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CONTRACT REPORT

Brussels sprouts the control of bitterness

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AUTHENTICATION

I declare that this work was done under my supervision according to the procedures described herein and that this report represents a true and accurate record of the results obtained.

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(on behalf of Dr M R Shipway, Head of Division of Horticultural Development, Horticulture Research International)

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SUMMARY

Brussels sprouts cultivars Rampart, Topline, Stephen and Cascade were grown at four fertiliser rates, and with and without irrigation to determine the effects of these treatments on bitterness of sprout buttons. The four fertiliser treatments were 250 and 150kg/ha N applied all in the base as ammonium nitrate, 150kg/ha N all in the base as ammonium sulphate and 150kg/ha N as ammonium nitrate split equally between base and top dressing. Bitterness of buttons was measured chemically by checking the levels of glucosinolates, sinigrin and progoitrin, which are known to contribute to bitterness, and, by taste panels. Harvesting was split over three dates for each treatment.

Fertiliser rates and irrigation had little effect on yield or quality but varieties had marked effect, Topline produced the highest yield and Stephen the lowest yield, Cascade and Rampart were intermediate.

Differences in bitterness between the varieties were detected by the taste panels and the chemical analysis. Stephen was identified as having moderate bitterness and Cascade, Rampart and Topline as having slight bitterness by the taste panels. The chemical analysis separated Rampart from Cascade and Topline as containing more sinigrin. Using principal component analysis bitterness in taste testing was closely related to sinigrim concentration. This analysis also revealed that bitterness increased with later harvests and in particular the flavour of Stephen deteriorated with later harvests. Stephen, when harvested early, treated with lower rates of nitrogen fertiliser and given irrigation tended to be less bitter than with other treatments and bitterness was reduced to similar levels as to those found in Rampart an acceptable variety in this trial.

It is suggested that in order to avoid producing bitter flavoured sprouts, growers should consider the following points. Varieties with a good flavour record should be chosen where possible. The crop should be harvested early where bitterness is suspected, and not left to stand in the field. Finally irrigation and lower rates of nitrogen can be used to slightly modify the flavour of bitter varieties.

INTRODUCTION

Brussels sprouts are a traditional British winter vegetable generally associated in consumers' minds with Sunday roasts and Christmas dinners. Demand for sprouts has declined over recent years and the area grown in the UK has fallen from 15,000ha in 1979/80 to an estimated 10,000ha in 1991/2 season. This drop can be attributed to various factors including the attraction of competing imported out-of-season vegetables and the change in eating patterns towards more snacks and convenience foods away from the traditional "meat-and-two-veg" meal with which sprouts were very much associated. It is also suggested that the flavour of the modern sprouts, particularly bitterness, is turning customers against them. It is debatable whether tastes have changed in favour of more bland flavours or whether modern growing techniques or varieties are indeed increasing bitterness in sprouts.

Bitterness was mentioned in the late 70's as a problem in frozen sprouts causing consumer rejection (MacLeod and Pikk 1979). Volatile flavour components including isothiocyanates were measured and found to vary with variety, plant spacing and freezing procedures. None of the material was tasted. It was concluded that although freezing procedures and other commercial presentation techniques greatly influenced these flavour components, variety and spacing also contributed significantly (MacLeod and Pikk 1978).

In the early 80's the chemical measurement of bitterness in sprouts advanced as individual glucosinolates were identified in the isothiocyanate compound group. Fenwick *et al* (1983) linked the presence of the glucosinolates sinigrin and progoitrin with the bitter flavour in sprouts. In combined taste tests and chemical analysis, bitter taste was correlated with sinigrin concentration and to a lesser extent with progoitrin, the precursor of goitrin a highly bitter compound found in other plants (Griffiths & Fenwick 1984). Individual varieties with high bitterness scores could contain high levels of sinigrin, or progoitrin or intermediate levels of both.

Over two years twenty-two varieties were tasted from five sites, only five varieties produced ratings greater than moderate (ie. 3 where 0 = mild and 5 = bitter) but these ratings were not consistent. For example Perfect Line scored from 0.6 to 4.0, over the five sites in 1979 and from 4.0 in 1979 to 1.6 in 1978 at one site. Citadel scored from 0 to 0.8 over the same range of sites and years. The reliability of these results does not appear to have been tested statistically but suggests that bitterness can be highly variable between sites and seasons.

The flavour of frozen sprouts has also been extensively studied by the Camden Food and Drink Research Association from 1980 to 1988 in collaboration with NIAB and ADAS. CDFRA found more consistency in bitterness ratings of varieties than previous workers. Using material from variety trials grown at up to five sites nationally clear difference between varieties in any one year were reported. These ratings tended to be maintained over the years that individual varieties remained in the trial (eg. Bedford 1984).

Where results from different sites were compared in 1980 and 1981 no significant difference in bitterness between sites was found (Bedford 1980, 1981). In subsequent reports, results from all sites were combined to improve the reliability of variety data (Bedford 1984) so disregarding any site to site variation.

Nitrogen fertiliser usage has also been examined in relation to bitterness in sprouts (ADAS 1980, Bedford 1984 and Scaife and Turner 1985). In 1980, three varieties were grown at six nitrogen rates, from 0 to 250kg/ha at HRI-Kirton and flavour was assessed at CFDRA, no significant effects of fertiliser rate on bitterness were found (ADAS 1980). In 1983 one variety was grown with sixteen nitrogen treatments, varying amount and timing of application, to give rates from 125 to 325kg/ha N at a site on the Lincolnshire Wolds, no significant effects of nitrogen rate on bitterness scores were reported (Bedford 1984). Scaife and Turner (1985), using an untrained panel, detected increases in bitterness with increasing nitrogen top dressing from 0 to 150kg/ha N following a base dressing of 100 to 176kg/ha N on three sites. Very little increase in yield was recorded suggesting that the top dressing was in excess of the requirement to maximise yield.

In chemical measurements of glucosinolates from nitrogen trials Heaney *et al* (1983) found decreasing levels of sinigrin and progoitrin as nitrogen levels increased from 0-250kg/ha N. They also tested the effect of irrigation on these two chemicals from a trial conducted at Luddington EHS. They reported a tendency to increased levels with later irrigation. Fenwick *et al* (1983b) also reported reduction in glucosinolate levels with increasing nitrogen rates and an increase when sulphur containing fertiliser was applied.

In this trial four varieties were chosen to represent the range of bitterness found in currently grown varieties. From NIAB trials Stephen had been described at slightly bitter while Cascade was the sweetest in the trial. Rampart fell between these two being described as fairly weak flavoured overall with slight sweetness and slight bitterness (Bedford 1989). Topline had not been included in any previous taste testing. The agronomic treatments included in this trial, (irrigation, nitrogen treatments and harvest dates) were used to determine whether such treatments could increase bitterness or alter the flavour characteristics of these varieties.

Yield and quality assessments were made at HRI-Kirton. Glucosinolates, sinigrin and progoitrin were measured at NIAB Cambridge and sensory assessments were made at CFDRA.

MATERIALS AND METHODS

Cultivations

Seeds of cultivars Cascade, Rampart, Stephen and Topline were sown on 15 March 1991 in GPG 308 modular trays. They were chitted for two days at 21°C and then transferred to an unheated venlo glasshouse. Plants were raised to a good commercial standard, using liquid feeds of 100:200mg/l N: K_2O up to three times a week. The trial was laid out in the field using a split plot design with irrigation treatments as main plots, fertiliser treatments as sub plots and varieties as sub-sub plots. There were three replicates.

Irrigation treatments:

1. Up to 50mm water applied at 50mm SMD
2. No irrigation

Fertiliser treatments:

1. 250kg/ha N as ammonium nitrate in the base
2. 150kg/ha N as ammonium nitrate in the base
3. 75kg/ha N as ammonium nitrate in the base plus 75kg/ha N as top dressing
4. 150kg/ha N as ammonium sulphate in the base

Varieties:

1. Cascade
2. Rampart
3. Stephen
4. Topline

The trial was planted on 16 May by hand at 510mm by 510mm row spacings to give an overall population of 38,400 plants/ha (15,500 plants/ac). Each sub-sub plot consisted of two rows of 17 plants, 30 of which were harvested. Sub plots of different fertiliser treatment were guarded by a minimum of two rows. Main irrigation plots were guarded by seven rows or 2.04m alleyways. Soil samples were taken pre-planting to four depths, 0-15, 15-30, 30-60 and 60-90cm for soil mineral N analysis. The crop was grown to a good commercial standard using the husbandry described in Appendix 1. Fertiliser treatments were applied by hand before planting and at top dressing as appropriate.

The soil moisture deficit (SMD) was calculated using Penman's equation (MAFF 1981) using an appropriate crop factor depending on growth stage. Irrigation was applied on three occasions as shown below.

Date	Amount applied (mm)
16 July	20
24 July	50
22 August	50

Recording

The trial was picked by hand in the field, approximately one-third of the stem at each of three harvests, separated by at least three weeks. The first harvest was taken when at least 90% of plants had some buttons over 30mm diameter in the lower third of the stem on that treatment. The second harvest was taken at least three weeks later from the middle third of the stem. For the second and third harvests crop deterioration was also a criteria and treatments not standing well were taken in preference even if the three week interval had not elapsed. Any effect of harvest recorded could also be due to position of buttons on the stem. There were restrictions on how many samples could be handled for sensory analysis so some harvest dates had to be adjusted (Table 1). All buttons were picked in the field, these were then graded by size into the following categories, 12.5-20, 20-25, 25-30, 30-40 and >40mm diameter, after any unmarketable buttons had been removed weight and class of buttons in each category was recorded. A sub-sample from each plot was assessed for colour, solidity, button shape, smoothness and winginess.

Sampling

Buttons from the 25-30mm size grade were collected from the three plots of each treatment in a crate. The buttons were mixed thoroughly and sub-samples of 1.5kg and 0.5kg were sent respectively to Camden FDRA and NIAB Cambridge for further analysis. Samples for Camden were packed in a strong cardboard box and dispatched overnight via a carrier. Samples for NIAB were held in nets overnight in an ice-bank store for dispatch the following day to MAFF Cambridge in cool boxes. These were transferred the next day to NIAB, and so arrived two days after picking and grading. It was agreed between the three sites that there would be no effect from these transport arrangement on the sensory or chemical qualities of the samples.

TABLE 1 HARVEST DATES

Treatment			Harvest date		
Variety	Irrigation	Fertiliser	Early	Mid	Late
Cascade	Irrigated	1	16.12.91	14.1.92	28.1.92
		2	16.12.91	14.1.92	28.1.92
		3	16.12.91	14.1.92	28.1.92
		4	16.12.91	14.1.92	28.1.92
	Non-irrigated	1	16.12.91	14.1.92	28.1.92
		2	16.12.91	14.1.92	28.1.92
		3	16.12.91	14.1.92	28.1.92
		4	16.12.91	14.1.92	28.1.92
Rampart	Irrigated	1	26.11.91	17.12.91	7.1.92
		2	26.11.91	17.12.91	7.1.92
		3	12.11.91	3.12.91	7.1.92
		4	26.11.91	17.12.91	7.1.92
	Non-irrigated	1	12.11.91	17.12.91	7.1.92
		2	12.11.91	3.12.91	7.1.92
		3	12.11.91	3.12.91	7.1.92
		4	12.11.91	3.12.91	7.1.92
Stephen	Irrigated	1	16.12.91	7.1.92	4.2.92
		2	16.12.91	7.1.92	4.2.92
		3	16.12.91	7.1.92	4.2.92
		4	16.12.91	7.1.92	4.2.92
	Non-irrigated	1	16.12.91	7.1.92	4.2.92
		2	16.12.91	7.1.92	4.2.92
		3	16.12.91	7.1.92	4.2.92
		4	16.12.91	7.1.92	4.2.92
Topline	Irrigated	1	26.11.91	16.12.91	14.1.92
		2	12.11.91	3.12.91	14.1.92
		3	12.11.91	3.12.91	14.1.92
		4	12.11.91	3.12.91	14.1.92
	Non-irrigated	1	12.11.91	3.12.91	14.1.92
		2	12.11.91	3.12.91	14.1.92
		3	12.11.91	3.12.91	14.1.92
		4	12.11.91	16.12.91	14.1.92

COMMERCIAL IN CONFIDENCE

Sensory appraisal

Upon receipt, the day after harvest, the samples were put into chill storage and were tasted within two days of receipt, with the following exceptions:-

1. Samples of Stephen delivered 17 December, tasted 20 December.
2. Samples of Topline delivered 15 January, tasted 20 January.

Cooking

Sprouts were prepared for cooking in a standard manner. The wing leaves and one outer layer of leaves were removed from each sprout. Two hundred and fifty grams of each sample was plunged into boiling water and cooked for five minutes, before tasting.

Sensory appraisal

Three replicate samples from each treatment were tasted by fully trained panels of at least three assessors. Because of the large number of samples involved, 24 samples for each variety at each harvest, separate panels were allocated to taste the different varieties. When two varieties were tasted together the panels were enlarged and contained the tasters allocated to both varieties. The samples were assessed using the 'QAV' method of sensory appraisal (Adams *et al* 1981) and the scoring systems in Table 2.

Chemical analysis

Samples sent to NIAB were frozen, using liquid nitrogen and stored until the whole trial was complete. They were then analysed for progoitrin and sinigrin as mg/100g fresh material.

TABLE 2: SCORING SYSTEMS FOR QUALITY APPRAISAL OF BRUSSELS SPROUTS

		SCORE 1	2	3	4	5
COLOUR	Green	Very pale green	Pale green	Medium green	Moderately dark	Dark green
	Amounts of other colours (yellow khaki/brown)	Very slight	Slight	Moderate	Considerable	Very large
	Brightness	Dull	Slightly dull	Moderately bright	Very bright	Extremely bright
	Uniformity	Extremely non-uniform	Very non-uniform	Moderately non-uniform	Slightly non-uniform	Very uniform
FLAVOUR	Sweetness	Not at all	Slightly	Moderately	Very	Extremely
	Bitterness	Not at all	Slightly	Moderately	Very	Extremely
	Earthy	Not at all	Slightly	Moderately	Very	Extremely
	Nutty	Not at all	Slightly	Moderately	Very	Extremely
	Hot	Not at all	Slightly	Moderately	Very	Extremely
	Stale	Not at all	Slightly	Moderately	Very	Extremely
	Strength of flavour	Moderately weak	Fairly weak	Slightly weak	Slightly strong	Moderately strong
TEXTURE	Softness	Very soft	Moderately soft	Slightly soft	Slightly firm	Very firm
	Fibrousness	Not at all	Slightly	Moderately	Very	Extremely

Statistical analysis

The yield and quality records were subject to analysis of variance. The results of the sensory appraisal were analysed for each harvest date, using the Mann Whitney 'U' test for non-parametric comparisons. Where all treatments of one variety were harvested on the same day analysis of variance was carried out. As only one sample per treatment was analysed for chemical content no analysis of variance could be carried out. The results from sensory appraisal and chemical analysis were compared using principal component analysis.

RESULTS

Yield and quality

Total marketable yields and yields in size grades are given in table 3 as total over all three harvests. As the amount taken at each harvest was pre-determined by position on the stem, any comparisons of yield between harvests was not considered meaningful. There were no significant effects of nitrogen rate or irrigation on total yield. There were significant differences in yield between varieties with Topline producing the highest yield and Stephen the lowest yield, Cascade and Rampart were intermediate between these two. Of the four varieties only Stephen showed any effect of irrigation with higher yields from non-irrigated plots.

Quality declined with harvest (table 4). At the first harvest all the produce was class one except for a small amount of non-irrigated Rampart. By the second harvest all Rampart, Stephen and Topline was still class one but the Cascade was class two, at the third harvest both Topline and Cascade were class two while Rampart and Stephen remained class one. This may have had more to do with time of harvest than other factors as heavy frosts between 11 and 30 January when the class two produce was harvested may have damaged the sprouts. The third harvest of Stephen, in early February was still class one after these frosts.

TABLE 3 Yield, combined over all harvest, in size grades and waste

Variety	Irrigation	Yield in size grades t/ha 12.5-20mm	20-25mm	25-30mm	30-40mm	Yield 20-40mm t/ha	Total marketable yield t/ha	Total waste t/ha
Cascade	Irrigated	0.79	3.7	9.5	7.1	20.3	21.2	1.39
	None	0.95	4.1	9.9	5.6	19.6	20.6	0.93
	Mean	0.87	3.9	9.7	6.3	19.9	20.9	1.16
Rampart	Irrigated	0.27	3.6	12.3	6.1	22.0	22.3	0.83
	None	0.48	4.9	11.7	3.9	20.4	20.9	0.50
	Mean	0.37	4.2	12.0	5.0	21.2	21.6	0.67
Stephen	Irrigated	0.64	3.6	8.9	3.9	16.4	17.1	0.90
	None	0.55	3.3	10.8	5.4	19.6	20.1	0.85
	Mean	0.60	3.5	9.9	4.7	18.0	18.6	0.88
Topline	Irrigated	0.54	4.4	12.8	4.9	22.1	22.7	1.40
	None	0.49	4.7	13.7	4.6	22.9	23.4	0.68
	Mean	0.42	4.5	13.2	4.8	22.5	23.0	1.04
LSD variety x Irrgn		0.23	0.80	1.37	1.84	2.06	2.00	0.43
variety		0.18	0.51	0.75	1.36	1.49	1.46	0.26
	Irrigated	0.56	3.8	10.9	5.5	20.2	20.8	1.13
	None	0.62	4.3	11.5	4.9	20.6	21.2	0.74
LSD Irrign		0.15	1.07	2.15	1.68	2.02	1.92	0.61
Nitrogen								
250kg/ha	in base	0.56	4.1	10.8	5.6	20.6	21.1	0.93
150kg/ha	in base	0.58	3.8	11.5	5.3	20.5	21.1	1.06
150kg/ha	split	0.59	4.2	11.3	5.0	20.5	21.1	0.89
150kg/ha	as ammonium sulphate	0.63	4.0	11.1	4.9	20.1	20.8	0.87
LSD Nitrogen		0.15	0.55	0.83	0.86	0.95	0.94	0.36

Table 4 Percentage of marketable produce in class one or class two over the three harvests (not analysed)

Irrigation	Variety	Nitrogen	Harvest 1		Harvest 2		Harvest 3	
			Class 1	Class 2	Class 1	Class 2	Class 1	Class 2
Irrigated	Cascade	1	100	0	0	100	0	100
		2	100	0	0	100	0	100
		3	100	0	0	100	0	100
		4	100	0	0	100	0	100
	Rampart	1	100	0	100	0	100	0
		2	100	0	100	0	100	0
		3	100	0	100	0	100	0
		4	100	0	100	0	100	0
	Stephen	1	100	0	100	0	100	0
		2	100	0	100	0	100	0
		3	100	0	100	0	100	0
		4	100	0	100	0	100	0
	Topline	1	100	0	100	0	0	100
		2	100	0	100	0	0	100
		3	100	0	100	0	0	100
		4	100	0	100	0	0	100
None	Cascade	1	100	0	0	100	0	100
		2	100	0	0	100	0	100
		3	100	0	0	100	0	100
		4	100	0	0	100	0	100
	Rampart	1	100	0	100	0	100	0
		2	100	0	100	0	100	0
		3	67	33	100	0	100	0
		4	67	33	100	0	100	0
	Stephen	1	100	0	100	0	100	0
		2	100	0	100	0	100	0
		3	100	0	100	0	100	0
		4	100	0	100	0	100	0
	Topline	1	100	0	100	0	0	100
		2	100	0	100	0	0	100
		3	100	0	100	0	0	100
		4	100	0	100	0	0	5.9

TABLE 5 Quality characteristics of harvested buttons

Variety	Irrigation	Colour 9 = dark green 1 = pale green	Smoothness 9 = smooth 1 = rough	Solidity 9 = solid 1 = loose	Winginess 9 = good 1 = poor	Butt shape 9 = round 1 = long
Cascade	Irrigated	6.8	4.1	7.4	3.5	5.1
	None	6.8	4.5	7.5	4.3	5.2
	Mean	6.8	4.3	7.5	3.9	5.1
Rampart	Irrigated	7.2	6.0	7.3	5.3	6.1
	None	7.4	5.1	6.3	4.4	6.2
	Mean	7.3	5.6	7.8	4.8	6.2
Stephen	Irrigated	6.0	6.4	6.9	3.1	6.9
	None	6.0	6.2	6.9	3.3	6.5
	Mean	6.0	6.3	6.9	3.2	6.7
Topline	Irrigated	6.0	6.7	7.8	5.0	6.5
	None	6.1	6.7	8.1	4.8	6.7
	Mean	6.1	6.7	8.0	4.9	6.6
LSD variety x Irrigation		0.38	0.40	0.48	1.28	0.46
variety		0.25	0.28	0.31	0.45	0.30
	Irrigated	6.5	5.8	7.4	4.2	6.2
	None	6.6	5.6	7.2	4.2	6.2
LSD Irrigation		0.47	0.44	0.63	0.52	0.57
Nitrogen						
250kg/ha	in base	6.5	5.8	7.3	4.0	5.9
150kg/ha	in base	6.6	5.8	7.3	4.3	6.2
150kg/ha	split	6.6	5.4	7.2	4.1	6.4
150kg/ha	as Ammonium sulphate	6.4	5.8	7.3	4.4	6.2
LSD nitrogen		0.27	0.34	0.43	0.41	0.45

Colour, smoothness, solidity and winginess of buttons and butt shape were recorded at all three harvests but there were no major differences between similar treatments at different harvests. The results presented in table 5 are meaned over the three harvests. There were no differences between irrigation or nitrogen treatments but as expected there were between varieties. Rampart in particular was affected by irrigation, with sprouts from irrigated plots being smoother and more solid than those from non-irrigated plots.

Chemical analysis

Irrigation apparently had little effect on the levels of the two glucosinolates measured in this trial, sinigrin and progoitrin. The results have been summarised by harvest and variety and by harvest and nitrogen treatments to show any trends (Table 6). No statistical analysis was possible as only one sample per treatment was analysed. The full results are given in Appendix 2.

Variety and harvest date had a strong influence on chemical concentrations measured. Varieties Rampart and Stephen had high levels of sinigrin, Topline was intermediate and Cascade was low. Average levels of sinigrin increased from harvest 1 to harvest 3, individually Rampart showed the biggest increase (up by 50%) whereas Cascade remained fairly constant. Nitrogen treatments showed little difference at harvest 1 but by harvest 3 the ammonium sulphate treatment was 18% higher than 250kg/ha ammonium nitrate treatment.

Progoitrin concentrations were lower than for sinigrin. The main difference between the two chemicals was the low levels of progoitrin found in Rampart which did not vary with harvest. Stephen again had high concentrations, and Cascade and Topline low concentrations, which increased with harvest date. Differences between nitrogen treatments were up to 27% at the third harvest with the highest levels again being found in the ammonium sulphate treatment.

Table 6 Sinigrin and progoitrin concentrations in buttons (not subjected to statistical analysis)

Treatment	Sinigrin mg/100g fresh weight				Progoitrin mg/100g fresh weight			
	Harvest 1	Harvest 2	Harvest 3	Mean	Harvest 1	Harvest 2	Harvest 3	Mean
Variety								
Cascade	38.6	42.3	46.4	42.5	18.7	20.9	25.3	21.7
Rampart	111.9	138.2	168.4	139.5	13.2	11.7	14.5	13.1
Stephen	118.8	141.4	151.1	137.1	64.7	72.5	96.2	77.8
Topline	56.4	73.1	88.3	72.6	19.3	22.5	34.0	25.3
Mean	81.4	98.7	113.6	97.9	29.0	31.9	42.5	34.5
Nitrogen								
250kg/ha base	78.9	95.3	105.4	93.2	26.3	28.7	40.5	31.8
150kg/ha base	83.6	98.2	107.2	96.3	30.0	32.5	37.3	33.3
150kg/ha split	79.8	101.3	117.5	99.5	28.8	33.2	44.8	35.6
150kg/ha ammonium sulphate	83.4	100.2	124.3	102.6	30.8	33.2	47.4	37.1
Mean	81.4	98.7	113.6	97.9	29.0	31.9	42.5	34.5
Irrigation								
Irrigated				100.1				34.8
None				95.7				34.2

Sensory assessments

Fertiliser and Irrigation

There were no consistent flavour differences as a result of these treatments. The ammonium sulphate treatment was sometimes seen to have more negative factors (more bitter or stale or weaker), this was not always so. There were significant differences between irrigated and non-irrigated plots on two occasions. Irrigated plots of Cascade at first harvest had less hot flavour and those of Stephen at second harvest were less stale. There were no consistent differences on bitterness. Bitterness scores over all harvests are given in table 7.

Variety

Each variety was tasted by a separate taste panel and the results cannot, therefore, be compared statistically. However, a description of the colour, flavour and texture characteristics of each variety was produced (table 8).

Table 7   Bitterness scores from sensory appraisal

Treatment			Harvest			
Variety	Irrigation	Fertiliser	Early	Mid	Late	Mean
Cascade	Irrigated	1	2.0	2.2	2.0	
		2	2.3	2.2	2.2	
		3	2.1	2.4	2.3	
		4	1.7	2.9	2.3	
			2.0	2.4	2.2	2.2
	Non-irrigated	1	1.8	2.1	2.2	
		2	2.0	2.1	2.2	
		3	2.1	2.4	2.3	
		4	2.0	2.1	2.1	
			2.0	2.2	2.2	2.1
Rampart	Irrigated	1	2.3	2.0	2.4	
		2	2.2	2.0	2.7	
		3	2.5	2.1	2.3	
		4	2.5	1.7	2.6	
			2.4	2.0	2.5	2.3
	Non-irrigated	1	2.5	2.0	2.3	
		2	2.5	2.6	2.4	
		3	2.5	2.3	2.4	
		4	2.5	2.4	2.4	
			2.5	2.3	2.4	2.4
Stephen	Irrigated	1	2.8	3.2	2.9	
		2	2.8	3.0	3.0	
		3	2.6	2.9	2.4	
		4	2.4	3.2	2.8	
			2.7	3.1	2.8	2.9
	Non-irrigated	1	2.4	3.2	2.8	
		2	2.8	3.3	2.5	
		3	2.4	3.2	2.9	
		4	2.7	3.1	2.7	
			2.6	3.2	2.7	2.8
Cascade	Irrigated	1	2.1	2.6	2.8	
		2	2.3	2.1	2.6	
		3	2.1	2.3	2.3	
		4	2.8	2.3	2.3	
			2.3	2.3	2.5	2.4
	Non-irrigated	1	2.3	2.3	2.3	
		2	1.9	2.2	2.4	
		3	2.4	2.0	2.4	
		4	1.9	2.4	2.3	
			2.1	2.2	2.4	2.2

Table 8 Varietal characteristics

Topline	Colour	Moderately dark green, with slight amounts of yellow and khaki. Moderately bright and moderately non-uniform.
	Texture	Slightly soft with slight fibrousness.
	Flavour	Slightly weak, with slight sweetness and bitterness, slight earthiness and very slight hot flavour. Slight stale flavours at 2nd and 3rd harvests.
Rampart	Colour	Medium green with slight amounts of yellow and khaki. Moderately bright and moderately non-uniform.
	Texture	Slightly soft, with slight fibrousness at 1st harvest and moderate fibrousness at 2nd and 3rd harvests.
	Flavour	Slightly weak, with slight sweetness and slight bitterness and slight amounts of earthiness and hot flavours. Slight stale flavours at 2nd and 3rd harvests.
Cascade	Colour	Medium green, with slight amounts of khaki. Moderately bright and moderately non-uniform.
	Texture	Slightly soft, with slight fibrousness at 1st harvest and moderate fibrousness at 2nd and 3rd harvests.
	Flavour	Fairly weak, with slight sweetness and slight bitterness, slight earthiness at 2nd and 3rd harvests. Slightly stale.

Stephen	Colour	Medium green, with moderate amounts of yellow and slight amounts of khaki. Moderately bright and moderately non-uniform.
	Texture	Slightly soft and moderately fibrousness
	Flavour	Slightly weak, with slight sweetness and moderate bitterness and slight earthiness, hot and stale flavours.

Combined analysis

Principal component analysis of 16 chemical and sensory varieties measured the relatedness of various factors. The first component explained 29% of variation and the second explained a further 17%, 46% in total. Plotting the first and second component loadings of the original varieties (Fig 1) shows that some factors are closely related. Sinigrin is highly correlated with bitterness, earthiness and hot flavours. Progoitrin is highly correlated with yellow colouring. Sweetness is diagonally opposite sinigrin on the graph indicating that these two characteristics are at either ends of a continuous scale. The patterns emerging represent the samples tested here however similar patterns could be expected for Brussels sprouts in general.

By plotting the principal component scores of individual treatments in restricted sets, eg treatments receiving 250kg/ha identified by variety, a picture of the effect of those two factors on the flavour aspects if formed. The main factor in determining flavour characteristics is variety as seen in Fig 2. The individual varieties appear in distinct areas of the plot, plotting the same values by irrigation treatment (Fig 3) shows no distinct pattern, indicating there was no effect of irrigation on flavour at 250kg/ha N.

Variety

Stephen is clustered in the area occupied by Sinigrin, progoitrin, bitterness, hot and earthy flavours and yellow and khaki colours. Cascade is related to sweet and stale flavours. Topline appears in the area of nutty flavour, uniform and green colour and soft texture. Rampart appears midway between Stephen and Topline suggesting no extremes of flavour.

Fig 1

Original variate loadings

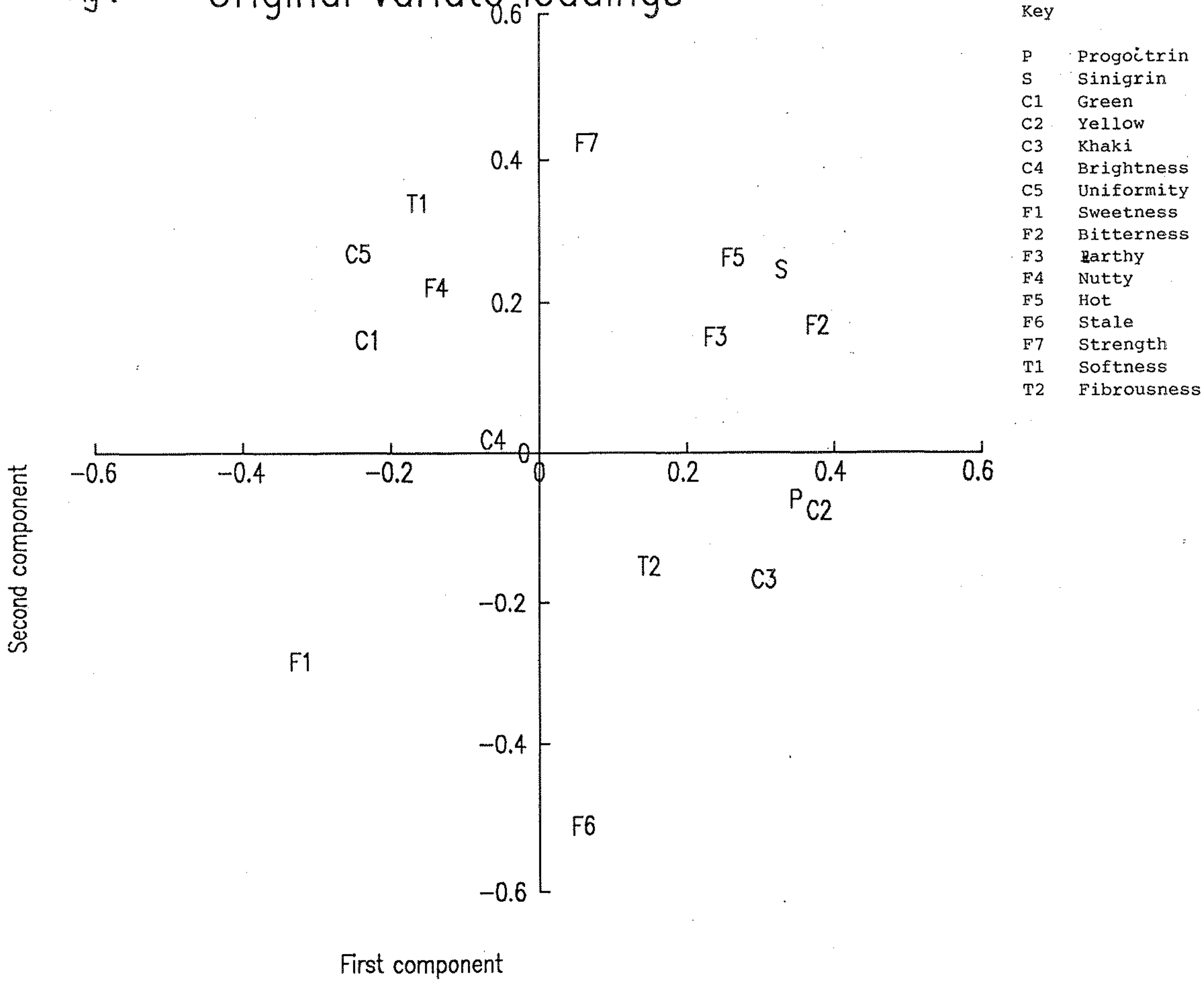


Fig. 2

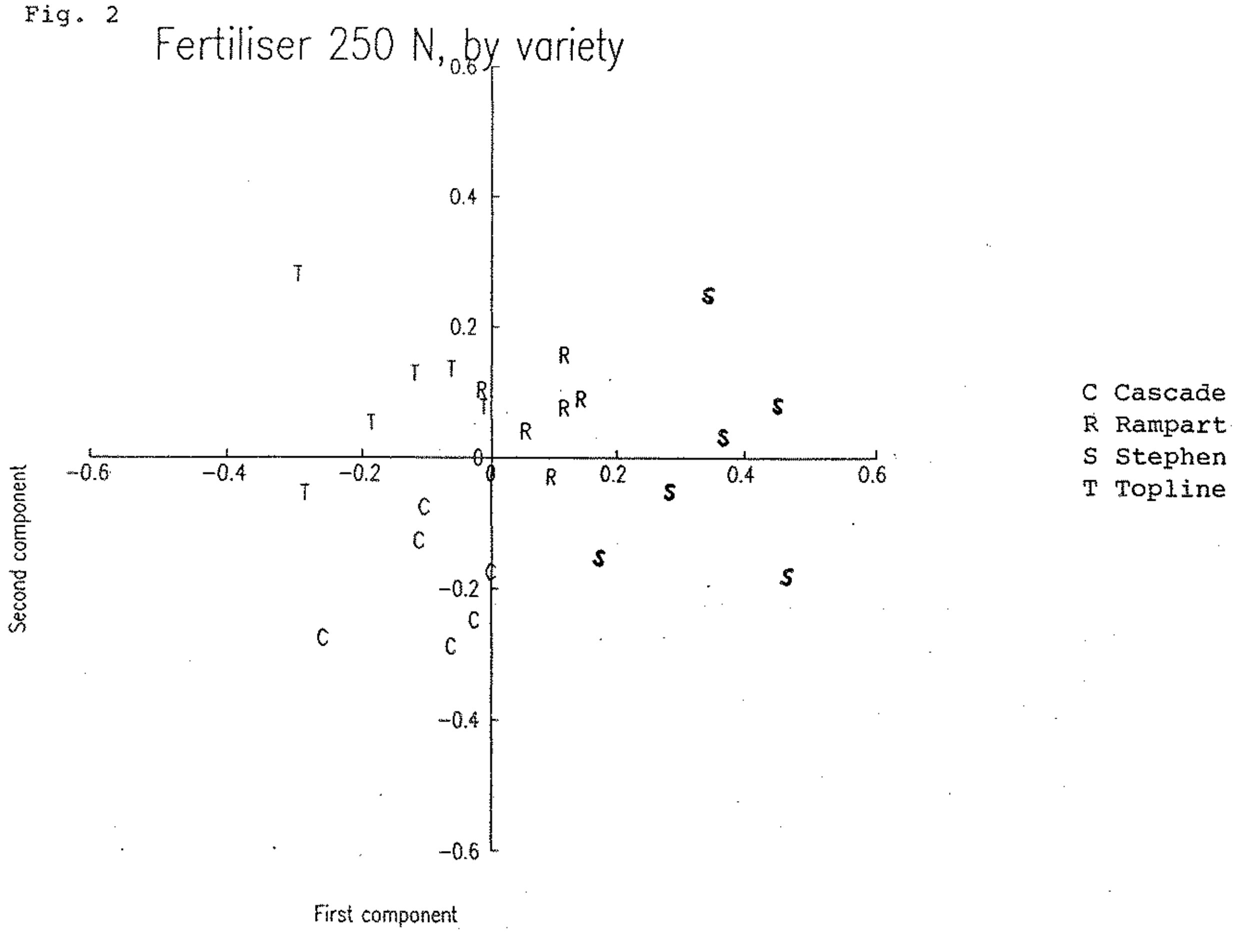
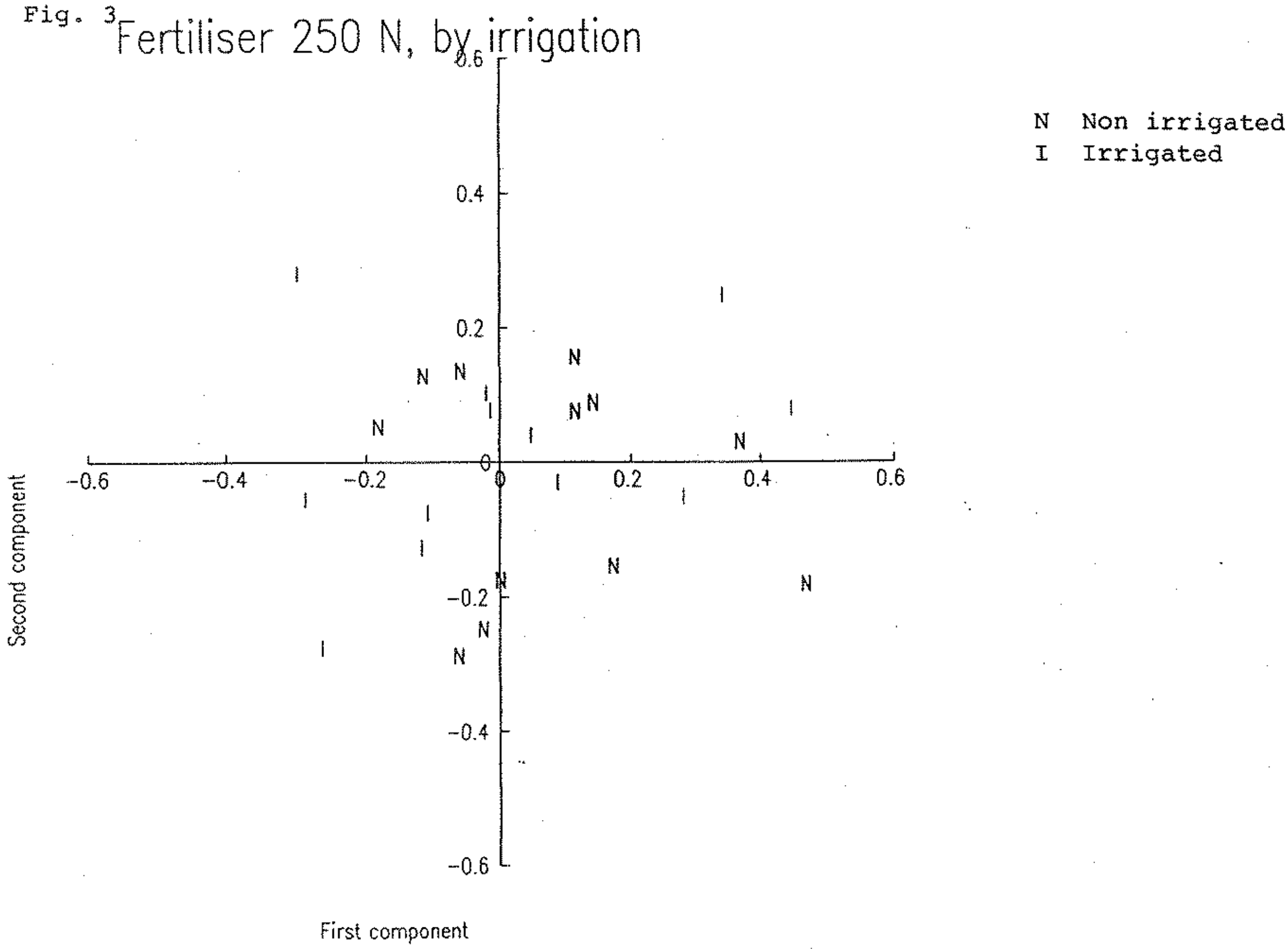

Fertiliser 250 N, by variety
Second component
First component
C Cascade
R Rampart
S Stephen
T Topline

Fig. 3


Fertiliser 250 N, by irrigation
Second component
First component
N Non irrigated
I Irrigated

Harvest

The pattern of distribution between harvests (Figs 4, 5 + 6) shows a gradual movement from the upper left hand side to the lower right hand side into the area of stale, fibrous, yellow and khaki. The general movement from left to right indicates a move away from sweetness towards bitterness with later harvest. By variety, Stephen shows the most movement, with harvest two being more closely associated with bitterness, sinigrin, earthy and hot flavours than either the earlier or later harvest. The movement from harvest two to harvest three is towards progoitrin, yellow and khaki colours.

Individual varieties - Stephen

Each variety was examined individually by harvest, irrigation and nitrogen, only Stephen and Rampart showed any distinct patterns. The effect of harvest on Stephen has been described. The effect of fertiliser was less clear than that of harvest for both varieties (Fig 7, 8) but all 250kg/ha N treatments were found on the right hand side while some of the lower rate treatments were located further from the bitter, hot, earthy complex of flavours. This indicates that perceived bitterness was increased in these two varieties by the high rate of nitrogen fertiliser.

The most striking pattern for Stephen was found by plotting irrigated and non-irrigated treatments (Fig 9). The non-irrigated treatments fall more below the x-axis, while the irrigated treatments are more widely spread particularly above the x-axis, some near the area of bitterness and some further away from it. In all the individual plots of Stephen the following three treatments appear well away from the area of bitterness, sinigrin, hot and earthy flavours:

Irrigated, harvest 1, 75kg/ha N
Irrigated, harvest 1, 150kg/ha N as ammonium sulphate
Irrigated, harvest 2, 150kg/ha N as ammonium nitrate

also located well away from the area of bitterness.

Non-irrigated, harvest 1, 250kg/ha N

Fig. 4

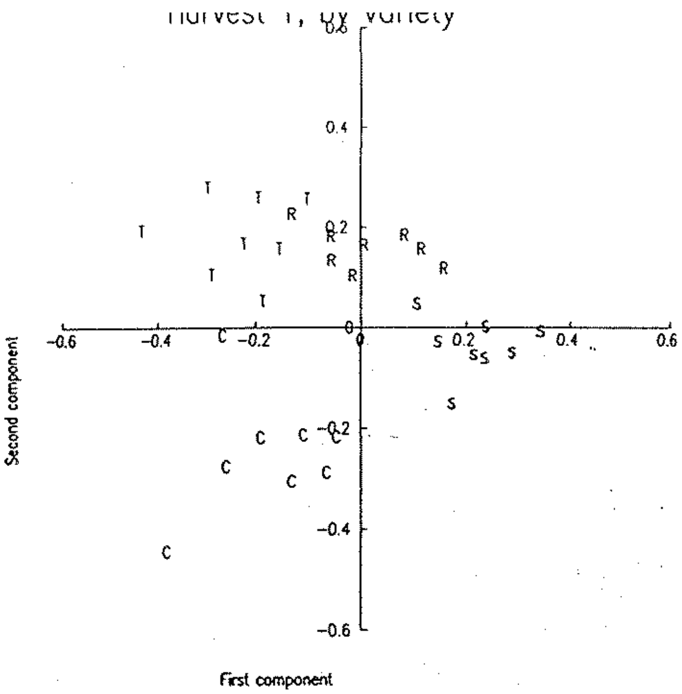


Fig. 5

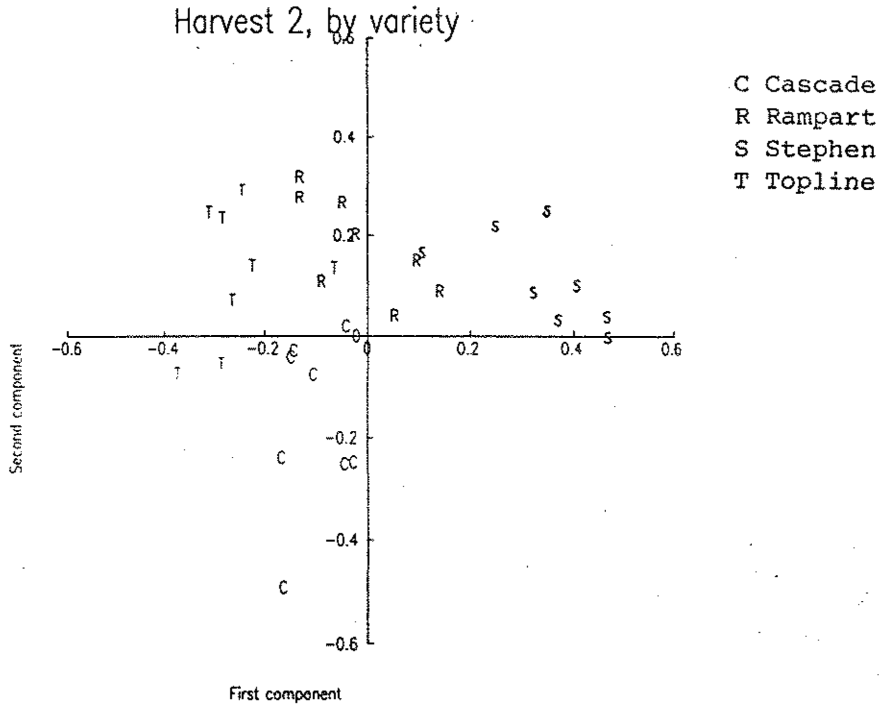
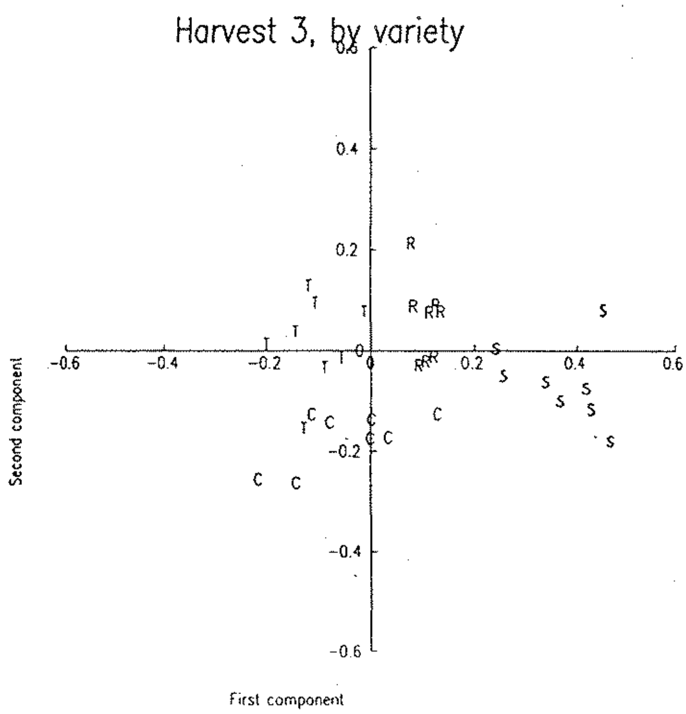


Fig. 6



Variety Stepenn, by fertiliser

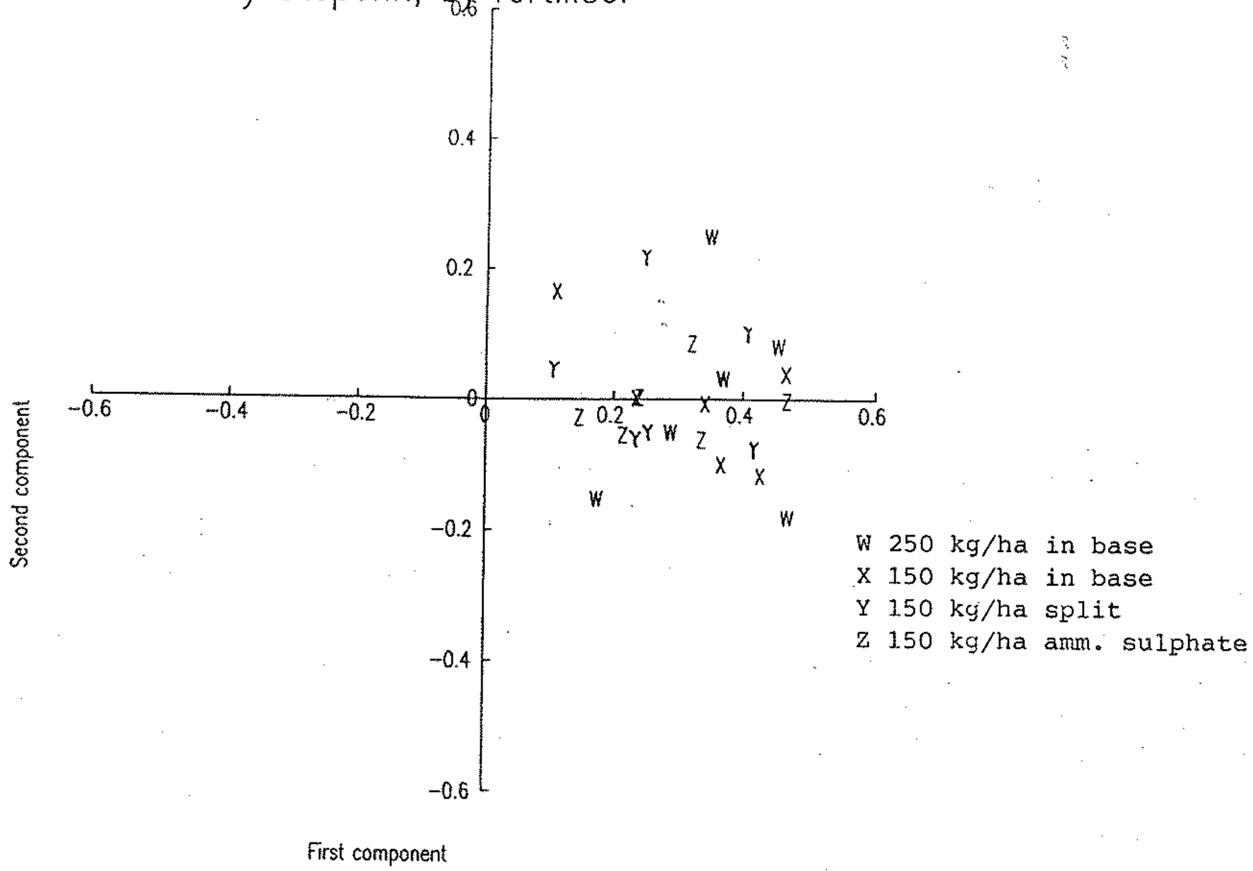


Fig. 8

Variety Rampart, by fertiliser

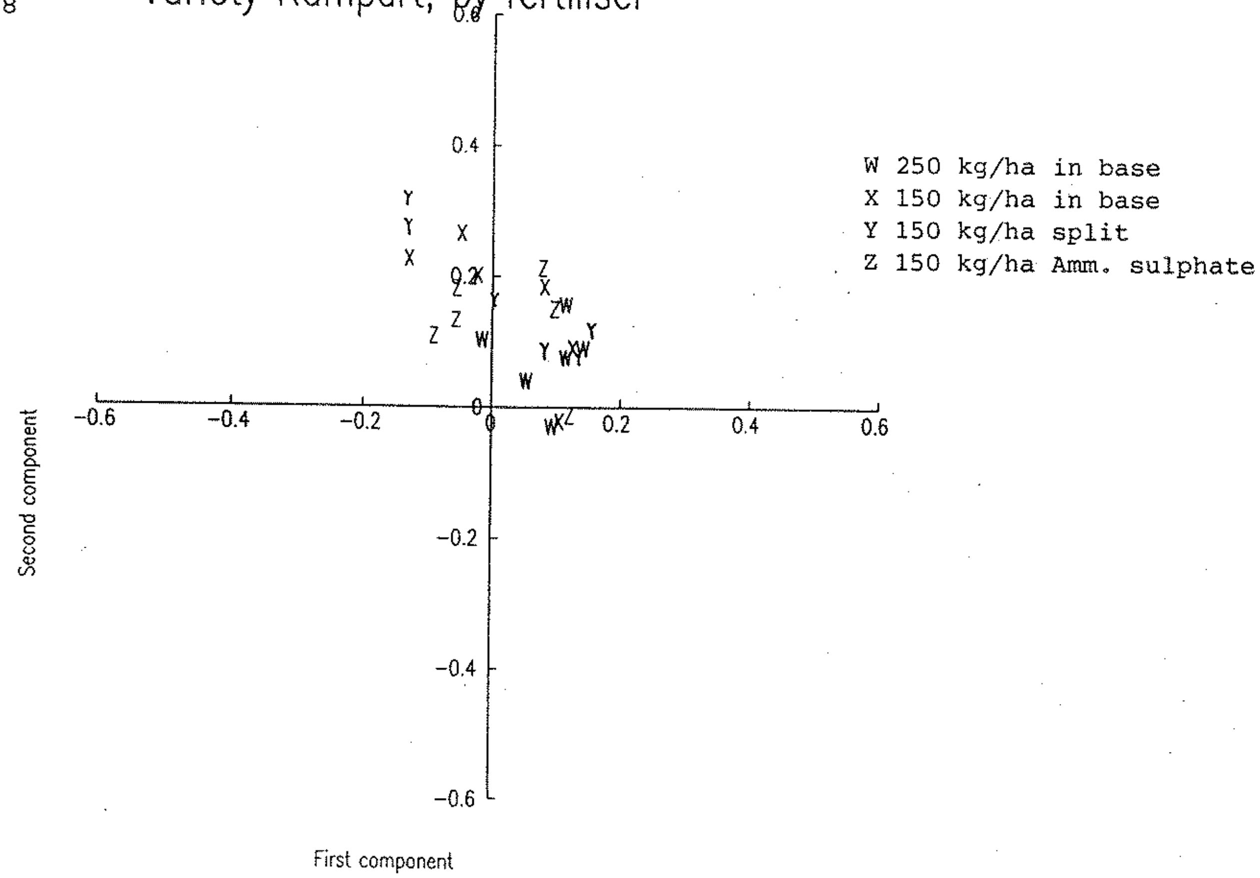
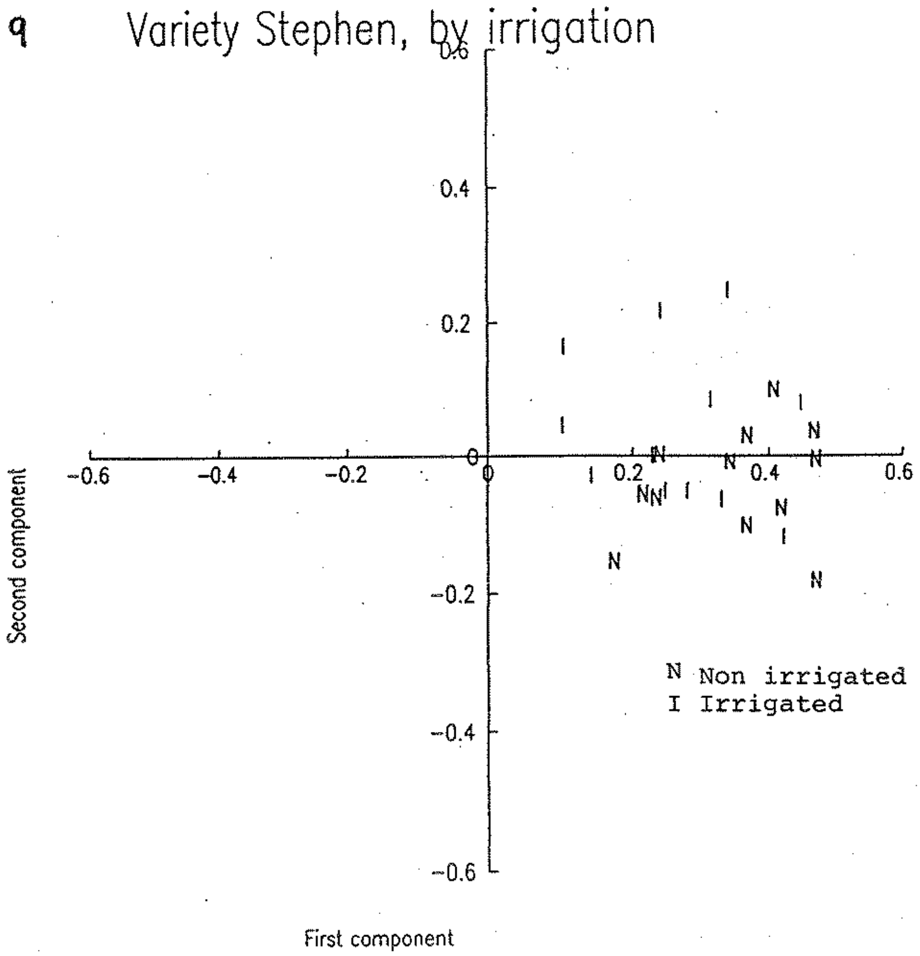


Fig 9



Variety Stephen, by irrigation
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
Second component
First component
N Non irrigated
I Irrigated

The first three treatment combinations fall within an area also occupied by Rampart and so could be described as being perceived as no more bitter than Rampart. These three treatment combinations have achieved the objective of modifying the flavour of a bitter variety to that of an acceptable variety. The common factors shared by these three combinations can be summarised as irrigation, low fertiliser and early harvest (two out of three).

Discussion

The results from the taste testing have identified Stephen as having moderate bitterness and Cascade, Rampart and Topline as having slight bitterness. The chemical analysis further separated these later three, showing that Rampart contained more of the glucosinolates measured than Topline and Cascade. Suggesting that Rampart was an intermediate and Topline and Cascade were non-bitter varieties. These results confirm the previous ratings of these varieties and in general support the view that bitterness in sprouts is primarily determined by variety (Heaney and Fenwick 1980).

It has been suggested that the constancy of the glucosinolate 'pattern' in sprouts would allow these characters to be selected for in a breeding programme (Heaney et al 1982). To breed and grow low bitterness sprouts would appear to be the long term solution to this problem. Low glucosinolate varieties of oilseed rape have been introduced, but in the case of oilseed rape the seed concentration of glucosinolates is governed by the maternal parent. In sprouts comparisons between F_1 hybrids and their parents suggests that the relative abundance or pattern in buttons is closely matched by the mean value for the parents. This suggests that varieties with a good 'pattern' eg low in sinigrin and progoitrin could be produced by breeding. There is some suggestion in the literature that breeding low levels of glucosinolates in sprouts would not be a good thing as the essential 'sprout' flavour would be reduced too (Heaney et al 1982), however in this trial two varieties with low levels of sinigrin and progoitrin, Cascade and Topline, were not considered unacceptably bland. It is encouraging to note that the newest variety in the trial, Topline, had good flavour characteristics (eg nuttiness) and low bitterness scores.

Until specifically bred non-bitter sprouts become available this work suggests some action that can be taken. Most important would be to select varieties that are ranked low in bitterness from previous tests (Bedford 1989) for example Cascade and Topline would be more suitable than Stephen, Edmund or Tardis that have all been reported to be bitter. This would be particularly important if growing on a site with a previous history of producing bitter sprouts.

In situations where it is necessary to include a known bitter variety in a production schedule these results suggest that it should be harvested early and not left to stand for too long, it should be irrigated if possible and low rates of nitrogen should be used avoiding excess nitrogen. Soil mineral nitrogen can be measured pre-planting and nitrogen rate adjusted in light of the results.

In this trial there was no indication that non-bitter varieties become more bitter when agronomic factors were adjusted however it did appear that a more bitter variety could be improved by growing techniques. These results were obtained from one season and one site only and should be tested in other seasons.

In a situation where consumers are becoming more particular about flavour, eg Flavourtop tomatoes in Tesco, tomatoes 'grown for flavour' in Sainsbury's, producers must guard against a product getting a poor flavour reputation.

STEP 1 Grow only varieties with good flavour record. Impress on seed companies that this is influencing your choice. This may encourage them to give more priority to this in breeding programmes.

STEP 2 Harvest early where bitterness is suspected (other good flavour characters declined with later harvests too) and programme crops for specific harvest to avoid over maturity.

STEP 3 Use of irrigation and lower rates of nitrogen can modify flavour slightly but cannot turn a bitter variety into a sweet one.

Acknowledgements

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References

Adams M J and Bedford L V. Revised by Geering J (1981). Technical memorandum No. 278. Camden Food Preservation Research Association.

ADAS (1980). The nitrogen nutrition of Brussels sprouts. Annual Review Kirton EHS pp 27-32.

Bedford L V (1980). Technical memorandum No. 282. Camden Food Preservation Research Association.

Bedford L V (1981). Technical memorandum No. 290. Camden Food Preservation Research Association.

Bedford L V (1984). Technical memorandum No. 375. Camden Food Preservation Research Association.

Bedford L V (1989). Technical memorandum No. 563. Camden Food Preservation Research Association.

Fenwick G R, N M Griffiths and R K Heaney (1983). Bitterness in Brussels sprouts (*Brassica oleracea* L. var *gemmifera*). The role of glucosinolates and their breakdown products. J Sci Food Agric 34: 73-80.

Fenwick G R, R K Heaney and W J Mullin (1983b). Glucosinolates and their breakdown products in food and feeding stuffs. Crit Ref Food Sci Nutr 18: 126-206.

Griffiths N M and G R Fenwick (1984). Sensory assessments of glucosinolates (and their breakdown products) in cruciferous foods. Progress in Flavour Research 1984, pp 51-66.

Heaney R K and G R Fenwick (1980). Glucosinolates in *Brassica* vegetables. Analysis of 22 varieties of Brussels sprout (*Brassica oleracea* L. var *gemmifera*) J Sci Food Agric 31: 785-93.

Heaney R K, E A Spinks and G R Fenwick (1983). The glucosinolate content of Brussels sprouts: factors affecting their relative abundance. Z. Pflanzenzuchtg 91: 219-26.

MacLeod A J and H E Pikk (1978). A comparison of the flavour composition of some Brussels sprout cultivars grown at different crop spacings. Phytochemistry 17: 1029-32.

MacLeod A J and H E Pikk (1979). Volatile flavour components of fresh and preserved Brussels sprouts grown at different crop spacings. Journal of Food Science 44: 1183-5, 1190.

Scaife A and M K Turner (1985). Effect of nitrogen top-dressing on Brussels sprout flavour. Annals of Applied Biology 106: 172-3.

APPENDIX 1 TRIAL CROP DIARY

Soil type	
Previous cropping:	1990 Grass, 1989 Brussels sprouts
Soil analysis:	pH 7.5, P index 4, K index 2 Soil mineral nitrogen 207kg/ha N index 1/2
Cultivations:	Ploughed November 1990 Worked with Lely roterra before planting
Fertiliser: base:	Nitrogen applied as treatments 25kg P_2O_5/ha, 200kg K_2O/ha
top:	applied 25.6.91 as treatments
Planting:	Sown 15 March, planted 16 May
Herbicides:	Propachlor as 9l/ha Ramrod and chlorthal-dimethyl as 6kg/ha Dacthal applied 20.5.91
Insecticides:	Demeton-S-Methyl as 560ml/ha Metasystos 55 and Cypermethrin as 250ml/ha. Ambush C in 600l/ha water applied on 23.7.91, 1.8.91 and 21-24.8.91. Trichlorfon as 1.5kg/ha Dipterex 80 and Agral applied 20.9.91.
Fungicides:	Mancozeb & Metalaxyl as 2kg/ha Fubol 75WP and Chlorothalonil as 2l/ha Bombardier applied 6.8.91. Iprodione as 2l/ha Rovral Flo and Triadimenol as 500ml/ha. Bayfidan applied 27.8.91. Chlorothalonil & Metalaxyl as 2l/ha Folio 575FW applied 23.10.91.

Irrigation: 2.6.91 - 25mm water applied to whole trial for establishment.

16.7.91 - 20mm water applied to irrigated treatments only.

22-26.7.91 - 50mm water applied to irrigated treatments only.

22.8.91 - 50mm water applied to irrigated treatments only.

APPENDIX 2 CHEMICAL ANALYSIS

BRUSSELS SPROUT GLUCOSINOLATE CONTENT 1991/2 HARVEST PERIOD

Progoitrin content mg/100g fresh material

Treatment	Harvest date Early	Mid	Late	Overall Mean
C1I	15.4	15.7	23.5	
C2I	18.2	24.7	22.1	
C3I	20.3	21.7	23.2	
C4I	22.8	24.5	33.1	
Mean CI	19.2	21.7	25.5	22.1
C1N	17.7	17.3	23.0	
C2N	17.3	21.5	21.9	
C3N	17.7	21.9	28.2	
C4N	20.4	20.1	27.3	
Mean CN	18.3	20.2	25.1	21.2
R1I	12.2	10.8	11.2	
R2I	11.9	11.1	15.3	
R3I	12.4	13.3	12.8	
R4I	14.3	13.8	16.6	
Mean RI	12.7	12.3	14.0	13.0
R1N	11.6	10.9	14.1	
R2N	14.2	11.7	14.6	
R3N	16.0	9.2	14.3	
R4N	12.6	13.1	16.8	
Mean RN	13.6	11.2	15.0	13.3

S1I	60.1	67.7	82.7	
S2I	71.1	73.3	90.8	
S3I	61.0	77.6	102.4	
S4I	66.3	69.2	115.8	
Mean SI	64.6	72.0	97.9	78.2
S1N	61.8	68.7	105.8	
S2N	63.8	73.9	85.6	
S3N	62.7	71.9	95.8	
S4N	71.0	77.5	90.5	
Mean SN	64.8	73.0	94.4	77.4
T1I	17.4	21.0	36.8	
T2I	20.7	21.1	24.8	
T3I	22.8	25.5	35.6	
T4I	19.7	22.3	42.7	
Mean TI	20.2	22.5	35.0	25.9
T1N	14.2	17.6	27.5	
T2N	23.0	22.9	22.9	
T3N	17.2	24.2	46.2	
T4N	19.6	25.1	36.2	
Mean TN	18.5	22.5	33.2	24.7

BRUSSELS SPROUT GLUCOSINOLATE CONTENT 1991/2 HARVEST PERIOD

Sinigrin content mg/100g fresh material

Treatment	Harvest date Early	Mid	Late	Overall Mean
C1I	31.5	33.7	44.1	
C2I	36.3	47.1	41.6	
C3I	38.7	43.3	43.2	
C4I	37.7	45.9	57.2	
Mean CI	36.1	42.5	46.5	41.7
C1N	42.5	37.1	42.8	
C2N	37.8	42.7	42.3	
C3N	40.4	45.5	50.8	
C4N	44.4	43.0	49.5	
Mean CN	41.3	41.1	46.4	43.2
R1I	108.1	138.9	151.0	
R2I	120.1	147.9	177.0	
R3I	113.8	156.5	170.2	
R4I	122.1	158.3	199.6	
Mean RI	116.0	150.4	174.5	147.0
R1N	101.0	145.2	150.0	
R2N	108.6	114.2	158.9	
R3N	104.8	122.1	158.2	
R4N	116.3	122.1	182.5	
Mean RN	107.7	125.9	162.4	132.0
S1I	121.9	137.9	130.1	
S2I	129.5	147.2	157.4	
S3I	110.6	150.4	171.3	
S4I	119.7	132.9	158.5	
Mean SI	120.4	142.1	154.3	139.0

S1N	120.5	129.4	149.4	
S2N	114.3	146.0	146.1	
S3N	116.7	142.3	150.6	
S4N	117.4	144.8	145.7	
Mean SN	117.2	140.6	148.0	135.3
T1I	53.4	72.6	92.5	
T2I	63.2	60.5	67.4	
T3I	59.1	77.7	88.2	
T4I	53.4	75.0	112.7	
Mean TI	57.3	71.5	90.2	73.0
T1N	52.1	67.5	27.5	
T2N	59.4	79.8	22.9	
T3N	54.3	72.6	46.2	
T4N	56.4	79.4	36.2	
Mean TN	55.6	74.8	33.2	72.3

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