PT209
Determination of factors causing stem end browning in russet burbank potatoes

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DETERMINATION OF FACTORS CAUSING STEM END BROWNING IN RUSSET BURBANK POTATOES IN THE BALLARAT DISTRICT, VICTORIA

FINAL REPORT OF PROJECT PT 209
To Horticultural Research and Development Corporation
DECEMBER 1994

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1. Summary

Industry summary

Comparing stem-end browning and sugar levels of Russet Burbank potatoes

A field survey study on stem end browning was conducted at different sites in the Ballarat District in 1992/93 and 1993/94. There were significant differences between sites in the incidence of stem-end browning of tubers. In 1992/93, the levels of stem end browning increased between sites by 71.8 - 105.1 % for sites 7, 4, 8, 14 and 15 compared to site 3. In the 1993/94 season, the level of stem end browning of fries was increased by 84.4%-92.8% between sites 1, 2, 3 and 4 compared with those from sites 18 and 19. There were also significant differences between sites in the number of fry faces where browning was evident.

In 1992/93, sugar levels in tubers were significantly different ($P \geq 0.05$) between sites. At the stem ends of tubers, fructose and glucose levels were lower in site 1 compared with all other sites while site 16 produced tubers with the highest levels of these sugars. Stem end glucose levels in tubers from sites 4, 5, 7 and 10 were not significantly different. Site 2 produced tubers low in stem end sucrose level compared with all other sites while site 4 produced tubers with the highest concentrations. At the bud ends, fructose and glucose levels were lower in tubers from sites 1 and 15 compared with the other sites. Site 16 produced tubers with the highest levels of bud end fructose and glucose (Table 2). Bud end sucrose levels were low in tubers from site 2 but high in tubers from sites 4, 8, 13 and 16.

Comparison of sugar levels of tubers with or without stem end browning

There was a significant difference ($P \geq 0.05$) in sugar levels between tubers with or without stem end browning. The levels of stem end glucose were 2.2 times, fructose 1.8 times and sucrose 1.2 times higher in tubers with browning compared to those without browning. Tubers with browning had higher total sugar levels at the stem ends than those without browning. Fructose, glucose and sucrose levels at the bud ends were not significantly different between tubers with or without browning.

Technical summary

Comparing stem-end browning and sugar levels of Russet Burbank potatoes

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from sites 16, 17, 18, 19 had less number of faces with browning. Similarly, there were significant differences between sites in the length and width of browning on the faces of fries. On fry faces at sites 2, 3 and 4 the browning was longer and wider compared with browning on fries at sites 18 and 19.

In 1992/93, sugar levels in tubers were significantly different (P≥0.05) between sites. At the stem ends of tubers, fructose and glucose levels were lower in site 1 compared with all other sites while site 16 produced tubers with the highest levels of these sugars. Stem end glucose levels in tubers from sites 4, 5, 7 and 10 were not significantly different. Site 2 produced tubers low in stem end sucrose level compared with all other sites while site 4 produced tubers with the highest concentrations. At the bud ends, fructose and glucose levels were lower in tubers from sites 1 and 15 compared with the other sites. Site 16 produced tubers with the highest levels of bud end fructose and glucose (Table 2). Bud end sucrose levels were low in tubers from site 2 but high in tubers from sites 4, 8, 13 and 16.

Comparison of sugar levels of tubers with or without stem end browning

There was a significant difference (P≥0.05) in sugar levels between tubers with or without stem end browning. The levels of stem end glucose were 2.2 times, fructose 1.8 times and sucrose 1.2 times higher in tubers with browning compared to those without browning. Tubers with browning had higher total sugar levels at the stem ends than those without browning. Fructose, glucose and sucrose levels at the bud ends were not significantly different between tubers with or without browning.

2. Recommendations

Extension/adoption

The recent studies have established that stem end browning in Russet Burbank potatoes is prevalent in the Ballarat District of Victoria and is associated with increased amount of reducing sugar at the stem ends. There were significant differences between the sites in the levels of stem end browning and sugars. The project was terminated before the end of the specified time due to the departure of the principal investigator. Consequently, the influence of environmental factors and the effects of these factors on stem end of french fries could not be established. The sudden termination had made it impossible for the extension and adoption of the results from the project by the potato farming community.

Directions for future Research

Further work is warranted to elucidate the effect of storage conditions (temperature, time) on stem end browning in Russet Burbank potatoes. The environmental factors of temperature, soil moisture and nutrition at critical growth stages should be monitored at each sampling site. Since irrigation plays an important role in crop development, the type of irrigation (furrow and sprinkler) should be compared at each site. Longer period of time and large sample size are required to obtain reasonable results which may be beneficial to the potato industry.

Financial/commercial benefits of adoptions

As a result of the premature termination of the project, the economic importance and benefits resulting from the findings of the research to the potato industry could not be achieved.

3.0 TECHNICAL REPORT

Determination of Factors Causing Stem End Browning In Russet Burbank Potatoes In The Ballart District, Victoria

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Summary

A field survey study on the occurrence of stem end browning was carried out in the Ballarat District of Victoria over two years. Results showed a prevalence of this physiological order in the area. There were significant differences between sites studied in the levels of stem end browning and associated increased sugar levels. In 1992/93, the levels of stem end browning of fries were between 71.8-105.1% for sites 4, 7, 8, 14 and 15 with sites 4 and 7 having the highest levels. In 1993/94, the levels were 84.4-92.8 for sites 1, 2, 3 and 4. There were also significant differences between sites in the number of fry faces where browning was evident. Fries from sites 16, 17, 18, 19 had less number of faces with browning. Similarly, there were significant differences between sites in the length and width of browning faces of fries. On fry faces at sites 2, 3 and 4 the browning was longer and wider compared with browning at sites 18 and 19.

Sugar levels in tubers were significantly different ($P \geq 0.05$) between sites. At the stem ends of tubers, fructose and glucose levels were lower in site 1 compared with all other sites while site 16 produced tubers with the highest levels of these sugars. Site 2 produced tubers low in stem end sucrose level compared with all other sites while site 4 produced tubers with the highest concentrations. There was significant difference in sugar levels between tubers with or without stem end browning. The levels of stem end glucose were 2.2 times, fructose 1.8 times and sucrose 1.2 times higher in tubers with browning compared to those without browning. Tubers with browning had higher total sugar levels than those without browning at their respective stem ends. Fructose, glucose and sucrose levels at the bud ends were not significantly different whether tubers had browning or not.

Introduction

Processing quality of potatoes for french fries is largely determined by their colour after frying. Stem-end fry colour has become an important quality for french fries. Processors require a light uniform fry colour. Excessive darkening and development of off-flavours due to high reducing sugar content makes processed potato products unacceptable to the market (Stevenson *et. al.*, 1964; Pritchard and Adam, 1994). "The eye-appeal" or fry colour is a factor of great importance in determining the market or consumer acceptance of french fries (Pereira *et al.* 1993). Dark french fries may have undesirable flavour and consequently become unattractive to the consumer (Stevenson *et al.*, 1964).

In this study, fry colour will be referred to as stem end browning, defined as a disorder of sugar metabolism, associated with field stress, and expressed as an after-fry darkening at the stem end of the tuber.

In America, large economic losses are incurred by potato growers as a result of dark-end french fries caused by excess reducing sugars in the potato cultivar Russet Burbank (Kincaid *et. al.*, 1993). The growing incidence of stem end browning, physiological disorder, is having a significant economic impact on the potato industry in Australia. Losses due to this incidence have been estimated to average 10%, but can sometimes reach 50% for particular suppliers. In 1992, losses of about 6% ($11,400) due to stem end browning were incurred by the potato industry in Victoria (René de Jong, personal communication).

Stem end browning is a physiological disorder or condition associated with increased levels of reducing sugars in the stem ends of french fries (Marquez and Anon, 1986; Ledl, 1990; Eldredge, 1991). This browning is caused by a non-enzymatic reaction (Maillard reactions) between reducing sugars (fructose and glucose) and amino compounds (Ledl, 1990) at high temperatures (Talburt *et al.*,

1975). Several factors contribute to the accumulation of reducing sugars in the stem end. Researchers have reported that tubers from plants exposed to heat or water stress during early tuber development accumulate reducing sugars in their stem-ends (Iritani and Weller, 1974; Owings *et al.*, 1978; Eldredge, 1991). This results in a condition known as "dark-end" in which the stem ends of the french fry develop a dark brown colour when fried. Sucrose is also known to contribute to this discolouration of Russet Burbank tubers upon frying (Leszkowiat *et al.*, 1990).

The cultivar, Russet Burbank is highly susceptible to drought. Tubers of Russet Burbank were severely mis-shaped by early or late season water stress (Miller and Martin 1987a,b). Water stress before tuber initiation has been reported to reduce tuber set (van Loon, 1981) and yield (MacKerron and Jeffries, 1986). However, reports differ on the effects of early-season moisture stress on tuber quality. Iritani and Weller (1973) found that moisture stress during tuber initiation leads to dark stem-end fry colour. The physiological basis for the accumulation of reducing sugars in the stem end of Russet Burbank tubers exposed to water and heat stress is unknown. Iritani (1981) determined that water and heat stress during tuber bulking resulted in increased sucrose and decreased starch in the tuber stem end at harvest. He speculated that the excess sucrose could be converted to reducing sugar during storage and could thus cause browning when fried. Research workers have found that stressed tubers accumulate more reducing sugars in the stem end relative to the bud end resulting in dark fry colour at the stem end (Iritani and Weller, 1973, 1978; Iritani *et al.*, 1973; Owings *et. al.*, 1978; Shock *et. al.*, 1993). However, some research has found that early-season water stress before tuber initiation reduced the incidence of dark stem-ends in Russet Burbank potatoes (Shock *et. al.*, 1992, 1993; Kincaid *et. al.*, 1993; Trout *et. al.*, 1994) . Shock *et. al.* (1992) reported that the first irrigation should be applied no sooner than full plant emergence in order to obtain the optimum yield and processing quality.

Stevenson *et. al.* (1964) found that both hereditary and environmental factors determine the sugar content in potato tubers. In contrast, Pereira *et. al.* (1993) found that reducing sugar levels in parent lines were independent of their progenies. Storage temperature and pre-conditioning of tubers affect the amount of reducing sugars in the stem ends and consequently fry colour. It has been demonstrated that tubers of most chipping cultivars stored at low temperatures, for example below 9-10°C (Coffin *et. al.*, 1987) and 8°C (Pritchard and Adam, 1992; 1994) accumulate appreciable amounts of reducing sugars (Coffin *et. al.*, 1987; Brown *et. al.*, 1990; Pritchard and Adam, 1994). Yamaguchi *et. al.* (1964) found that Russet Burbank tubers have the highest starch and lowest sugar content when grown at soil temperatures between 15 and 24°C compared with tubers grown at higher temperatures. Pre-conditioning of Russet Burbank potatoes for up to 70 days at 15°C lowered the reducing sugar concentrations to levels acceptable for processing as french fries (Pritchard and Adam, 1992).

Irrigation frequency and timing of stress can also affect potato quality (Miller and Martin, 1985). Potatoes growing in sandy soils required daily irrigation amounts which were close to daily evapo-transpiration to avoid reductions in tuber yield and quality (Hang and Miller, 1986). Kincaid *et. al.* (1993) reported that more frequent irrigation produced slightly higher quality tubers and lower incidence of dark-ends of Russet Burbank tubers when fried. Stark and Cann (1992) found that irrigation deficits imposed during early to mid tuber bulking caused the highest percentages of fries with dark stem-ends. It has also been demonstrated that the Russet Burbank cultivar consistently showed significantly lighter stem-end colours (Jensen *et. al.*, 1988) and produced better quality tubers with much lower incidence of sugar ends under sprinkler irrigation (Trout *et al.*, 1994). They reported that there was less water stress imposed on Russet Burbank because of the uniform supply of the required amount of water by the sprinklers. The sprinkler water had evaporative cooling effect and as a consequence lowered the soil temperature.

The Australian french fry industry demands a uniformly lightly coloured product from the Russet Burbank variety of potato. Recently, in Australia, for this cultivar, physiological disorder stem-end browning has become common with this cultivar. The aberration of normal sugar metabolism associated with stem end browning has been scientifically explained and circumstantial evidence implicate heat and moisture stress during early tuber development.

These studies, based on the cultivar Russet Burbank, aimed to:

(i) determine if stem-end browning resulted in alterations in sugar concentrations of the tuber,
(ii) assess the effects of stem-end browning on cell morphology and
(iii) assess environmental factors (moisture, temperatures, nutrition) associated with stem-end browning.
(iv) provide a guide to manage stem end browning under local conditions

Materials and methods

A. Cell morphology-Histology studies

Preparation of tissue from potato tubers

Russet Burbank tubers were collected from M^{c}Cains, Ballarat on 8 October, 1992 and stored at approximately 4°C until required. Small cubes (approximately 1 mm^3) were cut after 7 days in storage and then placed in formol-acetic alcohol (FAA) solutions.

Procedure 1

Tissue samples were taken from a region (i) 3 mm from the tuber surface where browning symptoms were clearly evident, (ii) 8 mm from surface of the same tuber where there was no browning and (iii) 3 mm from the surface of a tuber without browning. Samples were dehydrated after being fixed in formol-acetic alcohol (FAA) for one week through ethanol series as shown below: 50% ethanol for 20 minutes and 70%. Dehydration continued after 6 days. Specimens were allowed to remain in 80% ethanol for 15-20 minutes, 90% for 15-20 minutes and 2 x 100% for 15-20 minutes. Specimens were infiltrated with LR white resin (medium grade) in a ratio of 1:3 or 30:90; 1:1 or 60:60; 3:1 or 90:30 resin:100% ethanol. They were later polymerised in oven at either 60°C for 5 hours or 60°C for 8 hours. The polymerisation process continued until 100% resin was reached Sections of specimens were made, stained with toluidine blue (0.05%, pH 9.2) and then examined under light microscope.

Procedure 2

Tissue was fixed in 2.5% glutaraldehyde in 25 mM phosphate buffer of pH 7 for one hour, then under vacuum for approximately one hour and at room temperature for 22 hours. One drop of Tween 20 per 100 ml of fixative was added. Specimens were dehydrated through ethanol series: 10, 20, 30, 50, 70%. Dehydration commenced again as previously described in a series 80, 90 and 3 x 100% for 20 minutes each. Specimens were then infiltrated with resin (LR white, hard grade) as in Procedure 1 above and then in 100 % resin. They were polymerised at 60°C for 6 hours.

B. Field Surveys

Field sampling of potato tubers (1992/93)

Following crop senescence, potato tubers were sampled from sixteen different sites in the Ballarat district. Tuber samples were taken randomly at three different transects out from a neutron probe. Ten tubers were taken from each site and their fresh weight, diameter, moisture content and frying colour were measured.

Field sampling of potato tubers (1993/94)

Nineteen sites in the Ballarat district were selected for sampling in April 1994. At five locations within each site, a 3-m row length was dug and fifteen tubers in the size range 100-350 were selected. From this sample, ten tubers were selected and their fresh weight, diameter, moisture content, stem end fry colour and the area of discolouration measured. A total of 127 tubers (44 tubers without and 83 tubers with browning) were selected for sugar analysis. It was planned to select two tubers, one

without and the other with stem-end browning from each site, however, it was not possible to select tubers without stem end browning at some sites.

Stem end fry colour determination

The stem and bud ends of each of the 10 tubers were noted. The outer skin layer of each tuber was peeled off being cautious that little or no flesh was removed. The tuber was rinsed in mild water, dried and cut into equal halves longitudinally through the widest point. The internal portion of the stem end was visually examined for browning.

The potato tuber was divided into quarters longitudinally. From these, two longitudinal strips (1 cm) were removed from the centre. The two strips were then placed in a deep fryer with oil and fried at 180°C for 2 minutes. The stem ends of these strips were rated visually according to a colour designation chart immediately after frying. The numerical ratings of 1-5 were used with 1 being light and 5 being dark (USDA, 1988). The number of faces of the fry where browning at the stem end was evident and the length and width of browning on each face was recorded.

Moisture content of tubers

A portion from the middle of the tuber was placed in a blender at high speed for 15 seconds. Twenty grams of this homogeneous sample was put in a clean dry moisture tin of known weight and dried in an oven at 105°C for 16 hours and then in a desiccator for 30 minutes and weighed. The weight of the sample was recorded and the moisture content determined.

(ii) Sugar analysis

Sugars were determined by high performance liquid chromatography (HPLC) on juice extracted from a composite sample. For the two quarters not used for frying, sections were cut at the stem and bud ends at a distance of 2 cm from each end. The stem end and bud ends were weighed separately and recorded. The stem end portions were placed in the juicerator and the juice collected into a 100 ml beaker. The same procedure was used to collect juice from the bud end portions. The beaker was placed in tray with ice layer to separate starch from the juice. The juice was filtered using the Büchner filtration equipment into a clean beaker. The filtered juice of both stem and bud ends were separately diluted in the ratio of 1:5 with 100% ethanol to achieve an 80% ethanol final solution. The mixture was shaken for 2 hours to facilitate the precipitation of proteins. A bulb pipette was used to add 10 ml of the filtrate to a clean 10 ml plastic centrifuge tube and centrifuged at 1800 revolutions per minute for 10 minutes and filtered through 0.45 µm filters and then run on the HPLC equipment under designated conditions.

Environmental data

Soil moisture using neutron probe and rainfall using rain gauge were recorded for each site every Tuesday and Friday throughout the growing period. The amount of irrigation water applied was also recorded for all sites. Data for pan-evaporation and minimum and maximum temperatures were collected from 2 local Meteorological Stations.

Statistical analysis

In 1992/93, the fresh weight, diameter, moisture content of tubers, stem-end browning and sugar levels in tubers analysed using analysis of variance to compare differences between sites. In 1993/94, stem end browning, number, length and width of fry faces where browning was evident were also analysed as above. Restricted maximum likelihood (REML) was used to compare fresh weight, moisture content and fructose, glucose and sucrose levels of tubers with or without browning due to the unbalanced structure in 1993/94. In both periods, least significant difference (P=0.05) was used to compare treatment means.The environmental data for 1993/94 was graphed but there was no obvious relationship.

Results

Cell morphology

No significant differences in cell morphology were observed between samples. Dark staining granules were observed in the cytoplasm of the pith cells of all three samples. The granules were less dense in a tuber with stem-end browning for sample taken 8 mm from the surface compared with the other samples. This may have been caused by uneven staining of samples. Poor fixation was achieved in areas of high concentration of starch grains.

Field survey studies for comparing stem-end browning and sugar levels of Russet Burbank potatoes in the Ballarat District

Results from the 1992/93 field surveys indicated significant differences ($P \geq 0.05$) between sites in the fresh weight, diameter, moisture content of tubers, stem-end browning and sugar levels in tubers.

The level of stem end browning was 71.8 - 105.1 % for sites 7, 4, 8, 14 and 15 compared to site 3. Tubers harvested from sites 1, 2, 3, 9, 10,11,12, 13, and 16 had similar levels of stem end browning (Figure 1). Sites 7 and 4 had the highest levels of stem end browning (Table 1).

At the stem ends of tubers, fructose and glucose levels were significantly lower in site 1 compared with all other sites while site 16 produced tubers with the highest levels of these sugars. Stem end glucose levels in tubers from sites 4, 5, 7 and 10 were not significantly different (Figure 2). Site 2 produced tubers low in sucrose level compared with all other sites while site 4 produced tubers with the highest concentrations of stem end sucrose. Tubers harvested from site 7 had low level of stem end sucrose compared with those from sites 4, 5, 7, 8, 16, 13 and 15 (Figure 2). For the bud ends of tubers, fructose and glucose levels were lower from sites 1 and 15 compared with the other sites. Bud end sucrose levels were low in tubers from site 2 but high in tubers from sites 4, 8, 13 and 16 (Figure 3).

The fresh weight and diameter of tubers from site 5 was significantly smaller compared with those from sites 1, 4, 6, 8, 11 and 16. Tubers from site 16 had lower moisture content compared with the other sites except for sites 10 and 13 (Table 2).

In 1993/94, there were significant differences ($P \geq 0.05$) between sites in the levels of stem-end browning ranging from 84.4 to 92.8% for sites 1, 2, 3 and 4 compared with those from sites 18 and 19 (Figure 4). There were also significant differences between sites in the number of faces where browning was evident. Fries from sites 16, 17, 18, 19 had less number of faces with browning compared with all other sites except site 8 (Figure 4). Similarly, there were significant differences between sites in the length and width of browning faces of fries. On fry faces at sites 2, 3 and 4 the browning was longer and wider compared with browning at sites 18 and 19 (Figure 5).

Comparison of the fresh weight, moisture content of tubers and stem end browning in tubers with or without browning

There was no significant difference ($P \geq 0.05$) between the fresh weight of potato tubers with or without stem end browning. The moisture content of tubers with stem end browning was significantly higher than those without browning. Tubers with browning had higher total sugar (fructose, glucose, sucrose) levels than those with browning at their respective stem ends. However, there was no difference between the total amount of fructose, glucose and sucrose at the bud ends of tubers with or without browning (Table 3). The levels of stem end glucose were 2.2 times, fructose 1.8 times and sucrose 1.2 times of tubers with browning higher than those without browning. Fructose, glucose and sucrose levels at bud ends were not significantly different whether tubers had browning or not (Figure 6).

There were no significance differences between sites for any of the environmental data and therefore the data is not presented, though there must have been critical moisture levels at different stages of crop development.

Discussion

It is evident from our studies that stem-end browning is associated with both increased and unequal distribution of reducing sugars (fructose and glucose). Weaver *et al.* (1970), Owing *et al* (1973) and Iritani and Weller (1973a,b) reported that the bud end of Russet Burbank contained higher amounts of sugars than the stem ends contrasting with the findings of this study. Similar observations with Russet Burbank had been made by other workers (Marquez and Anon, 1986; Ledl, 1990; Eldredge, 1991; Kincaid *et al.*, 1993; Prichard and Adam, 1994). Our results have indicated that high concentrations of reducing sugars in tubers is associated with stem end browning in french fries as reported by other workers (Ledl 1990; Eldredge, 1991; Kincaid *et al.*, 1993; Prichard and Adam, 1992; 1994).

The results from the study showed no differences between the cell morphology of tubers with or without stem end browning.

The present study has indicated differences between sites in stem end browning and sugar levels. However, correlation between stem end browning, sugar levels and environmental factors such as temperature was not established. This is in contrast to the findings of Mazza (1983) who reported correlation between fry colour, sucrose, reducing sugars and temperature. The reason may be that, in the present study, temperature and pan-evaporation data were collected from only two Meteorological Stations in the Ballarat District and not at the individual sampling sites.

Results from the present studies have indicated sample sizes for stem-end browning determinations to be highly variable. This supports the views of Shock *et al.*, (1994) who reported that high variability between tubers introduced error in estimates of stem-end browning of fry colour from a 5 to 10 tuber sample and suggested twenty tubers to be a reasonable sample size per site.

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Table 1. Ranking of stem end browning and sugar levels in tubers harvested from 16 sites in the Ballarat District (1992/93 seaeon). (Ranking 1-16, 1 = highest, 16 lowest).

Site	Stem end browning	Stem end sugar levels			Bud end sugar levels		
		Fructose	Glucose	Sucrose	Fructose	Glucose	Sucrose
1	14	16	16	15	16	16	12
2	13	12	9	16	13	12	16
3	15	10	7	8	14	9	9
4	2	2	2	1	2	2	3
5	7	5	5	7	3	3	7
6	6	11	11	10	12	11	10
7	1	4	3	11	5	4	14
8	3	8	10	3	4	5	2
9	12	14	15	9	8	14	8
10	10	3	4	5	7	7	5
11	11	9	12	13	11	6	13
12	9	6	8	14	6	8	15
13	8	7	6	2	9	10	1
14	4	13	13	12	10	13	11
15	5	15	14	6	15	15	6
16	7	1	1	4	1	1	4

Table 2. Comparison of the fresh weight, diameter and moisture content of tubers harvested from different properties in the Ballarat District, 1992/93 season.

Site	Weight (g)	Diameter (mm)	Moisture content (%)
1	250.7	66.4	76.57
2	191.5	63.7	76.92
3	170.4	58.6	77.44
4	237.9	63.4	77.21
5	148.6	55.2	76.57
6	212.4	60.7	77.26
7	176.0	61.3	77.28
8	254.1	68.2	77.17
9	168.5	59.2	77.28
10	148.8	58.8	75.8
11	274.7	63.8	76.73
12	200.3	60.1	78.05
13	190.8	61.1	72.91
14	166.8	61.4	77.19
15	177.4	59.1	77.26
16	232.9	63.5	71.82
Lsd ($P \geq 0.05$)	56.742	5.531	4.635

Table 3. Comparsion of fresh weight, moisture content and total sugars (fructose + glucose + sucrose) of Russet Burbank tubers with and without browning at both ends, 1993/94 season.

Tubers	Weight (g)	Moisture content	Stem end [A]total sugars	Bud end [A]total sugars
With browning	190.8	77.06	2.209	1.041
Without browning	197.8	75.95	1.503	1.050
Lsd (P=0.05)	0.052	0.063	0.324	0.127

[A] Total sugars = fructose + glucose + sucrose

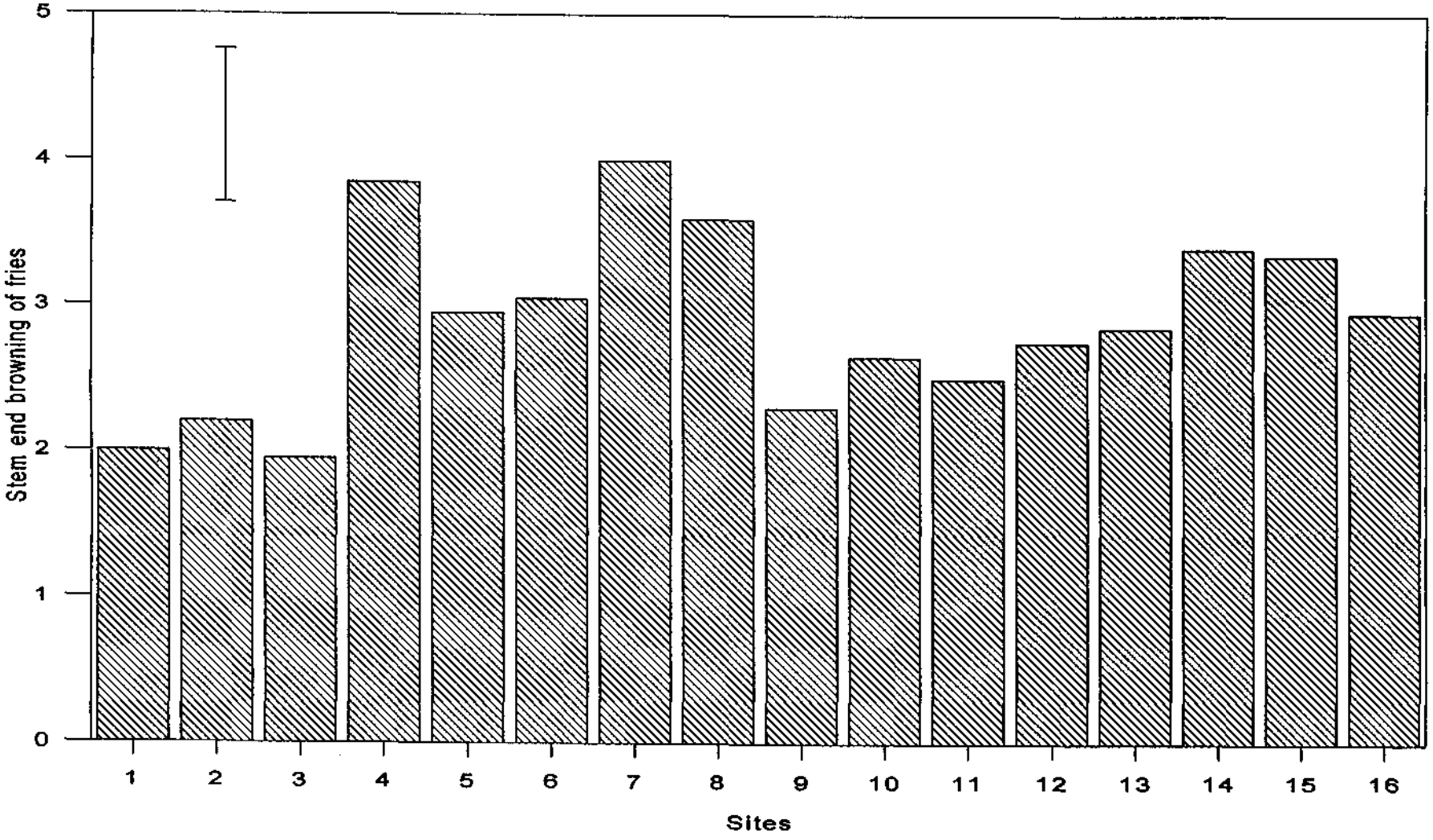

Fig 1. Comparison of the level of stem end browning of fried Russet Burbank tubers from different sites in the Ballarat District (1992/93 season). Vertical lines represent Lsd (P=0.05).

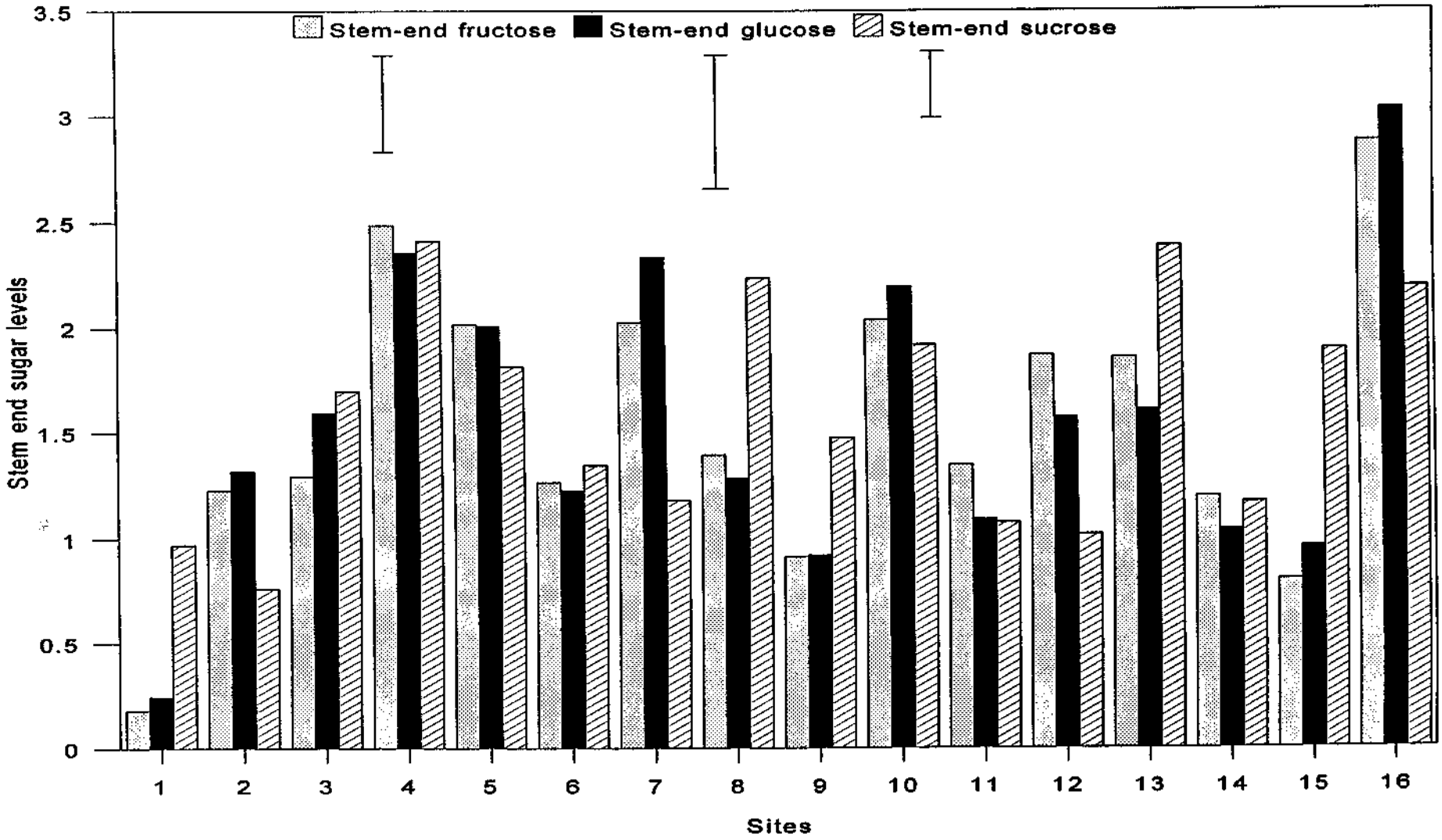

Fig 2. Comparison of sugar levels at the stem end of Russet Burbank potato tubers from different sites in the Ballarat District (1992/93 season). Vertical lines represent Lsd (P=0.05).

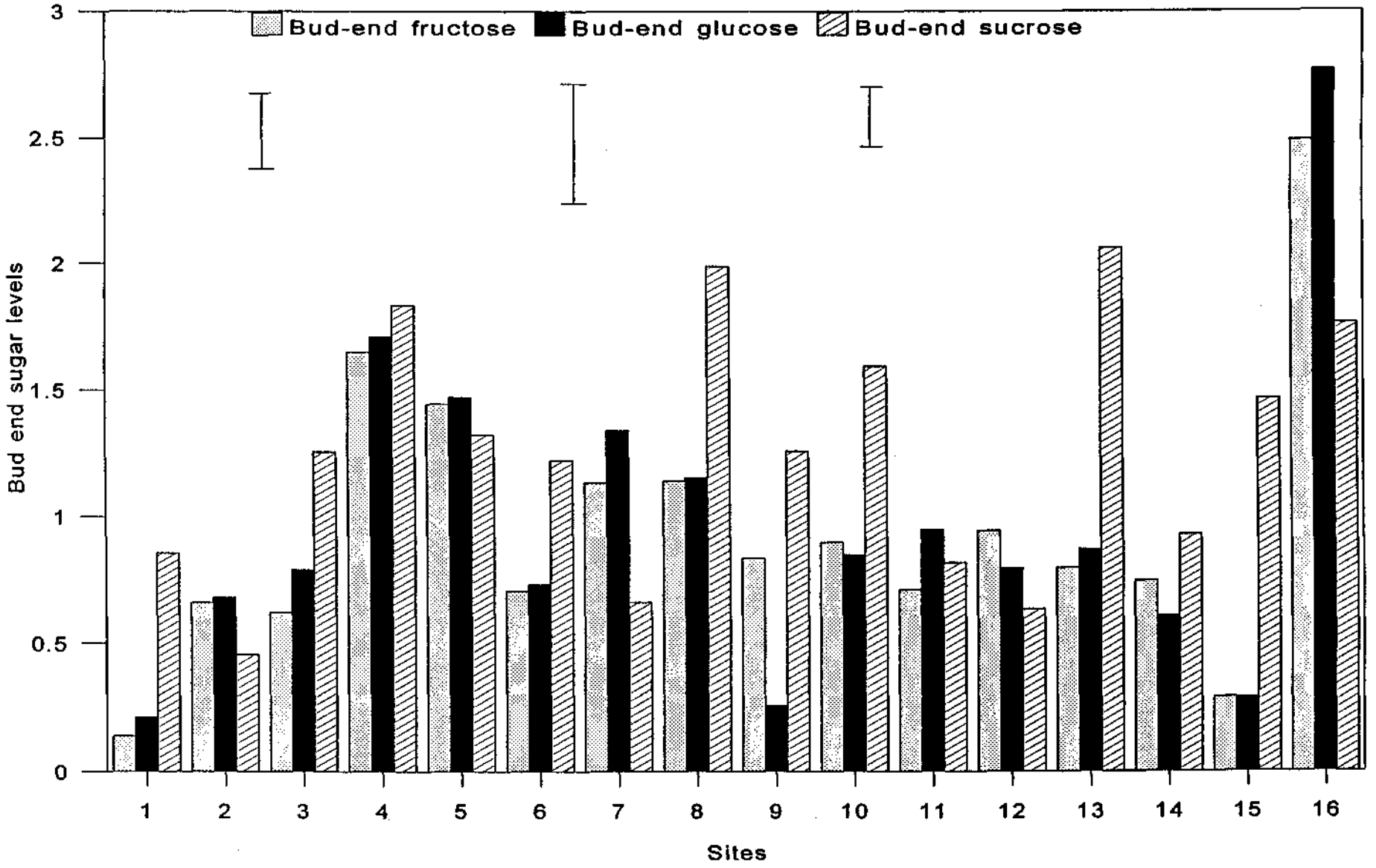

Fig 3. Comparison of sugar levels at the bud end of Russet Burbank potato tubers harvested from different sites in the Ballarat District (1992/93 season). Vertical lines represent Lsd (P=0.05).

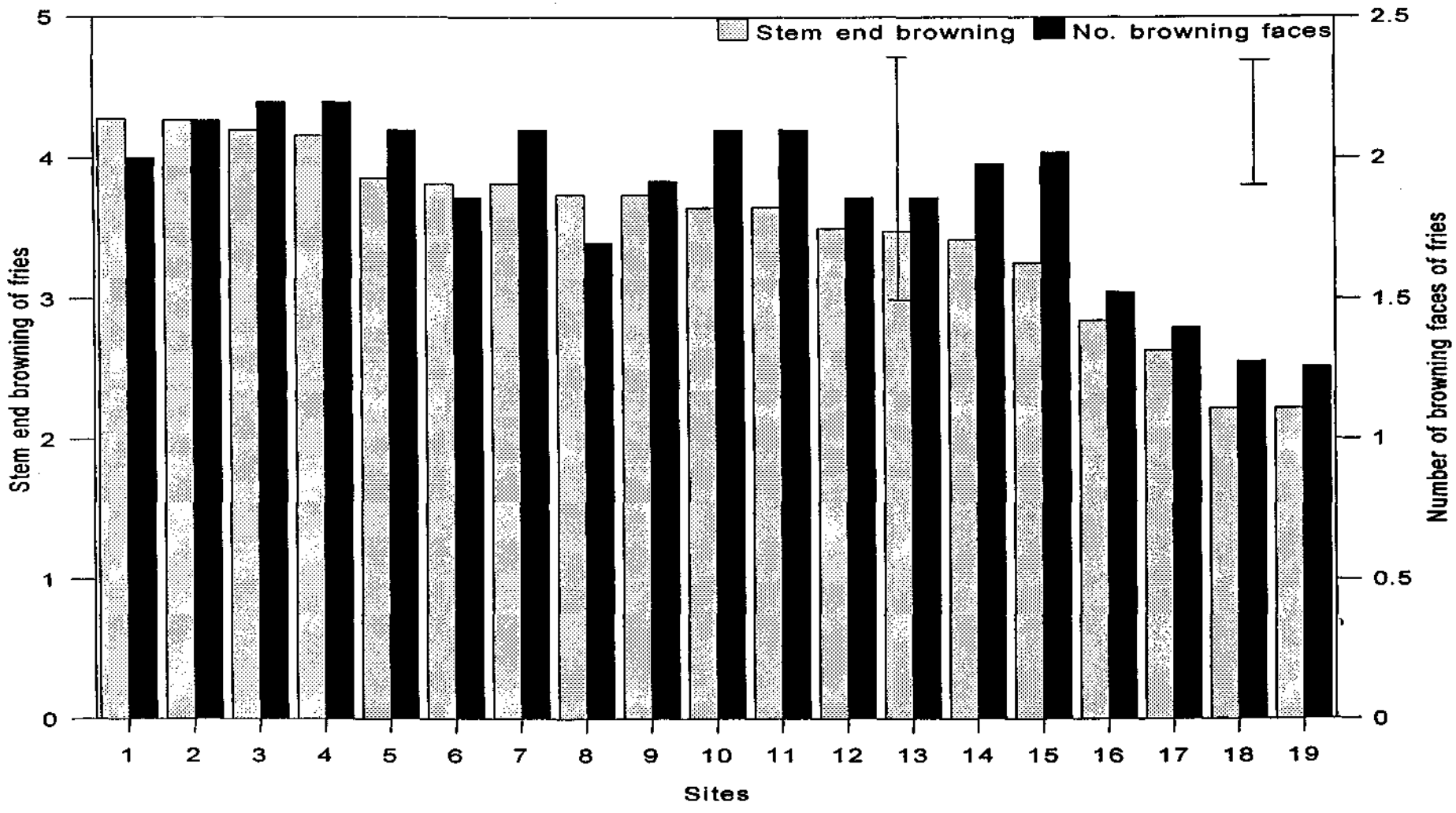

Fig 4. Comparison of the level of stem end browning and number of faces with browning of Russet Burbank fries from different sites in the Ballarat District (1993/94). Vertical lines represent Lsd (P=0.05).

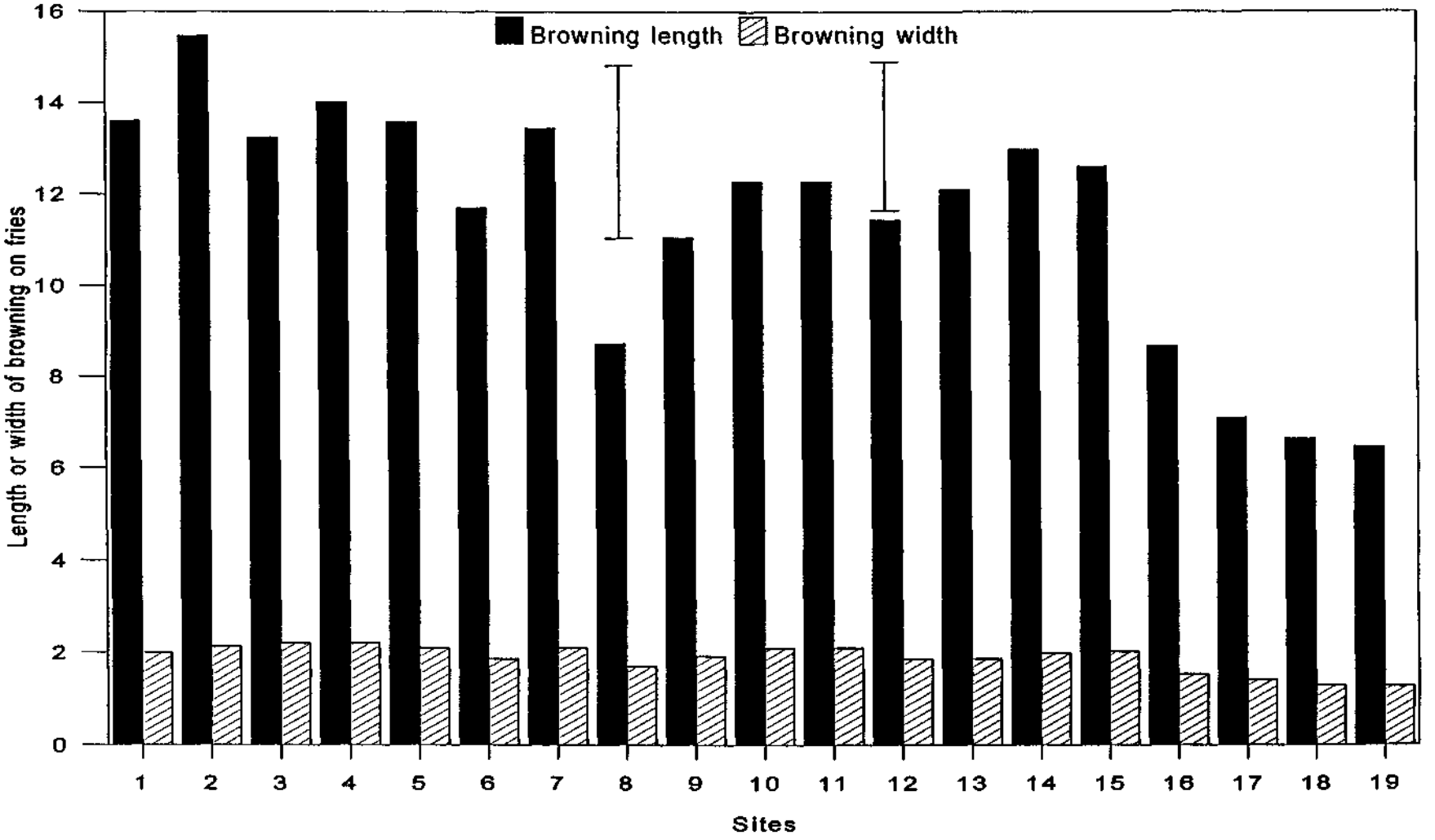

Fig 5. Comparison of the length and width of browning Russet Burbank fries from different sites in the Ballarat District, 1993/94 season. Vertical lines represent Lsd (P=0.05).

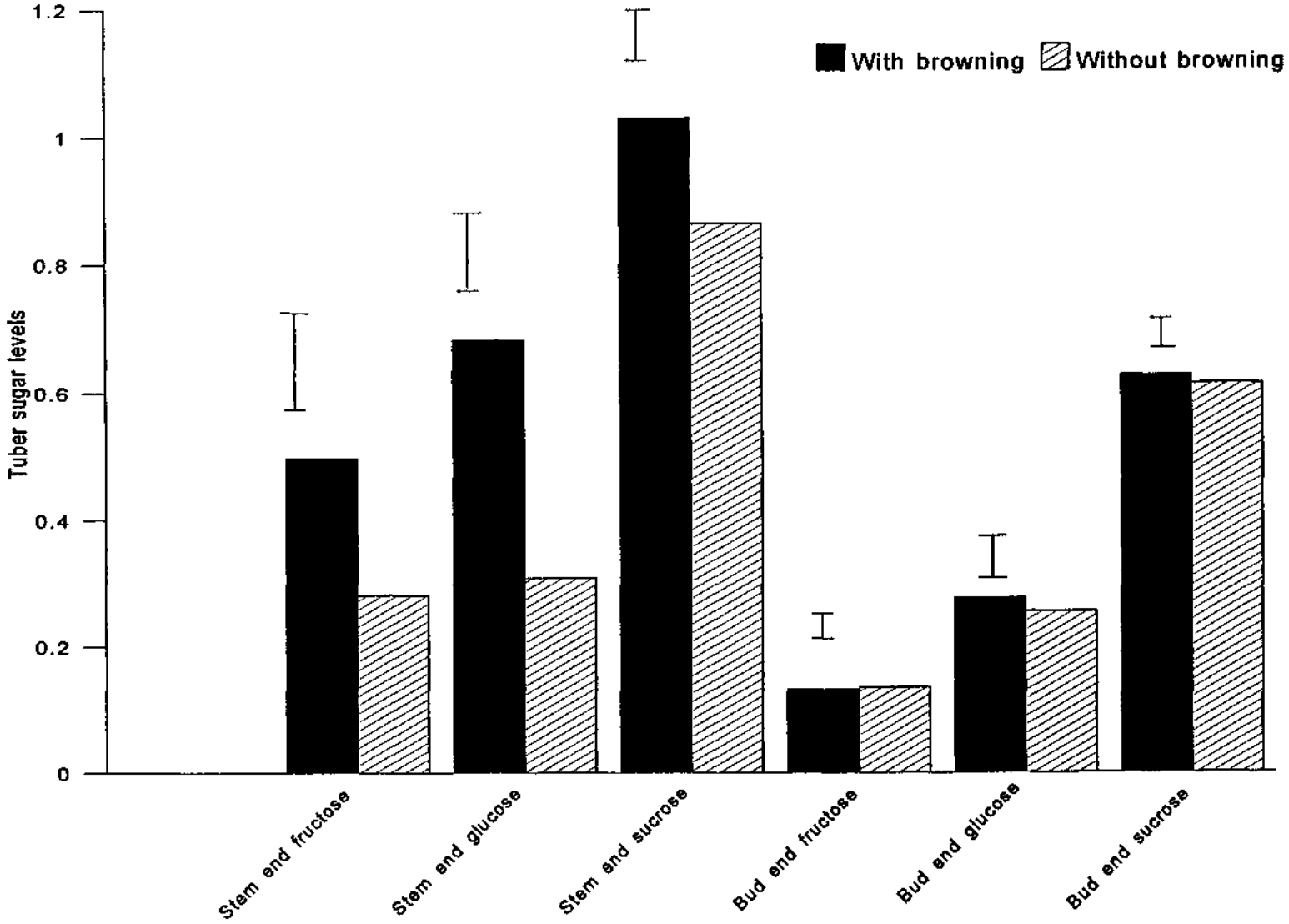

Fig 6. Comparison of sugar levels between Russet Burbank potato tubers with and without browning at both the stem and bud ends, 1993/94. Vertical lines represent Lsd (P=0.05).

Appendix 1. Environmental data for soil moisture, pan-evaporation and rainfall.

Site	Soil moisture (inches)	Pan-evaporation (inches)	Rainfall (inches)
1	4.69	0.21	0.34
2	3.0	0.21	0.24
3	3.17	0.21	0.32
4	2.95	0.23	0.46
5	2.74	0.23	0.23
6	4.03	0.21	0.27
7	2.72	0.21	0.28
8	3.62	0.21	0.31
9	3.28	0.21	0.4
10	3.48	0.21	0.28
11	3.33	0.21	0.31
12	2.82	0.21	0.58
13	3.58	0.21	0.45
14	3.21	0.23	0.55
15	2.94	0.23	0.35
16	3.54	0.21	1.0
17	2.84	0.23	0.37
18	2.62	0.23	0.40
19	2.94	0.22	0.28

Appendix 2. Data for Figures 1, 2 & 3 (Comparison of the level of stem end browning of fries, stem end and and bud end sugar levels of Russet Burbank tubers from different sites in the Ballarat District, 1992/93 season).

Site		Stem end sugar levels (mg/g)			Bud end sugar levels (mg/g)		
	Level of stem end browning	Fructose	Glucose	Sucrose	Fructose	Glucose	Sucrose
1	2.0	0.182	0.245	0.972	0.140	0.215	0.856
2	2.2	1.228	1.318	0.763	0.660	0.680	0.457
3	1.95	1.291	1.593	1.697	0.620	0.789	1.256
4	3.85	2.485	2.353	2.411	1.649	1.709	1.834
5	2.95	2.015	2.008	1.815	1.445	1.472	1.322
6	3.05	1.263	1.224	1.343	0.705	0.731	1.222
7	4.0	2.025	2.334	1.181	1.134	1.340	0.662
8	3.6	1.393	1.284	2.234	1.141	1.153	1.989
9	2.3	0.915	0.921	1.474	0.836	0.528	1.259
10	2.65	2.034	2.191	1.918	0.899	0.850	1.594
11	2.5	1.343	1.089	1.073	0.710	0.948	0.818
12	2.75	1.867	1.571	1.010	0.943	0.796	0.633
13	2.85	1.855	1.606	2.380	0.797	0.781	2.060
14	3.4	1.195	1.040	1.167	0.745	0.605	0.928
15	3.35	0.803	0.958	1.893	0.290	0.288	1.465
16	2.95	2.875	3.031	2.185	2.489	2.766	1.760
Lsd (P=0.05) df=159	1.154	0.482	0.645	0.287	0.343	0.458	0.255

Appendix 3. Figures 4 & 5. Comparison of the level of stem end browning, number, length and width of faces with browning of Russet Burbank fries from different sites in the Ballarat District (1993/94 season).

Site	Level of stem end browning	Number of fry faces with browning	Length of browning on fry faces	Width of browning on fry faces
1	4.280	2.0	13.60	7.76
2	4.265	2.133	15.46	8.60
3	4.199	2.199	13.23	10.83
4	4.160	2.20	14.02	10.02
5	3.860	2.10	13.58	8.68
6	3.820	1.860	11.70	8.38
7	3.820	2.10	13.44	9.94
8	3.740	1.70	8.72	7.62
9	3.740	1.920	11.06	9.40
10	3.650	2.10	12.27	8.88
11	3.650	2.10	12.27	8.88
12	3.50	1.860	11.44	8.52
13	3.480	1.860	12.10	10.22
14	3.420	1.980	12.98	9.28
15	3.260	2.020	12.60	9.74
16	2.850	1.525	8.67	5.60
17	2.640	1.40	7.08	3.32
18	2.220	1.280	6.60	5.08
19	2.220	1.260	6.44	4.46
Lsd (P=0.05). Df= 87	0.894	0.459	4.069	3.660

Appendix 4. Figure 6 Comparison of sugar levels between Russet Burbank potato tubers with and without browning at the stem and bud ends (1993/94 season).

Russet Burbank tubers	Sugar levels at stem end of tubers			Sugar level at Bud end of tubers		
	Fructose	Glucose	Sucrose	Fructose	Glucose	Sucrose
Tubers with browning	0.4984	0.6835	1.0320	0.1320	0.2756	0.6273
Tubers without browning	0.2803	0.3075	0.8653	0.1351	0.2543	0.6143
Lsd (P=0.05)	0.1556	0.1283	0.0931	0.0436	0.0654	0.0482
Degree of freedom	88	36	34	21	80	36