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THE EFFECTS OF DIFFERENT HORTICULTURAL PRACTICES ON THE CHEMICAL FLAVOUR COMPOSITION OF SOME CABBAGE CULTIVARS

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Abstract—Variations in the chemical flavour composition of three cultivars of cabbage were determined for plants of different horticultural histories. In some instances, for example when cabbages were grown at different crop spacings, some extreme variations in the chemical composition of the flavour extract were observed; in other instances (e.g. seasonal and maturity differences), variations in chemical composition were less extreme but still significant; and in some cases (e.g. employing a few selected agricultural additives) no significant chemical differences were observed. The results afford a crude but simple method for the production of cabbages of varying flavour and flavour strength.

INTRODUCTION

For any particular plant food the effects on its flavour of the use of different horticultural environments for growth or of genetically different varieties have rarely been extensively studied, except by Freeman and Mossadeghi [1–6]. These authors have investigated in particular the effect of sulphate nutrition on the flavour of onion [1], garlic and wild onion [2], watercress [3], and radish, cabbage and white mustard [4]. They have also studied the effect of water regime on the flavour strength of vegetables [5], examining in particular watercress, cabbage and onion [6]. The fact that more work has not been carried out in this area is rather surprising especially when it is appreciated that in the case of watercress, to consider just one example, flavour preferences amongst consumers vary greatly, although little or no attempt has been made to satisfy these preferences utilising different varieties or growing conditions. Freeman and Mossadeghi demonstrated clearly that a range of flavour strength for watercress from weak to strong could readily be achieved simply by variations in the amount of sulphate available to the growing plant [3]. Similarly, although to a lesser extent, flavour strength of watercress was shown to vary depending on the amount of water available to the growing plant, those produced under conditions of water stress attaining stronger flavour [6]. It would seem possible, therefore, that in this instance at least, consumer preferences could fairly easily be satisfied by simple variations in horticultural practices. Since this paper deals with cabbage it is relevant to point out that in agreement with their work on watercress, Freeman and Mossadeghi showed that cabbages grown under water stress also developed a stronger flavour [6].

Over the past few years we have carried out a more extensive survey of the effects of different horticultural practices on the flavour composition of cabbage. As well as the influences of irrigation on flavour, we have also studied variations within a season, maturity differences, some crop spacing differences, the effects of one or two general fertilizers, pesticides and herbicides, and also the extent to which some different cultivars vary in flavour composition. In all instances studies have been based more on a comprehensive chemical investigation of variations in the identified volatile flavour components of cabbage; nevertheless, this work was supported by limited sensory comparisons as well.

Although, unlike watercress, cabbage is not necessarily subject to strong consumer preferences, it is a much maligned vegetable in flavour terms and previous work has demonstrated that the flavour composition of the cabbage is liable to gross variations dependant on cooking methods [7] and on its commercial preservation [8]. It seemed possible, therefore, that this plant might also show flavour differences due to variations in horticultural methods, which might thus satisfy such consumer preferences as do exist with cabbage. Variations were selected that in general would be relatively simple for growers to adopt should the product prove particularly desirable. Thus, detailed modifications in chemical nutrition were avoided and all growing differences were conducted relatively crudely in the field.

RESULTS AND DISCUSSION

Table 1 lists the volatile flavour components previously determined for cabbage in this laboratory [7–9]. These results were obtained for the F_1 hybrid Summer Monarch (SM) under standard experimental conditions.

In all the experiments described here exactly the same flavour sample preparation and analysis procedures were employed enabling valid comparisons to be made of results from cabbages of different horticultural histories. In no instance did duplicate analyses on different plants of cabbages submitted to exactly the same growing conditions show any significant variation for any of the individual components, so any major

Table 1. Volatile flavour components of cabbage

Compound	Approximate percentage relative abundance
Methanethiol	0.5
Acetaldehyde	7.5
Dimethyl sulphide	34.0
Propanal	6.0
Acetone	6.5
Acrolein	0.5
n-Butanal	2.5
Butanone	0.5
Methanol	8.0
Ethanol	1.0
3-Pentanone	4.0
Diacetyl	1.0
Acrylonitrile	1.0
Butyl methyl sulphide	1.0
Crotonaldehyde	0.5
Dipropyl sulphide	1.0
Dimethyl disulphide	0.5
n-Hexanal	3.0
cis-Crotononitrile	0.5
Allyl alcohol	0.1
4-Heptanone	0.1
trans-Pent-2-enal	0.5
trans-Crotononitrile	0.5
Allyl cyanide	3.0
trans-Crotyl alcohol	0.5
trans-Hex-2-enal	2.0
Methyl propyl disulphide	0.5
cis-Pent-3-en-1-ol	0.5
Acetoin	0.5
cis-Pent-2-en-1-ol	0.1
Propyl isothiocyanate	1.5
n-Hexanol	0.1
Allyl isothiocyanate	6.0
cis-Hex-3-en-1-ol	4.0
Butyl isothiocyanate	1.0
trans-Hept-2-en-1-ol	0.5

differences between results for the following experiments can justifiably be ascribed to the particular horticultural variable. In most instances, at least triplicate analyses were performed to ensure reproducibility. The complete detailed figures for all the variations considered will not be quoted here, since in many instances no significant differences were observed, but if required all the data can be consulted [10]. In this paper attention will be directed only to the major differences. It should be emphasised that only quantitative variations were observed; in no instance did a difference in horticultural history produce a new compound, nor the absence of a compound normally obtained.

Differences between cultivars

The cultivars studied showed quite marked differences in relative percentages for many flavour components, and it is possible to distinguish two distinct groups: Summer Monarch (SM) and Elsoms New Hybrid (ENH) on the one hand, and Ennes Cross (EX), Autumn Monarch (AM) and Winter Monarch (WM) on the other. Thus, the first two produced relatively high quantities of acetaldehyde, dimethyl sulphide, propanal, *trans*-hex-2-enal, and allyl isothiocyanate, and relatively low quantities of methanol and ethanol, when compared to the others. Table 2 gives a broad representation of the differences between the cultivars based on compound type, and it can be seen that EX, AM and WM were all deficient compared with SM and ENH in the important sulphur compounds (particularly the isothiocyanates) and aldehydes (both saturated and unsaturated) whilst they produced excess of the bland flavoured saturated alcohols. Tasting tests confirmed the stronger, and generally agreed better, flavour of SM and ENH. Since all plants were grown under identical conditions these differences must be due to differences in the inherent chemical composition of the particular cultivars, and it is likely, for example, that SM and ENH contain more available methionine than the others. Apart from explaining the greater amount of dimethyl sulphide produced by these cultivars, this could also account for the greater amounts of methanol produced by the others. This is due to the fact that whilst it has been shown that heating methionine and pectin together produces dimethyl sulphide, heating pectin alone under similar conditions causes hydrolysis to form excess methanol [11]. Furthermore, whilst there was surprisingly good agreement between results for a cultivar (SM) grown over a number of years under as identical conditions as possible by far the most significant difference observed was during one year when the dimethyl sulphide content (normally about 34%) fell to 11% whilst the methanol content (normally about 8%) increased to 32%. This would appear to support a connection between the origins of these two compounds, and possibly during this particular exceptional year for some reason the plants were unable to synthesise as much methionine as usual.

Although as stated above agreement between results for cultivars grown over a period of years was surprisingly good bearing in mind natural climatic variations, there were occasional appreciable differences such as just indicated. Further discussion of such results here is obviously not called for since the fine details of variations in growing conditions cannot be assessed, although from one year to the next plants were grown under as near identical circumstances as possible. The point remains however that it may not have been appreciated before how greatly the chemical flavour composition of such a plant does vary naturally from season to season. This deduction would of course be missed during normal flavour panel work since it is difficult (though not impossible) for panelists to 'remember' exactly a flavour from one year to the next.

From the above series of experiments it was possible to conclude that the better flavoured cultivars were SM and ENH. For this reason all subsequent experiments were conducted on these cultivars, and on only one representative of the less desirable trio (EX).

Variations during a season

This work too would be difficult to accomplish by a routine taste panel and for this reason no supporting sensory results can be reported here.

The cultivars SM and ENH showed remarkably similar behaviour in their seasonal variations so only the results for the former will be quoted. Table 2 gives results for variations in percentage abundances of broad classes of compounds throughout a season. All the plants studied were of comparable maturity, having been sown,

Table 2. Total percentages of groups of compounds from cabbages of varying horticultural history

Horticultural variable		Class of compound							
		Sulphur compounds %	Saturated aldehydes %	Saturated alcohols %	Unsaturated aldehydes %	Unsaturated alcohols %	Ketones %	Isothio-cyanates* %	Nitriles %
(a) Cultivar									
	Summer Monarch (SM)	45.8	19.4	9.1	3.7	5.3	12.6	8.5	4.9
	Elsoms New Hybrid (ENH)	30.7	25.3	8.6	3.5	3.2	15.1	9.1	6.1
	Ennes Cross (EX)	9.5	4.7	42.5	1.1	7.7	9.6	1.2	20.5
	Autumn Monarch (AM)	8.1	4.7	44.5	1.2	3.7	27.3	1.8	6.0
	Winter Monarch (WM)	8.6	2.8	56.5	1.6	2.6	18.1	1.4	3.5
(b) Season (SM)	Early season	29.8	8.4	11.0	16.0	5.6	14.2	15.1	6.5
	Mid season	45.8	19.4	9.1	3.7	5.3	12.6	8.5	4.9
	Late season	6.0	11.3	41.5	4.1	1.9	23.6	1.2	3.5
Season (EX)	Early season	41.7	15.6	9.5	2.5	4.7	9.2	31.0	11.6
	Mid season	9.5	4.7	42.5	1.1	7.7	9.6	1.2	20.5
	Late season	11.6	5.9	17.6	0.8	1.7	11.9	0.8	46.5
(c) Maturity (ENH)	Pre-mature	13.5	3.9	13.6	4.0	5.2	48.7	10.6	2.6
	Mature	30.7	25.3	8.6	3.5	3.2	15.1	9.1	6.1
	Over-mature	6.4	4.4	75.1	0.3	0.8	4.9	2.0	0.3
Maturity (EX)	Pre-mature	10.5	2.8	65.0	0.7	2.2	8.0	0.7	8.0
	Mature	9.5	4.7	42.5	1.1	7.7	9.6	1.2	20.5
	Over-mature	14.4	8.4	49.0	2.1	6.1	7.6	1.7	6.5
(d) Crop spacing (SM)	45 cm	49.2	16.3	3.1	5.0	5.5	8.0	33.0	6.0
	60 cm	45.8	19.4	9.1	3.7	5.3	12.6	8.5	4.9
	75 cm	21.9	9.4	46.0	2.5	8.2	8.2	1.6	2.5
Crop spacing (EX)	45 cm	3.1	1.3	19.1	1.2	0.8	71.9	0.2	2.5
	60 cm	9.5	4.7	42.5	1.1	7.7	9.6	1.2	20.5
	75 cm	2.7	0.6	89.1	0.3	0.4	1.6	0.5	1.5

* Also included under sulphur compounds.

planted out and harvested at set intervals; as a result, the differences observed are due basically to variations within the season. From Table 2 it can be seen that there were a number of interesting trends in variation of chemical composition for SM which would be expected to affect flavour. The mid season cabbages showed a peak for the desirable sulphur compounds and saturated aldehydes which coupled with the minimum for the rather bland flavoured saturated alcohols would tend to represent the best flavoured plants. The lesser trend for the ketones would support this. Considering specific compounds, again the link between dimethyl sulphide and methanol was observed with the former decreasing to a very low 2.5% in late season plants whilst the alcohol increased to an excessive 40%. Allyl isothiocyanate is one of the most important contributors to cabbage flavour, providing a characteristic, desirable 'bite' to the flavour when present in moderate amount. This compound showed a consistent downward trend during a season from a high 13% initially, through about 6% at mid season to less than 0.1% at the end. Again this supports the suggestion of the superiority of the mid season plants in that the early ones would be a little too bitter whilst the late ones would be rather bland. Nevertheless, this is a way in which cabbages of varying flavour strength could easily be produced, possibly even to suit consumer preferences. Allyl cyanide, a less important co-degradation product of glucosinolates with the isothiocyanate, showed the same trend.

Table 2 also gives similar results for EX and, as perhaps might be expected, it did not show the same behaviour as SM and ENH. However, the differences were quite extreme and the desirability of mid season plants does not apply here, in that sulphur compounds and aldehydes decreased markedly after early season, with saturated alcohols showing a peak at mid season. An overall conclusion would be that the satisfying of flavour preferences based on seasonal variations would only be viable when taking into account the particular cultivar as well. The early season EX would have a very powerful flavour with all other later EX plants being rather insipid. It is interesting to note that whilst EX showed the same decreasing trend for allyl isothiocyanate (from a very high 23.5% to 0.1%) as SM and ENH, its allyl cyanide content did not also decrease but actually increased, and to an extraordinary extent (11.5% to 46.5%); this amply confirms the previous flavour strength assertion. Chemically this trend must mean that available glucosinolate did not decrease as the season proceeded, but that there was a change in the balance of the relevant degradative mechanisms.

Differences in maturity

For all three cultivars, plants were examined when not yet mature, when mature, and when almost going to seed. Again SM and ENH showed very similar behaviour, so Table 2 gives results for compound type variations only for ENH. As perhaps might be expected the mature plant showed a peak for generally desirable compounds (e.g. sulphur compounds, saturated aldehydes) and a minimum for less desirable compounds (e.g. saturated alcohols). In addition, this behaviour provides some further justification for the broad distinction into desirable and undesirable groups of compounds in flavour terms in that it would be expected that the mature plant would produce the correct, characteristic balance. For specific compounds, again the link between methanol and dimethyl sulphide was observed with the latter decreasing from 27% to a very low 2.5% from maturity to over maturity, whilst the alcohol increased from 5% to a phenomenal 75%. As a result over-mature ENH cabbages would be expected to be very insipid, and simple tasting trials confirmed this. Allyl isothiocyanate decreased during the series. Acetone was high for the immature plant and again tasting tests confirmed the undesirability of this, although the immature cabbage was rated rather higher than the over-mature, presumably due to the extra flavour provided by the slight excess of allyl isothiocyanate.

Table 2 also gives comparable results for EX. These were quite different from those of ENH (and SM) and overall most groups of compounds varied little through the series. A broad deduction would be that with EX the stage of maturity is unimportant allowing the grower greater flexibility for harvesting. The taste panelists could not distinguish between the three types for EX.

Differences in crop spacing

A normal spacing for cabbages on planting out is 60 cm from the nearest neighbours. To improve yield growers are tending to closer spacings and it has been suggested that this affects resultant flavour. These experiments were designed to test that suggestion. In this instance results for SM and ENH were not as similar as usual but Table 2 gives the figure for SM only. It can be seen that flavour composition did vary significantly with crop spacing and it can be suggested that 60 cm gave about the best results, and tasting tests provided clear cut confirmation. The percentage of sulphur compounds increased with closer spacing, possibly to an undesirably high level. The same behaviour was shown by the isothiocyanates, but in this instance the increase at close spacing was definitely excessive. Tasting tests did confirm the much stronger flavour of the close grown plants.

Saturated alcohols decreased with closer spacings and the high content at the wider spacing did produce a lower flavour strength. Considering specific compounds, allyl isothiocyanate increased from 1% at wide spacing to a very high 24% at close spacing and this was mainly responsible for the variation in flavour strength. It is interesting to compare these flavour strength results with those of Freeman and Mossadeghi who found that cabbages grown under water stress had stronger flavour [6]. In this instance the stress factor was less specific, simply growing the plants rather too close to each other but the result of stronger flavour was the same.

The results for EX are also shown in Table 2, and the overall picture is not as greatly different from SM as usual. Here too, saturated alcohols decreased with closer spacing, although all the figures were much higher, and the wider spaced plants were definitely inferior in flavour. However, although neither the sulphur compounds in general nor allyl isothiocyanate in particular showed the same trends as for SM, the closer spaced EX was also still less favoured but in this instance due to its blander flavour (71.9% ketones) rather than due to high flavour strength as with the SM.

Although in all instances here tasters generally preferred the 60 cm spaced cabbage, there were distinct differences in flavour caused by varying crop spacings and it may well be that many consumers would prefer, for example, the stronger, more bitter flavour of the closely grown SM. This is therefore a very simple method of providing variously flavoured products to suit the market, although again this is only feasible taking into account the particular cultivar.

Table 3. Horticultural variables investigated

(a) Different cultivars
- Summer Monarch
- Elsoms New Hybrid
- Ennes Cross
- Autumn Monarch
- Winter Monarch

(Summer Monarch, Elsoms New Hybrid, Ennes Cross: All three cultivars studied in all expreriments below)

(b) Variations within a season.
1. Early season: sown 22 Feb.; planted out 2 May; harvested end July.
2. Mid season: sown 10 April; planted out 7 June; harvested end August.
3. Late season: sown 15 May; planted out 26 June; harvested end September.

(c) Differences in maturity.
All sown and planted out at the same time (e.g. 4 April, 3 June respectively).
1. Pre-mature harvested end July.
2. Mature harvested end August.
3. Over-mature harvested end September

(d) Differences in crop spacing, ('square' spacing).
1. 45 cm apart.
2. 60 cm apart.
3. 75 cm apart.

(e) Effect of fertilizer, herbicide, pesticide.
Fertilizer used: National growmore (general balance).
Herbicide used: Paraquat; 10 days after planting out.
Pesticides used: Malathion or DDT; 1 month after planting out.

The effect of fertilizer, herbicide or pesticide

Plants were grown with administration of either a fertilzer or a herbicide or a pesticide and results compared with those for plants grown without any such treatment. Various permutations of these additives were also studied. In all instances only very few minor differences were observed in the percentages of flavour components produced, and so results are not quoted here. However, it can be concluded that the use of the three particular agricultural additives selected (all commonly used by growers, see Table 3) does not materially affect the flavour of the product, although obviously this conclusion cannot be extended to other fertilizers, herbicides and pesticides without further study.

EXPERIMENTAL

All the cabbages used in this work were grown specially by the London University Botanical Supply Unit according to specified conditions. The cabbages used were all F_1 hybrids (Summer Monarch, Elsoms New Hybrid, Ennes Cross, Autumn Monarch and Winter Monarch) and were all grown from seed. Seeds were sown outside without protection at the end of March or early April (unless otherwise specified in Table 3). When the plants reached a height of 13–15 cm they were transplanted to their final positions at a spacing of 60 cm square (unless otherwise given in Table 3). The soil type was a relatively thin (*ca* 30 cm) layer of sandy topsoil, overlying the Bagshot sands. Generally, sampling of the plants was commenced in July and finished in October or November. Batches of cabbages were examined weekly, usually according to maturity. 6 plants, with roots intact, were provided for each experimental variable, allowing for at least duplicate analyses and for some selection. Further selection occurred in the field where far more than 6 plants were grown for each variation. If necessary, plants were stored in a cold room at a temp. of 4° but the length of time of storage after lifting from the ground was kept to a minimum and never exceeded 4 days. Table 3 summarises the experiments conducted. All plants were analysed for their volatile flavour components in exactly the same manner, and the techniques employed have already been reported in detail [7–9]. In essence the plants were chopped, immersed in H_2O and steam distilled via a reflux condenser to a U-tube trap cooled in liquid N_2 where the volatile flavour components were condensed. The method is quantitative in that no volatiles are collected in a second trap beyond the first. The sample obtained in this manner always possessed a characteristic cabbage aroma. It was analysed by GLC using a Pye 104 instrument equipped with a flame ionisation detector. Identifications of separated components were achieved by GC–MS, and quantitative assessments of individual components were accomplished by peak area measurements from the gas chromatogram and corrected for response factors of the detector.

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