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A COMPARISON OF THE CHEMICAL FLAVOUR COMPOSITION OF SOME BRUSSELS SPROUTS CULTIVARS GROWN AT DIFFERENT CROP SPACINGS

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Key Word Index—*Brassica oleracea*; Cruciferae; Brussels sprout; flavour volatiles; isothiocyanates; effect of crop spacing.

Abstract—Variations in the chemical flavour composition of six cultivars of Brussels sprout were determined for plants grown at three different crop spacings (30, 45 and 60 cm from nearest neighbours). Appreciable variations in the chemical composition of the flavour extracts were observed and it was possible to distinguish the better flavoured cultivars in all cases. In general, flavour strength increased the closer together the plants were grown. The results indicate a crude yet simple method for the production of Brussels sprouts of varying flavour and flavour strength.

INTRODUCTION

Previous work on cabbage has shown that the chemical flavour composition of the cooked vegetable varies significantly dependent on a number of factors, including the cooking procedure [1], the part of the plant used [1], any commercial preservation [2], the nature of certain horticultural practices [3], and the particular cultivar [3]. In many respects some of the more interesting findings were the significant differences in flavour composition encountered as a result of variations in horticulture [3]. In particular it was shown that some of the cultivars examined could produce very different flavour results, and of the range of horticultural practices that were studied, crop spacing most affected the composition of the resultant flavour volatiles. These types of variations in horticulture could be important to the grower in affording a crude, though seemingly effective, method of simple flavour control over the vegetable produced. For this reason a more extensive survey of these two variables was carried out, but in this instance on Brussels sprouts. An additional objective was thus to ascertain whether the same overall effects would be shown by a different plant, albeit taxonomically a very closely related one. A previous investigation of the volatile flavour components of cooked Brussels sprouts compared with those of cabbage gave results that understandably were very similar, but differences were observed [4].

Since about half the Brussels sprouts grown in this Country are produced specifically for the frozen food market, crop spacings were selected in this work that had relevance to this important economic area as well as to the fresh vegetable market. For the latter, the plants are normally grown at a spacing of about 60 × 60 cm, whilst for freezing sprouts are usually grown at a spacing of 45 × 45 cm. The crop spacings selected for this study comprised a short linear range of 30, 45 and 60 cm square. In this way close, average and wide spacings with respect to frozen sprouts were obtained, whilst for the same series conventional and close spacings only were obtained for fresh sprouts. It is unlikely that plants would ever be grown commercially as close as 30 cm square for either market. However, the plants grown by us at this closest spacing were generally perfectly healthy, although the weight yield of sprouts per plant was usually a little low. Furthermore, it is worth commenting that plants are sometimes grown closer than 45 × 45 cm for the frozen sprout market, and this was one reason for concentrating on the closer end of the scale.

Table 1. Volatile flavour components of Brussels sprouts, cv Atlas

Compound	Approximate percentage relative abundance
Diethyl ether	0.001
Methanethiol	0.1
Acetaldehyde	5.1
Dimethyl sulphide	14.2
Propanal	3.8
Acetone	25.8
n-Butanal	1.3
Butanone	2.6
Methanol	11.7
Ethanol	4.9
Pentan-3-one	2.5
Diacetyl	1.2
But-2-enal	2.1
Dimethyl disulphide	1.2
n-Hexanal	2.7
Allyl alcohol	0.1
trans-Pent-2-enal	0.9
Allyl cyanide	1.6
trans-But-2-en-1-ol	0.3
trans-Hex-2-enal	3.8
Methyl propyl disulphide	0.6
cis-Pent-3-en-1-ol	2.9
Acetoin	0.6
cis-Pent-2-en-1-ol	0.1
Isopropyl isothiocyanate	0.8
Allyl isothiocyanate	5.2
cis-Hex-3-en-1-ol	2.5
Butyl isothiocyanate	0.5
trans-Hept-2-en-1-ol	0.1

RESULTS AND DISCUSSION

Table 1 lists the volatile flavour components of cooked Brussels sprouts as determined for the Atlas cultivar grown at the median crop spacing of 45 cm from nearest neighbours. These results compare very well with those previously determined for Brussels sprouts, but on unknown cultivars [4]. Compared with the identically determined data for cabbage [3], the results are not very different, indicating the expected similarity between the biochemistry of two closely related plants. However, there are some very minor qualitative differences as well as some quantitative ones. These latter are probably more important in flavour terms, and in particular the dimethyl sulphide produced by Brussels sprouts (*ca* 14%) is far less than that produced by cabbage (*ca* 34%), and the acetone produced is far more (*ca* 26% compared with about 7%). Because of this lesser production of dimethyl sulphide the other sulphur compounds (in particular allyl isothiocyanate and dimethyl disulphide) become relatively more important to Brussels sprout flavour. Acetone is, of course, a flavour diluent and is sometimes produced to an extremely large extent by sprouts. The reason for this is uncertain.

Differences between cultivars

As with the similar results for cabbage [3], the Brussels sprouts cultivars studied showed quite marked differences in relative percentages for many flavour components, and again it is possible to distinguish two distinct groups: Atlas and Epigram on the one hand, and Cambridge Special, Green Light, UR32 and UR36 on the other. The first two produced relatively high quantities of dimethyl sulphide, dimethyl disulphide, acetaldehyde, *n*-hexanal and *trans*-hex-2-enal, and very much lower quantities of acetone, when compared with the others. Table 2 gives a broad representation of the differences between the cultivars based on class of compound at all the three crop spacings considered. Detailed figures for all the individual compounds for all the experiments conducted in this project are not quoted here, but they can be consulted if required [5]. Considering initially the results for the cultivars grown at the median spacing, Table 2 shows that only Atlas and Epigram produced good quantities of the important sulphur compounds and aldehydes (both saturated and unsaturated, particularly the latter), whilst they gave only moderate amounts of the bland flavoured ketones (mainly acetone). The other cultivars produced far greater amounts of ketones, particularly Green Light and UR32. Simple tasting tests (i.e. not using trained panels) confirmed the stronger and very much better flavour of Atlas and Epigram compared with Green Light and UR32 which, not surprisingly, had very flat and indistinct flavour. Intermediate in preference, although ranked much less desirable than the better two cultivars, were Cambridge Special and UR36. Both of these produced reasonable quantities of the important isothiocyanates giving a desirable 'bite' to the flavour, but other sulphur compounds were lacking. They also gave ketones in amounts intermediate between those of the most favoured and least favoured pairs of cultivars, and although Cambridge Special produced rather less than UR36 this was compensated for by its relatively very high level of production of allyl cyanide, which is not a desirable flavour component.

It can be concluded, therefore, that when grown at the 45 cm square crop spacing there were considerable differences between Brussels sprouts cultivars in their chemical flavour composition, and of those studied here only Atlas and Epigram had good flavour with Green Light and UR32 having very poor flavour.

Similar conclusions can be drawn when the cultivars

Table 2. Total percentages of groups of compounds from some Brussels sprout cultivars grown at different crop spacings

Cultivar, crop spacing (cm)		Class of compound							
		Sulphur compounds %	Saturated aldehydes %	Saturated alcohols %	Unsaturated aldehydes %	Unsaturated alcohols %	Ketones %	Isothiocyanates* %	Nitriles %
Atlas	30	25.2	6.0	2.8	8.2	7 2	42.6	12.0	7.8
	45	22.6	12.9	16.6	6.8	6.0	32 7	6.5	1.6
	60	10.8	3.8	10.7	0.6	1.1	72.5	0.3	0.3
Epigram	30	39.9	4.2	2.8	8.7	3.3	38.7	12.5	2.1
	45	37.5	6.6	6.2	6.6	2.6	36.2	7.4	3.5
	60	10.2	6.0	1.4	1.2	1.6	72.8	1 3	6.2
Cambridge Special	30	14.3	1.8	8.9	8.1	7.9	57.6	8.4	1.1
	45	6.1	2.6	10.6	1.9	6.5	54.2	4.4	17.4
	60	0.6	0.6	0.4	0.1	0.3	97.5	0.2	0.4
Green Light	30	8.8	9.9	3.3	7.9	9.5	19.8	3.0	40.1
	45	1.4	1.2	1.8	0.3	0.8	92.9	0.8	0.6
	60	18.2	2.8	5.4	0.9	1.8	67.2	1.3	3.4
UR 32	30	22.1	9.0	20.0	4.8	9.3	30.0	14.1	4.0
	45	1.1	0.9	1.6	0.3	0.8	92.6	0.5	2.0
	60	6.7	2.3	3.2	0.5	0.4	84 1	0.9	2.6
UR 36	30	11.8	15.3	19.6	2.5	1.6	42.3	1.4	6.1
	45	9.5	2.6	8.9	0.9	0.4	72.9	5.8	3.9
	60	6.7	3.4	4.9	1.1	1.2	79 7	1.3	2.1

* Also included under sulphur compounds.

are grown at other crop spacings (30 or 60 cm from nearest neighbours), but in these instances the results are less clear cut. At both of these other spacings Atlas and Epigram retained their flavour superiority over the other cultivars, but in general to a lesser extent. At 60 cm spacing, for example, Green Light improved in chemical flavour composition to be a good flavoured alternative, confirmed by tasting tests. UR 32 also improved to an extent, but Cambridge Special was very poor indeed with 97.5 % of its flavour volatiles being due to ketones (97 % acetone). At 30 cm spacing though, Cambridge Special was much better, and apart from UR32 it most closely approached the stronger flavour of Atlas and Epigram. Green Light was poorest in flavour at this spacing due presumably to its extraordinarily high production of allyl cyanide.

In conclusion, therefore, listings of Brussels sprouts cultivars in order of superior flavour characteristics vary over the three crop spacings studied, and although Atlas and Epigram were the best in all three instances the remaining lower sequences of the listings varied considerably.

Differences in crop spacing

The normal spacings for Brussels sprouts on planting out have already been mentioned. However, to improve yield, growers sometimes tend to closer crop spacings than usual, but it has already been shown for cabbage that such variations in spacings considerably affect the chemical flavour compositions of the resultant plants [3]. This series of experiments on Brussels sprouts was designed to ascertain whether their flavour was also affected by varying crop spacing, and if so whether the clear-cut trends shown by cabbage for certain groups of compounds would be the same for sprouts.

Plants grown at wider crop spacing might be expected to produce more of the volatile flavour compounds than those grown at closer spacings, since the former would have a greater supply of nutrients available. In fact this was true for Brussels sprouts, and for the UR32 cultivar, for example the ratio of total volatiles produced from 60 tc 45 to 30 cm spacing was *ca* 50:25:1. Other cultivars showed the same effect but generally not to such a great extent, and on average about ten times the amount of volatiles was produced at the widest spacing as at the closest. Although interesting, these findings need not necessarily affect flavour, of course, in that it is the relative proportions of the significant compounds which are produced in any particular instance which is most important.

Table 2 gives the results for the effect of different crop spacings on the total percentages of groups of volatile flavour compounds produced for all the six Brussels sprouts cultivars studied. It can be seen that as with cabbage [3], flavour composition did vary markedly with crop spacing in all instances. The two best flavoured cultivars, Atlas and Epigram, were described by tasters as having the best flavour of all sprouts tested, when grown at 45 cm spacing. At 30 cm spacing they were somewhat less preferred due to their flavour being rather too strong (presumably due in part to the extra isothiocyanate produced); whilst at 60 cm their flavour was definitely inferior in being rather bland. Similar preferences were stated, although less positively and for different reasons, for UR36, but overall this cultivar had poorer flavour than Atlas or Epigram. The other cultivars all showed different behaviour. Cambridge Special had best flavour when grown at 30 cm spacing, basically due to its production of reasonable quantities of isothiocyanates, and to its lesser formation of ketones and allyl cyanide than the excessive amounts given at other spacings. On the other hand, Green Light gave best flavour at 60 cm spacing, since at 45 cm it gave excess ketones and at 30 cm it gave a large excess of allyl cyanide. However, overall Green Light was not a good flavoured cultivar under any circumstances. Similarly, UR32 was also a poor flavoured cultivar, and it produced its worst at median spacing. Tasters slightly preferred its flavour at 30 cm spacing compared with 60 cm, but found it rather too strong compared with other cultivars at that spacing.

Considering trends in the chemical composition of the flavour volatiles with crop spacing, it is possible to distinguish clearly three cultivars which all show virtually identical behaviour. These are Atlas, Epigram and Cambridge Special. As with the preferred cabbage cultivars [3], these three showed consistent increases in amounts of sulphur compounds produced (particularly isothiocyanates) with closer spacing. It was this that was mainly responsible for the stronger, more bitter flavour of these cultivars when grown close together. Isothiocyanates are most important contributors to Brussels sprout flavour, providing a characteristic desirable 'bite' to the flavour when present in moderate amount. The other cultivars did not show this type of behaviour, but they did all produce more isothiocyanates at 30 cm spacing than at 60 cm, and only Green Light did not do the same for sulphur compounds in general. Again, as with cabbage [3], Atlas, Epigram and Cambridge Special showed an increase in the production of the important unsaturated aldehydes with closer spacings, and also a peak in the formation of saturated aldehydes at the median spacing. In both instances, the other three cultivars did not conform, but overall unsaturated aldehydes were much greater at 30 than at 60 cm. Unsaturated alcohols are also important flavour components of green vegetables, many giving a desirable 'green' aspect to the flavour, and these too were produced in greater amounts at closer spacings by Atlas, Epigram and Cambridge Special. UR32 showed the same behaviour, and although the other two cultivars both showed a minimum at 45 cm, again overall the amounts increased from widest to closest spacing.

It is noticeable that for the best three cultivars (and to some extent for the other three also) all the desirable classes of flavour compounds increase with closer crop spacing, presumably because stress conditions induce increased biosynthesis of their low molecular weight precursors.

For cabbage it was the saturated alcohols which were generally responsible for the weaker flavour of plants grown at wider spacings [3]. With sprouts, however, these compounds were not a problem and did not show much of a consistent pattern, although again Atlas, Epigram and Cambridge Special showed the same behaviour in exhibiting a peak for the saturated alcohols at 45 cm spacing. This level was never excessive, however, and as already emphasized it was the ketones which were sometimes produced in very large amounts by sprouts. In such instances it was acetone that was the chief culprit, and indeed it was occasionally produced in extraordinarily high percentages (97 % in one case). Therefore, it was clearly this compound which was almost exclusively responsible in such cases for the virtual lack of flavour.

Again Atlas, Epigram and Cambridge Special showed the same trend for the ketones in exhibiting a desirable minimum at a crop spacing of 45 cm. The unfortunate Green Light and UR32 cultivars produced a maximum of ketone formation at the middle spacing, and both at a very high level of about 93%. This is totally responsible for their extremely poor flavours at that spacing. The other cultivar, UR36, showed increase in ketone production with wider spacing, and overall all the cultivars investigated formed more ketones at the widest spacing than at the closest. The reason for the greater production of acetone at these wider spacings is obscure.

EXPERIMENTAL

All the Brussels sprouts used in this work were grown specially by the London University Botanical Supply Unit according to specified conditions. Six different cultivars were examined Atlas, Epigram, Cambridge Special, Green Light, UR32 and UR36. All were grown from seed. Seeds were sown outside without protection during early April 1969, a year that turned out to be about average as far as climate was concerned. When the plants reached a height of about 10 cm (in early June) they were transplanted to their final position at spacings of 30 × 30, 45 × 45 or 60 × 60 cm. The soil type comprised *ca* 30 cm sandy topsoil overlying Bagshot sand. Generally, sampling of the plants was during October and early November and was timed according to maturity. Six plants, with roots intact, were provided for each cultivar at each crop spacing, allowing for at least duplicate analyses and for some random selection. Further such selection occurred in the field where rather more than six plants were grown for each variation. It was occasionally necessary to store the plants for two or three days before analysis when too many matured at about the same time, and in such instances plants were kept at 4°. All plants were analysed for the volatile flavour components in exactly the same manner, and the techniques employed have already been reported in detail [1–3, 6]. In no case did duplicate analyses on sprouts from different plants (but the same cultivar grown at the same crop spacing) produce variations in quantitative data greater than ±5% of the measurement. In such duplicate analyses, no qualitative differences were ever observed.

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