	-	-

Each plot was four rows wide by 8 m long, with only the two middle rows used for BC assessment. A single row was 0.75 m wide and within-row plant spacing was 0.40 m. The portion of each plot harvested and assessed contained a total of 40 plants, arranged in two rows. Gypsum (23.26% Ca) was incorporated into Ca-supplemented plots prior to transplanting, with Ca at 1.16 t ha^{-1}. Commercially produced sprouts of sweetpotato cultivar Owairaka Red were transplanted into the field on 5 January 2006 and watered-in with overhead irrigation. Trial plots along the two main axes and diagonals of the trial were comprehensively soil sampled and submitted for nutrient analysis on 14 March 2006, just as inter-row canopy cover was almost complete.

Urea (46% N) was broadcast by hand on 17 March 2006, with nitrogen at 600 kg ha^{-1}. Solubor (20.5% B) was also applied on 17 March, with boron at 3 kg ha^{-1}. Solubor was applied over the foliage using a hand-operated backpack sprayer. The spray boom extended over the entire plot width (3 m) and delivered 300 l ha^{-1} (Hardi 4110-12 spray nozzles). The nitrogen and boron treatments were well watered into the soil by overhead irrigation (*c*. 25 mm). Of the eight trial columns, four had drip tape placed along each row crest, to ensure nutrient uptake should the season prove dry. Plant tops were mown off on 18 May 2006, and the roots harvested by a two-row, tractor-drawn harvester.

Following harvest, individual storage roots of marketable size (2.5 cm diameter or greater) were individually cut in half along their length and assessed for the presence/absence of BC (Appendix II). The data were analysed using the statistical software package GENSTAT™. A logit transformation was used to equalise the variance across the BC dataset prior to analysis.

4 Results

Supplemental watering via drip tape was not required, as rainfall was plentiful over the season following nitrogen and boron applications (Figure 1). Based on comprehensive soil testing (14 March) just prior to the supplementary nitrogen and boron applications, there were some systematic base nutrient gradients down the main slope of the trial. Linear regression analysis of base nutrient levels against position down the slope showed significant increasing levels (Figure 2) of available nitrogen ($P<0.001$) and boron ($P<0.001$), but not calcium ($P=0.372$). However any effects of this on the trial results were minimised by the high degree of two-dimensional replication and blocking. The mean soil calcium level (14 March) in plots without the addition of gypsum was 9.89 me 100 g^{-1}, whereas the addition of soil-incorporated gypsum gave a significantly higher calcium level of 11.48 me 100 g^{-1} ($P<0.001$).

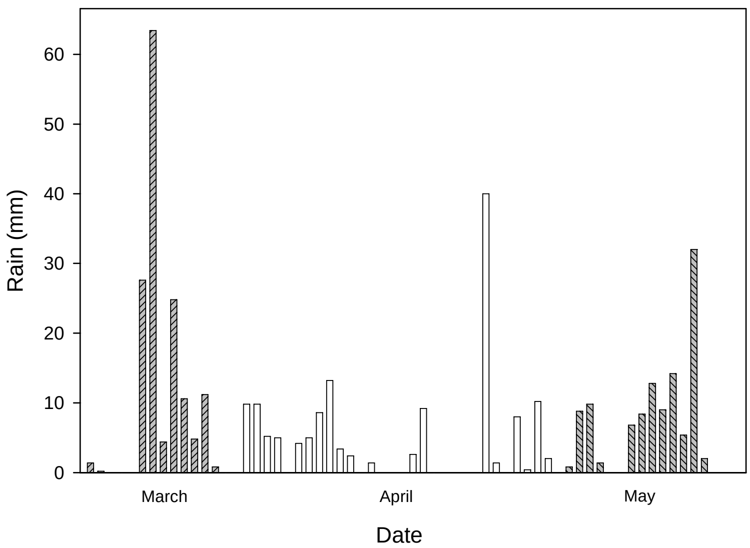

Figure 1: Daily rainfall (mm) at the Pukekohe Research Centre from nitrogen and boron application (17 March 2006) until trial completion (18 May 2006).

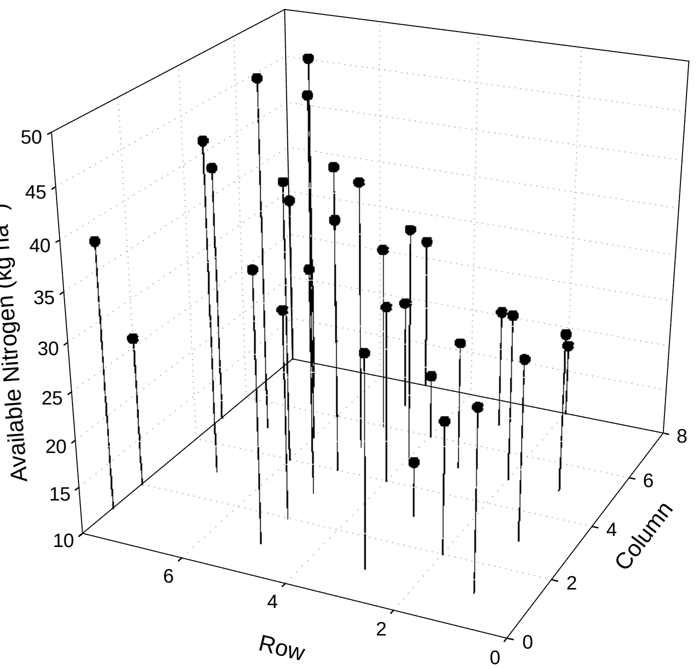

Figure 2: Systematic change in base available nitrogen levels (kg ha^{-1}) down main trial site slope (Rows 1 to 8), established by soil sampling on 14 March 2006.

4.1 Brown centre incidence

The BC disorder was widespread throughout the trial (96.9% of the plots), but the level of incidence across the individual plots varied widely (0.0 to 39.2 %). The trial was a full factorial design for the three supplementary nutrient treatments (presence/absence) of nitrogen, boron and calcium. There were no significant changes to the incidence of BC through the addition of boron (*P*=0.748), calcium (*P*=0.960), or any of the interactions: nitrogen x boron (*P*=0.705), nitrogen x calcium (*P*=0.325), boron x calcium (*P*=0.169), or nitrogen x boron x calcium (*P*=0.147). However, the addition of supplementary nitrogen (Table 2) effectively halved the mean incidence of BC (*P*<0.001).

*Table 2: Effect of supplementary nitrogen application on incidence of the brown centre disorder in sweetpotato (*Ipomoea batatas *(L.) Lam.) cultivar Owairaka Red. Data were transformed (logit) to stabilise the variance.*

Nitrogen fertiliser	Brown centre incidence (%)	
Absent	13.9[a]	(-1.8)
Present	6.8	(-2.6)
$LSD_{0.05}$ (df =42)		0.31

[a]Back-transformed means.

4.2 *Storage root yield*

There were no significant changes to total sweetpotato yield through the addition of boron (*P*=0.950), calcium (*P*=0.324), or any of the interactions: nitrogen x boron (*P*=0.744), nitrogen x calcium (*P*=0.285), boron x calcium (*P*=0.210), or nitrogen x boron x calcium (*P*=0.800). However the addition of supplementary nitrogen (Table 3) reduced mean root yield by 12.7% (*P*=0.003).

*Table 3: Effect of supplementary nitrogen application on total storage root yield (t ha^{-1}) in sweetpotato (*Ipomoea batatas *(L.) Lam.) cultivar Owairaka Red.*

Nitrogen fertiliser	Storage root yield (t ha^{-1})
Absent	16.5
Present	14.4
$LSD_{0.05}$ (df =42)	1.3

4.3 *Storage root dry matter content*

There were no significant changes to sweetpotato storage root dry matter content (%) through the addition of boron (*P*=0.551), calcium (*P*=0.116), or any of the interactions: nitrogen x boron (*P*=0.378), nitrogen x calcium (*P*=0.262), boron x calcium (*P*=0.149), or nitrogen x boron x calcium (*P*=0.121). However the addition of supplementary nitrogen (Table 4) gave a slight reduction in mean storage root dry matter content of 3.2 % (*P*=0.021).

Table 4: Effect of supplementary nitrogen application on storage root dry matter content (%) in sweetpotato (Ipomoea batatas (L.) Lam.) cultivar Owairaka Red.

Nitrogen fertiliser	Storage root dry matter content (%)
Absent	21.03
Present	20.35
$LSD_{0.05}$ (df =42)	0.566

Amongst the nutrient treatments, there were no significant differences (*P*>0.05) in numbers of marketable storage roots (roots of 2.5 cm diameter or greater).

5 Discussion

5.1 Current research findings

The BC disorder, as seen in New Zealand sweetpotato crops, has not been reported within international literature. However an earlier New Zealand study (Lewthwaite et al. 1999) has shown that the incidence of BC increases with increasing soil nitrogen levels. The mechanism by which high nitrogen levels induce BC is not known.

The nutrients boron (Gupta 1979; Mengel & Kirkby 1982) and calcium (Collier & Tibbitts 1982; Ferguson & Watkins 1989) have long been associated with tissue discolouration and necrosis in horticultural crops. Boron deficiency is well recognised internationally as a cause of sweetpotato root tissue discolouration (Willis 1943; O'Sullivan et al. 1997). Although foliar boron is commonly applied to North American sweetpotato crops, there is some suggestion that boron is not readily transported within the sweetpotato plant (O'Sullivan et al. 1997).

Established soil boron and calcium levels (Appendix I) were supplemented in this trial. The water supply over the period of rapid root enlargement was adequate for nutrient uptake. However, there were no significant BC responses to supplemental boron or calcium, nor were there any significant interaction responses involving these two nutrients. In contrast, supplemental nitrogen gave a highly significant reduction in BC incidence (*P*<0.001).

Supplemental boron and calcium did not significantly affect storage root yield. It is reported that under high nitrogen conditions, sweetpotato dry matter distribution is modified, and vines may grow at the expense of root yield, although the degree of yield loss is cultivar-dependent (O'Sullivan et al. 1997). As expected, in the cultivar Owairaka Red, which can show rampant vine growth, root yield was reduced by addition of nitrogen (*P*=0.003).

Supplemental boron and calcium did not significantly affect storage root dry matter content. Increasing nitrogen levels are reported to decrease root dry matter content (Hammett & Miller 1982), as seen to a moderate degree in this trial (P=0.021). The number of storage roots per plant is established early in crop growth. Under trial conditions where the nutrient supply was modified well into the season, the lack of a significant treatment response in numbers of storage roots of a marketable size is to be expected.

Based on the investigative studies to date and supported by grower observations, it has now been well established that the BC disorder:

1. is cultivar-dependent;
2. is not caused by a disease organism;
3. occurs repeatedly in harvests after mid April;
4. is not caused by tissue chilling injury;
5. is modified by soil nitrogen levels;
6. is not influenced by boron or calcium availability.

5.2 Proposed research

Based on current knowledge, it is suggested that the BC disorder occurs in the presence of:

1. a cultivar with naturally vigorous growth;
2. high soil nitrogen levels, that promote excessive canopy growth;
3. decreasing levels of incident radiation over the harvest period.

A working hypothesis, to be tested in the coming season, is that BC is caused by high soil nitrogen levels that encourage excessive canopy growth in the already vigorous cultivar Owairaka Red. As the canopy ages and solar radiation levels decrease over the harvest period, carbohydrate is remobilised from storage roots to maintain the canopy, causing localised areas of storage root tissue necrosis.

In the previous study (Lewthwaite et al. 1999), high nitrogen levels applied three times over a 33-day period) significantly promoted the incidence of BC (P<0.001). In the current study, a single high dose of supplemental nitrogen followed by weeks of regular rainfall with associated nitrogen leaching reduced the incidence of BC (P<0.001). Both results are consistent with the proposed hypothesis, as nitrogen level and time of application relative to canopy development may variously influence either the canopy's structural growth, leaf area persistence, or both. The photosynthetic efficiency of the canopy relative to its structural mass would drive the demand for carbohydrate remobilisation from storage roots.

This is supported by literature, which reports:

- Sweetpotato is very efficient in obtaining nitrogen from soils even when nitrogen fertiliser is not provided and it may form associations with nitrogen-fixing soil bacteria such as *Azospirillum brasilense* (Hill & Bacon 1984; Yoneyama et al. 1998).

- As sweetpotato plant nitrogen content increases, leaf area duration or leaf area persistence increases (Tsuno & Fujise 1965).
- Under excess nitrogen conditions, the leaf area index may become too high and cause leaf shedding through mutual shading (Tsuno & Fujise 1965; Haynes et al. 1967).
- The period just prior to sweetpotato harvest is characterised by the rapid accumulation of photosynthate in storage roots, which can be affected by high nitrogen levels (Hartemink et al. 2000).
- Sweetpotato cultivar Owairaka Red naturally partitions disproportionately high levels of photosynthate into stem growth (Lewthwaite & Triggs 2000).
- In some cultivars, when the supply of photosynthates is limiting, a greater proportion is used in stems (Austin & Aung 1973; Martin 1985), especially under shade treatments where canopy growth may be favoured (Oswald et al. 1995).
- Over the harvesting months of March, April and May, average incident monthly radiation (years 1986 to 2001) at the Pukekohe Research Centre decreased from 15.6 to 11.0 and 7.7 MJ m^{-2} respectively (NIWA).

6 Acknowledgements

AGMARDT and Horticulture New Zealand are thanked for supporting and funding this project.

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Appendices

Appendix 1

Hill Laboratories

R J Hill Laboratories Limited

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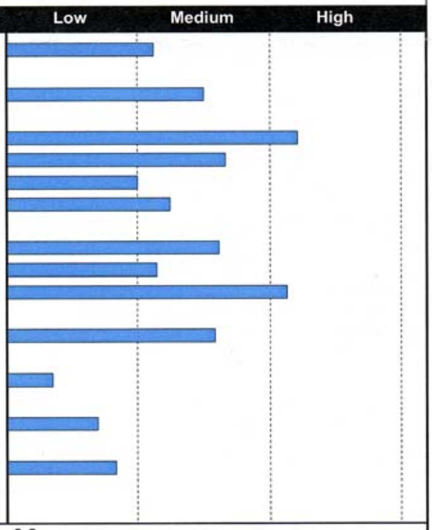
ANALYSIS RESULTS

Client:	Crop & Food Research	**Laboratory No.:**	286127/1
Address:	49 Cronin Road	**Registered:**	5-Nov-2005
	R D 1	**Reported:**	9-Nov-2005 Version: 2
	PUKEKOHE	**Order No.:**	29098
		Submitted By:	Mr S Lewthwaite
Client Phone:	09 238 6414	**Client Ref:**	

Sample Name: OSBC1
Sample Type: SOIL Sweet Potato (S75)

Analysis		Level Found	Medium Range
pH		6.0	5.9 - 6.8
Olsen P	(mg/L)	75	50 - 100
Potassium	(me/100g)	1.56	0.70 - 1.40
Calcium	(me/100g)	9.9	6.0 - 12.0
Magnesium	(me/100g)	0.99	1.00 - 3.00
Sodium	(me/100g)	0.12	0.00 - 0.50
CEC	(me/100g)	20	12 - 25
Base Saturation	(%)	63	60 - 85
Volume Weight	(g/mL)	1.03	0.60 - 1.00
Boron	(mg/kg)	1.6	1.0 - 2.0
Available N	(kg/ha)	67	100 - 150
Organic Matter	(%)	4.8	7.0 - 17.0
Total Carbon	(%)	2.8	
Total Nitrogen	(%)	0.26	0.30 - 0.60
C/N Ratio		10.5	
AMN/TN Ratio	(%)	1.6	



Base Saturation	K 7.9	Ca 50	Mg 5.0	Na 0.6
MAF Units	K 33	Ca 13	Mg 23	Na 6
Anaerobically Mineralisable N	44 ug/g			

The above nutrient graph compares the levels found with reference interpretation levels. NOTE: It is important that the correct sample type be assigned, and that the recommended sampling procedure has been followed. R J Hill Laboratories Limited does not accept any responsibility for the resulting use of this information.

No Laboratory Comments

Submitter: Mr S Lewthwaite, Crop & Food Research, c/o Crop & Food Research, 49 Cronin Road, R D 1, PUKEKOHE

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ANALYSIS RESULTS

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	PUKEKOHE	**Order No.:**	29098
		Submitted By:	Mr S Lewthwaite
Client Phone:	09 238 6414	**Client Ref:**	

The following table gives a brief description of the analysis methods for this job. The COV (coeffient of variation) gives a measure of precision and is sometimes referred to as the Relative Standard Deviation, ie the standard deviation expressed as a percentage of the absolute value.

For further details and explanations, please contact the laboratory.
These samples were collected by yourselves (or your agent) and analysed as received at this laboratory.

Analyte	Method	COV(%)
Soil		
Soil Preparation (Dry and Grind)*	Air dried at 35 - 40°C overnight (residual moisture typically 4%) and crushed to pass through a 2 mm screen.	-
Sample Registration*	Samples were analysed as received.	-
pH	1:2 (v/v) soil:water slurry followed by potentiometric determination of pH.	1
Phosphorus	Olsen extraction followed by Molybdenum Blue colorimetry.	6
Potassium, Calcium, Magnesium, Sodium	1M Neutral ammonium acetate extraction followed by ICP-OES.	4
CEC	Summation of extractable cations (K, Ca, Mg, Na) and extractable acidity.	4
Base Saturation	Calculated from Extractable Cations and Cation Exchange Capacity.	4
Volume Weight	The weight/volume ratio of dried, ground soil.	2
Boron	0.01M Calcium chloride extraction followed by ICP-OES.	11
Anaerobically Mineralisable N*	As for Available Nitrogen but reported as ug/g.	-
Available Nitrogen*	Determined by NIRS, calibration based on Avaliable N by Anaerobic incubation followed by extraction using 2M KCl followed by Berthelot colorimetry. (Calculation based on 15cm depth sample).	-
Organic Matter	Organic Matter is 1.72 x Total Carbon.	5
Total Nitrogen*, Total Carbon*	Dumas combustion.	-

* Indicates a non IANZ accredited test.

Signatory: W.M Homewood

Submitter: Mr S Lewthwaite, Crop & Food Research, c/o Crop & Food Research, 49 Cronin Road, R D 1, PUKEKOHE

Appendix II

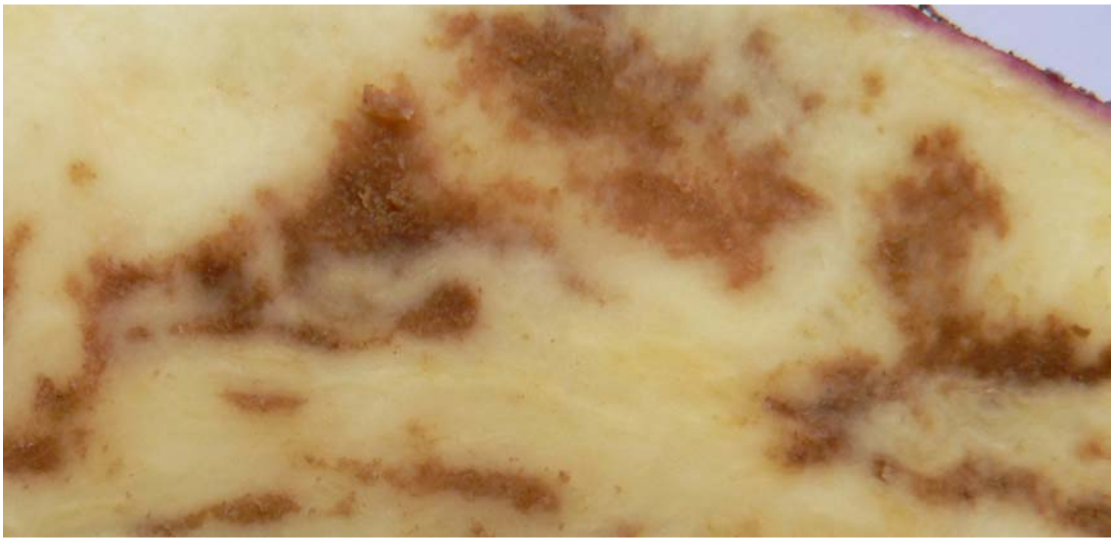

*Plate 1: Detail of brown centre disorder symptoms within the storage root tissue of sweetpotato (*Ipomoea batatas *(L.) Lam.) cultivar Owairaka Red.*

*Plate 2: Longitudinal section of a sweetpotato (*Ipomoea batatas *(L.) Lam.) cultivar Owairaka Red storage root, showing the distribution of moderately severe brown centre disorder symptoms.*

*Plate 3: Symptom-less external appearance of a sweetpotato (*Ipomoea batatas *(L.) Lam.) cultivar Owairaka Red storage root, despite a severe occurrence of the brown centre disorder (see Plate 4).*

*Plate 4: Longitudinal section of a sweetpotato (*Ipomoea batatas *(L.) Lam.) cultivar Owairaka Red storage root, showing the distribution of severe brown centre disorder symptoms. The root showed no external symptoms of the disorder.*