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I.2 Aroma in Fruit and Vegetables

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INTRODUCTION

Quality of food can be divided into sensory and hidden quality. In the sensory area there is appearance, texture, and flavour. Of these characteristics, appearance is the most important at point of purchase. This is followed by texture and then by flavour, i.e. aroma and taste when the food is consumed (Kramer, 1973). While it has been established that taste is "four dimensional", aroma is much more complex and has many dimensions.

The importance of aroma in fruit and vegetables in relation to consumer acceptability is a matter of debate. For example, there is no doubt that with onions aroma is important, as it is with certain apple cultivars and in wine and fruit juices. It can be countered that aroma of many foods is only of major importance to the flavourist who wishes to blend chemical compounds to produce a flavour and is of secondary importance to the consumer who may buy on price, appearance and texture.

Kazeniac (1977) has pointed out that an important criterion for the success of a food flavour appears to be recognition and compatability of the flavour of the food with flavours familiar to the consumer. The increased interest in home-grown foods offers evidence of changing habits towards natural food flavours. In the UK there are signs that the domestic purchaser is selecting fruit on sensory properties (Williams and Knee, 1977) especially Cox's Orange Pippin apples. However, the position with Golden Delicious is different and both Belgian, British and Irish consumers seem to buy on the basis of colour (Monin, 1974; Centre Français du Commerce Exterieur, 1975; Gormley and Egan, 1977).

This paper reviews some of the work on the identification of aroma compounds in fruit and vegetables, gives an account of aroma related

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studies at Kinsealy Research Centre and touches on other aspects of aroma including off-flavours and aroma in processed foods.

AROMA COMPOUNDS IN FRUIT AND VEGETABLES

The separation and identification of aroma giving compounds in fruit and vegetables is complex, involving gas liquid chromatography (g.l.c.) and mass spectrometry (m.s.) studies and the contribution of the compounds thus identified to human sensory perception is even more difficult to quantify. There is extensive literature on this topic and only some review articles are referred to here.

Von Sydow (1971) suggested a system of odour classification, with 40 odour qualities, and also model correlation techniques using single or multiple correlations. Flavour chemistry in the 1970s has been outlined by Rohan (1972), while Nursten (1975) has discussed the chemistry of flavour, past, present and future.

VEGETABLES

Macleod (1970) has reviewed the chemistry of vegetable flavours pointing out that less attention had been given to vegetables than to fruits, juices and alcoholic beverages. A survey has also been carried out on vegetable volatiles by Johnson *et al.* (1971,a,b). The genus *Allium* contains the most highly flavoured vegetables, i.e. onion, garlic, and chives, and their flavour chemistry has been outlined by Abraham *et al.* (1976) and Whitaker (1976). The most important flavour compounds in the *Allium* species include thiols, sulphides, disulphides, trisulphides, and thiosulphinates. In brassicas, sulphur compounds are again important. Brassicas contain sinigrin which under the action of enzymes can produce allyl isothiocyanate as a potential flavour compound. In blanched products, e.g. frozen Brussels sprouts, the enzymes are destroyed and some of the flavour compounds are not formed. The complexity of the situation in relation to the number of volatile compounds present can be seen as follows; in French beans 24 volatile substances were identified by g.l.c. of which only two seemed to contribute to flavour (Kramer and Fox, 1966); in peas about 80 compounds have been identified (Johnson *et al.*, 1971a), while in tomatoes about 110 have been found (Johnson *et al.*, 1971b).

FRUIT

Information on volatiles in fruit is extensive and Nursten (1970) has reviewed fruit volatiles under the headings of nature of the volatiles and their biosynthesis. He lists 160 different volatile compounds for apples, 56 for bananas, 155 for oranges, and 143 for strawberries. Most of these compounds are acids, esters, carbonyls, ethers, or acetals. He suggested that methanol may come from pectin, branched alcohols from the appropriate amino acids as may aldehydes. Acetals are probably formed from aldehydes and alcohols, organic acids are usually formed from other organic acids or sugars while the formation of esters may be more complex than a straight interaction between alcohols and acids. Salunkhe and Do (1976) have reviewed the biogenesis of aroma constituents of fruits and vegetables.

IMPORTANT VOLATILE FLAVOUR COMPONENTS

With regard to the number of compounds producing aromas in fruit and vegetables, the question arises as to the practical significance of these. This can be approached in two ways; their significance to the flavourist and their significance to the consumer or buyer.

Fruit can be placed in four categories on the basis of their flavour volatiles: (i) fruits whose aroma is largely given by one compound, i.e. a character impact compound; (ii) fruits in which a small number of compounds are involved; (iii) fruits where a large number of compounds are required to reproduce the aroma; and (iv) fruits whose aroma cannot be reproduced even by a large number of compounds (Nursten, 1977). In addition to hydroxy compounds, aldehydes, ketones, acids, esters, and sulphur-containing compounds, oxygen heterocyclics have also been found to be important (Flament, 1975). Pyrazines are important components in vegetables especially those with a methoxyl group (Murray and Whitfield, 1975).

Some foods whose aroma is largely given by one compound or group of similar compounds are as follows: pear (*trans*-2, *cis*-4-decadienoates), cucumber (*trans*-2, *cis*-6-nonadienal), green pepper (2-isobutyl-3-methoxypyrazine), raw potato (2-isopropyl-3-methoxypyrazine), cooked mushrooms (1-octen-3-one), and beetroot (geosmin). In Delicious apples, raspberries, tomatoes and celery, aroma is given by a character impact compound plus a number of other contributory flavour compounds. Williams *et al.* (1977) have shown that 4-methoxyallylbenzene is an important compound in Cox apple aroma.

FLAVOURISTS, FOOD PROCESSORS, AND CONSUMERS

The basic work described above is of considerable significance for flavourists, who are continually seeking new and better synthetic and extracted flavours. It also has application for food processors as it may enable them to modify a process in order to conserve a flavour. Plant production specialists and plant breeders also benefit as they may be able to grow or select for increased amounts of character impact or aroma compounds while the "fresh" food storage expert may be able to improve storage conditions.

When the aroma of a food is due to a character impact compound, correlation with sensory evaluation can be tested by splitting the carrier gas into several streams on exit from the g.l.c. where panelists can smell the aromatics. When a number of compounds rather than a chemical impact compound is involved the correlation with sensory evaluation is more difficult and complex techniques as described by von Sydow *et al.* (1970) must be used. A scheme for establishing the organoleptic importance of the individual components of a flavour in a systematic fashion has been suggested by Parliment and Scarpellino (1977) using modified flavour profile techniques.

Broderick (1974a,b, 1975a,b) in a series of articles on the aroma components in fruits outlines how basic g.l.c. work may assist the flavourist. He lists aroma components identified in the fruits prior to 1952 some of which were used by flavourists. This is followed by those flavour components used commercially but not identified in the fruits. He then describes the additional results obtained since instrumental methods became standard procedures and points out that with apples, research results on aroma to date—for the flavourist—have not warranted the cost. In contrast, the research worker and flavourist have combined forces to produce good banana flavours. With pineapple, researchers have some distance to go before the results are likely to influence commercial pineapple flavours. In raspberries it has been established that α- and β-ionone are present, but flavourists had used ionones prior to their identification. As for strawberries, the extracted volatiles give a poor commercial flavour and the flavour must still be altered to suit the end use. Broderick concludes that the combination of the flavourist and aroma researcher has on balance been rewarding.

AROMA-RELATED RESEARCH AT KINSEALY RESEARCH CENTRE

Aroma-related research is carried out at Kinsealy Research Centre on apples, onions, and mushrooms. Most of the work on apples relates to Golden Delicious as it is the most important apple cultivar in Ireland. However, before giving details of this work it is useful to describe some concepts which are relevant to all food research at Kinsealy.

THE FOOD TRIANGLE, THE FOOD SYSTEM, THE QUALITY SPECTRUM

The food triangle employs the concept of a triangle with food in the centre, and the sides of the triangle representing the consumer, food quality, and human nutrition. While these three aspects are interrelated, a separate emphasis is given to each in all our food research. While aroma is a major aspect of sensory quality and falls on the quality side of the triangle, it must also be looked at from the consumer point of view—in the final analysis what does it mean to the consumer?

The food system is the second concept. Food is produced in a system which is continuous from the soil to the point of consumption and its quality including aroma, can be influenced by many factors along the way. One of the most important influences is intensification—with the motto "Yield Rules All"—being applied and this has resulted in a lowering of quality in some crops.

The third concept is the quality spectrum which is a list of quality factors for a given food in order of importance and also the point in the food chain where each quality factor is important. In this context, aroma of fruit and vegetables is important at the point of consumption and its degree of importance varies according to the cultivar in question.

PRACTICAL AROMA MEASUREMENTS

Because of the high cost of equipment for complex aroma analysis of foods many laboratories must use more practical aroma measurements. Two possible approaches are considered below.

Linking to another index

Taste panels at Kinsealy Research Centre have noted that there is a relationship in Golden Delicious apples between skin colour and aroma. Golden Delicious apples that have developed a degree of blush have a rich aroma while green fruit have little or no aroma. It is possible, therefore, to gain considerable information on aroma through linking it to colour data which is more readily measured. This has only been tested for Golden Delicious and may only apply in Ireland where there is considerable variation in skin colour of Golden Delicious from season to season and within cultural treatments in a given season.

These observations by taste panels were confirmed by selecting four groups of Golden Delicious apples which varied in colour from blush/yellow to yellow to green/yellow to green. The correct placing of the apples in four categories was confirmed by taking Hunter "a" value measurements on each apple on the blush and shaded sides and obtaining a mean for the two values. A different set of four apples was used for each of 12 panelists who were asked to place the apples in descending order from the most to least aromatic, on the basis of smell. The tests were carried out in a dark room where panelists were not influenced by the colour of the fruit. The results (Table I) show the mean Hunter "a" values for the four groups of apples and also the aroma ranking given by the panelists.

TABLE I

Aroma panel rank scores for 48 Golden Delicious apples placed in four categories on the basis of skin colour

Apple category	Hunter "a" values (mean)[a] for skin	Rank totals for 12 panelists[b]
Blush/yellow	+5·1	20 (most aromatic)
Yellow	−3·3	24
Green/yellow	−6·6	29
Green	−8·9	47 (least aromatic)

[a]Skin colour, means for blush and shaded side (Hunter "a" values, red (+), green (−)).
[b]Range for significance, 12 panelists × 4 samples, 21-39 ($P<0{\cdot}05$)

The blush/yellow samples were rated most aromatic and the green least aromatic with the yellow and green/yellow apples also being placed in the correct order. The results confirm the previous observations and suggest that skin colour can be used as a convenient index of aroma in Golden Delicious apples.

It is possible that linking to another index could also apply to other fruits and vegetables, e.g. a high soluble solids (SS) content probably indicates good husbandry and possibly a warm growing season which could also be reflected in a large amount of aroma giving compounds.

Saucepan-cone test system

This system employs a set of four to six stainless steel saucepans each fitted with a lid in the form of a cone. The saucepans, 19 cm in diameter, 10 cm tall, have a cone 10 cm from apex to base. There is a 4-cm aperture at the top of the cone which can be closed or opened by a stopper. This system enables six samples of food to be tested by panelists. A weighed quantity of sample is used and the panel members cannot see the sample. Aroma can be tested at different temperatures by placing the saucepans in a water bath or on a cooker in the case of foods during cooking. This system may have application for the aroma testing of soft fruit, jams, fruit pulps, soups, apples, and cooked foods, either during or after cooking. Samples are normally ranked from the most to the least aromatic or from the most to the least preferred aroma. The system can be used to evaluate the effect of production, storage, packaging, and processing techniques on the aroma of a wide range of fruit and vegetables. Loss of aroma in a given sample over a period of weeks or months could also be tested provided some form of calibration can be devised, possible using a known concentration of a synthetic or natural aroma which is characteristic of the food being tested.

APPLE AROMA

Flavour versus aroma of some apple cultivars/selections

The aroma and flavour of 26 cultivars/selections was compared using aroma and taste panels. Five samples were tested in each of five separate panels with Golden Delicious being included as the sixth sample in each panel (Table II). The samples were tested in December, 1978 (panels 1-5) and again in February, 1979 (panels 1A-5A) after post-harvest storage at 2°C. There were ten panelists in each panel. The apples were smelt unpeeled and were then evaluated for flavour as peeled slices with different codes the following day by the same panelists. Each panelist was asked to rank the samples from most (1) to least (6) aromatic; the rank totals were added and were referred to rank total tables (Kramer and Twigg, 1966; Gormley and Sherington, 1978) to determine statistical significance. In the flavour test each panelist was asked to rank samples from best (1) to worst (6) for flavour and the data analysed as above.

The rank totals in each panel for flavour and aroma were in turn ranked

TABLE II

Apple cultivars/selections tested for aroma, flavour and % soluble solids

Panels 1 and 1A	Panels 2 and 2A	Panels 3 and 3A
Sinta	Empire[a]	Nero 26[a]
Golden Delicious	Melrose	Jonathan
Suntan	Starkspur	Gala
Karmijn	Moss' Seedling[a]	Charden
Ivette	Golden Delicious	Golden Delicious
Kent	Crispin	Goldjon

Panels 4 and 4A	Panels 5 and 5A
Aori No. 1[a]	GD 85
Aori No. 2[a]	GD Smoothee
GD 88	GD C446
Gloster 69	GD 4E-23-10
Idared 68A	Golden Delicious
Golden Delicious	GD Stark

Panels 1-5 carried out December, 1978.
Panels 1A-5A carried out February, 1979.
[a]Tested in December, only. GD = Golden Delicious.

in order of magnitude with the lowest total being given 1 and the highest 6. Results show that there was a good relationship between aroma and flavour ranks for five cultivars/selections and between flavour rank and SS rank for nine cultivars/selections. Close agreement between the ranks for all three factors, i.e. aroma, flavour and SS was found for fruit of the cultivars Empire, Idared and the Japanese selections from Aomori Research Station, Aori No. 1 and Aori No. 2. In the samples tested in February, 1979 a good relationship was obtained between the ranks for aroma and flavour for six cultivars/selections and between flavour and SS ranks for ten cultivars/selections. Close agreement between ranks for all factors was obtained for the cultivars/selections Ivette, Starkspur, Goldjon, Idared, and GD Smoothee. These data suggest that aroma may be contributing significantly to the flavour of certain cultivars. However, this did not apply to all cultivars. These observations are made bearing in mind the limitations of the experiment in that panelists were asked to rank samples from most to least aromatic—and not for aroma preference—whereas they were asked to rank for flavour preference. It must also be recognized that it is not possible to have all cultivars/selections at their optimum for eating at the same time as some have longer high quality storage life than others.

French versus Irish Golden Delicious

A study (Gormley and Egan, 1977) in the seasons 1974-75 and 1975-76 compared the quality of Irish- and French-grown Golden Delicious apples. Samples were purchased at retail outlets in Dublin and the French Goldens were on average 48 and 28% more expensive per kg than the Irish in 1974-75 and 1975-76 respectively. The main quality difference between fruit from the two sources was in colour, the French fruit being green, and the Irish green/yellow to golden.

Thirty one samples were taken in 1974-75 and 27 in 1975-76. Each sample constituted 12 Irish and 12 French Goldens. The data (Table III) show that the Irish apples were yellow/golden in colour while the French apples were green which suggests on the basis of the data in Table I that the Irish apples had more aroma. This was borne out at the time of testing when taste panelists often remarked that the Irish Golden Delicious apples had a pleasant aroma while the green French apples had practically no detectable aroma. Yet, over a total of 58 paired comparison taste panels using peeled apples during the course of the experiment, the Irish apples were preferred significantly on six occasions, the French on nine occasions while on the remaining 43 occasions there was no significant preference. The grand mean SS values for Irish and French apples in 1974-75 were 12·4 and 12·2% respectively and in 1975-76 the values were 13·0 and 12·0%. These data suggest that aroma seemed to have little effect on flavour acceptance and

TABLE III

Mean skin colour[a] data (Hunter "a" values[b]) for Irish and French Golden Delicious apples purchased in November-March, 1974-75 and 1975-76

Month	French	Irish	Month	French	Irish
Nov. 74	−6	+7	Nov. 75	−10	+6
Dec. 74	−9	+7	Dec. 75	−7	+1
Jan. 75	−9	+4	Jan. 76	−8	−1
Feb. 75	−10	+5	Feb. 76	−9	−3
Mar. 75	−5	+7	Mar. 76	−9	0

[a]Measured on blush or most ripe side.
[b]a(−) = green, a = 0, yellow, a(+) = red.

the consumer seemed to be prepared to buy more expensive green French Golden Delicious apples. This may be because consumers equate the green colour with Granny Smith apples imported prior to the Golden Delicious season. The attitude of British consumers to French Goldens is similar (Centre Français du Commerce Extérieur, 1975); they also tend to think of green apples as crunchy and juicy and of yellow ones as over-mature and soft. Because French Goldens are picked at an immature stage they are greener than the Irish fruit. However, under Irish climatic conditions the natural colour for Golden Delicious apples is green/yellow to golden; if allowed to reach this stage of ripeness they will have good eating quality but if consumed when green they are of poor eating quality with little aroma (Gormley, 1975). The results of this study also agree with those from Belgium where a pink flush in Golden Delicious apples was consistent with high eating quality (Monin, 1974). The Belgian study also showed that home-grown Goldens were selling for a much lower price than those imported from France or the Cape.

Soil management and apple aroma

The effect of method of soil management on the quality of Golden Delicious apples was reported by Gormley *et al.* (1973) and it was shown that soil treatments giving high yields, e.g. overall herbicides, gave fruit of lower quality than plots which had been herbicide-treated or clean cultivated for three years followed by grassing down. Testing of fruit from this experiment was continued up to and including 1975 with similar results. The treatments were as follows:

(1) Clean cultivation.
(2) Clean cultivation for three years followed by grassing down.
(3) Overall herbicides.
(4) Overall herbicides for three years followed by grassing down.

(5) Overall herbicides plus straw mulch.
(6) Grassing down from planting time.

The data (Table IV) show mean values for skin colour and yield of Golden Delicious fruit from this experiment over the period 1973-75. The "grassing down" treatments (2 and 4) gave yellower fruit than the overall herbicide treatments and the rank correlation coefficient between skin colour and yield was −0·71. This suggests that fruit from high yielding treatments have less aroma than those from low yielding treatments. This may be related to the leaf/fruit ratio as discussed by Gormley *et al.* (1973). In the seasons 1969-71 and 1973-75 the rank correlation coefficients between skin colour and yield were negative and values ranged from −0·27 to −0·70. These data have application in relation to the effect of "intensification" on quality as discussed above. Gormley *et al.* (1973) have also indicated that yellowness in Golden Delicious apples may be associated with high SS values, so a favourable taste panel response to yellow Irish Golden Delicious apples could be due to a high SS content or a more intense aroma. However, it is more likely to be associated with a combination of both.

TABLE IV

Mean skin colour data and yield for Golden Delicious apples grown under different soil managements (1973-75)

Soil management treatment	Skin colour[a] (Hunter "a", blush side)	Yield (kg/tree)
1	−1·1	48·8
2	+3·2	42·8
3	−3·5	58·2
4	+0·6	41·7
5	−3·4	48·9
6	−1·6	42·1

[a]a(−) = green, a = 0, yellow, a(+) = red

Soil/climate and aroma

A study was begun in 1972 (O'Kennedy and McDonnell, 1974) to evaluate the performance of Golden Delicious apples in seven orchards representing a range of soil and climatic conditions. Data for skin colour (non-blush side), yield and SS over the seasons 1973-75 are presented in Table V; once again there was a high inverse relationship between skin colour and yield indicating that fruit from high yielding trees would have less aroma. The corresponding SS figures also correlated negatively with yield.

These experiments show that Golden Delicious, when grown in Ireland,

TABLE V

Mean skin colour data, % soluble solids and yield for Golden Delicious apples grown at seven different orchard locations over three seasons (1973-75)

Orchard location	Skin colour (C) (Hunter "a", non-blush side)	% Soluble solids	Yield (kg/tree) (Y)
Leixlip	−6·9	14·2	14
Tullow	−8·2	13·1	22
Cuffesgrange	−8·0	13·6	24
Bennettsbridge	−5·0	14·6	12
Piltown	−8·7	13·8	23
Dungarvan	−7·7	13·7	14
Clonroche	−6·9	14·1	10

Rank correlation coefficients: $C \times Y = -0{\cdot}78$
$\% SS \times Y = -0{\cdot}83$

appears sensitive to factors such as soil management, climate, and others. Whereas green Irish GD apples are of very poor flavour with low levels of SS and practically no aroma, if allowed to develop a degree of blush they have an excellent aroma and a high level of SS.

ONIONS

Onions have long been popular and remain widely used. They are usually graded on the basis of pungency and lachrymatory factor. There is extensive literature on the nature, estimation and origin of the volatiles in onions including recent papers by Tewari and Bandyopadhyay (1977), and Freeman and Whenham (1974, 1976). The chemistry of onion aroma will not be discussed here except to note that the volatile flavour compounds are not present in the intact vegetable but are formed by enzyme (alliinase) action on flavour precursors—derivatives of L-cysteine—to give pyruvic acid, ammonia, and sulphenic acid. Sulphenic acid undergoes a further change to give the lachrymatory compound, thiopropanol-S-oxide.

In Ireland onions valued at about £600,000 were imported in 1977 in addition to £35,000 worth of pickled onions. Research at Kinsealy Research Centre (Kenny, personal communication) aims to produce home-grown onions with good pungency and dry matter (DM) characteristics. A DM value equal to or greater than 12% is required for dehydration. Some aspects of this research are outlined below.

Pungency measurement

The Chemical Oxygen Demand (C.O.D.) method of Saguy *et al.* (1970), which has a correlation factor of $r = -0{\cdot}98$ with odour threshold, was used. The method requires that the onion/water macerate be left for 15 min before distillation. However, with many samples it would be convenient to macerate them and distil them in batches. This would result in samples being left standing for different lengths of time between maceration and distillation. Pungency C.O.D. tests on fresh and powdered onions left standing for up to 18·5 h between maceration and distillation show that the C.O.D. figures (i.e. the amount of water soluble reducing substances) increase with time of standing of the onion/water mixture prior to distillation (Table VI).

Standing overnight gave a two-fold increase in C.O.D. value for both fresh and dehydrated onion, and it is therefore necessary to adhere to a definite blending/distillation time interval whether it be 15 min or a conveniently longer period.

TABLE VI

Changes in pungency values (C.O.D. method) with varying time interval between blending and distilling the onion macerate

Interval between macerating and distillation (h)	C.O.D. values (ppm sucrose) Fresh onion	Powdered onion
0·7	1844	1249
2·0	2781	1816
17·0	4235	2990
18·5	4371	2964

Onion pungency—effect of peat and mineral soils

Pungency and dry matter content in onion cultivars grown in peat and mineral soil was tested six times between October 1972 and May 1973 (Table VII). The results show that dry matter (DM) values were suitably high for dehydration and all cultivars had similar pungency values. The effect of soil type was small. However, when the same cultivars and some additional ones were grown in peat in 1973-74 (Table VIII), DM and pungency values were very much lower. The differences between the two seasons were linked with prevailing climatic conditions. These data indicate that a payment scheme relating DM × pungency × ha would be desirable. Extensive tests on the pungency of dehydrated onion powder over a four-year-period showed that cv. Dura gave powder with a mean C.O.D. value

TABLE VII

Mean pungency (C.O.D. method) and dry matter (DM) values for onions grown in peat and mineral soil[a]

Cultivar	Peat soil		Mineral soil	
	C.O.D. (ppm sucrose)	% DM	C.O.D. (ppm sucrose)	% DM
Dura	2370	14·0	2712	15·1
Hygrow	2374	13·1	2236	12·6
Wijbo	2098	12·4	2384	13·3
Produdure	2466	12·7	2085	13·9
Mean	2327	13·1	2354	13·7

[a]Samples tested six times between October 1972 and May 1973.

TABLE VIII

Mean pungency (C.O.D. method) and dry matter (DM) values for onion cultivars grown in peat[a]

Cultivar	%DM	C.O.D. (ppm sucrose)	Cultivar	%DM	C.O.D. (ppm sucrose)
Buan	12·0	1657	Laco	9·9	2167
Hyduro	10·6	1627	Hygro	9·7	1816
Dura	10·8	1451	Wijbo	9·7	1824
Hyprodo	9·8	1860	Robusta	9·5	1859
Solidor	10·0	2027	Augusta	9·5	2004

[a]Samples tested four times between December 1973 and May 1974.

(ppm sucrose) of 1757 compared with 2166 for powder from cv. Robusta. The DM content of the cultivars was in the reverse order, Dura 13·1% and Robusta 10·5%.

MUSHROOMS

Mushrooms, like onions, have long been used to garnish foods. Aroma in the common field mushroom resides mainly in the pileus and also the central portion of the stipe exclusive of the cuticle (Bernhard and Simone, 1959).

Observations at Kinsealy Research Centre have suggested that freshly-picked mushrooms (*Agaricus bisporus*) have a poor flavour which improves during subsequent storage. This was confirmed by a taste panel in which 17 tasters ranked a series of five samples of cooked mushrooms for flavour of age zero, one, two, and three days post-harvest. The mushrooms had been stored at 15°C. The fifth sample was freshly-harvested flat mushrooms. All samples were sautéed in butter. The freshly-harvested sample was significantly downgraded ($P < 0.01$) for flavour, there being no difference between the other samples. In subsequent aroma assessments the panel preferred the aroma of the one- and two-day post-harvest sautéed mushrooms and downgraded that of the zero and three-day post-harvest samples. A combination of the flavour and aroma data above suggests that mushrooms held at about 15°C have an optimum flavour about two to three days after harvest.

OTHER AROMA STUDIES

Finally, other examples where aroma of fruit and vegetables is important are also considered briefly.

FRESH FRUIT AND VEGETABLES

Chill storage will generally reduce rate of loss of aroma. However, while chill storage maintains strawberries in good condition for two or three days as far as appearance and texture was concerned, loss of aroma was very noticeable. This was less evident in raspberries (Kenny, 1975). Certain forms of packaging, e.g. pre-packaging with synthetic films, may conserve aroma.

PROCESSED FRUIT AND VEGETABLES

Blanching results in loss of aroma in fruit and vegetables and may also destroy enzymes which are responsible for flavour development. In canned and dried vegetables, aroma is lost during heating and other odours may develop during the heating process. This does not imply that canned and dried products are inferior, but only that aroma and taste may be very different from those of the fresh fruit and vegetables (Guadagni, 1969). In canned fruits and vegetables the aroma is diluted by the syrup or brine respectively; in food dehydration volatiles are lost during drying, while in frozen foods a gradual loss of volatiles during storage occurs.

FRUIT AND VEGETABLE PRODUCTS

These include vegetable powders, jams, fruit juices, fruit pulps, wine and other items.

The aroma of vegetable powders and pieces (kibble), especially onion, is of particular importance as they are used as flavour ingredients based largely on volatile components (Kenny, 1973). Celeriac (turnip root celery) powder is used as a substitute for celery powder in some countries.

The importance of aroma in jam flavour may be greater than is generally realized. The soluble solids and natural acidity of soft fruit is modified in jam-making by the addition of sucrose and citric acid. The flavour as sensed by the consumer may be largely due to the aroma producing compounds. Bearing in mind that volatiles are lost during the boiling process, more attention should be given to the aroma of new strawberry cultivars/selections intended for jam-making using a simple test system such as the saucepan/cone system described in p. 40. Tests on confectionary jams using artificial flavouring materials (flavour boosters) obtained from two sources showed that in general, amounts recommended for addition were too high. Apricot, raspberry, and blackcurrant flavours were best but strawberry flavours from both sources gave jam with a very synthetic flavour (Gormley, 1973).

Aroma is important in fruit juice flavour and aspects of apple juice flavour have been reviewed by O'Beirne (1976). Kenny (personal communication) showed that apple juices made from Bramley's Seedling, Golden Delicious, Cox's Orange Pippin, and Laxton's Superb apples had low flavour acceptability when consumed individually. Combinations of Bramley's Seedling with other juices gave an improved flavour to the product while the addition of Cox juice gave a blend with a high level of aroma. Aroma is also important in the flavour of wine.

OFF-FLAVOUR

Many of the off-flavours in foods are caused by aroma compounds produced by changes in the food itself or by the interaction of outside agents, e.g. micro-organisms, with the food. A frequent occurrence in fruit is the production of alcohol to give a beer-like taste. Catty taints occur as sporadic outbreaks of objectionable odours in a range of foods including carrots, processed peas, raspberries, lemon juice and others. This off-flavour is due to mesityl oxide which is a contaminant found in solvents and elsewhere and may enter the food-chain in can lacquers, through the use of solvents for solubilizing colours and flavours, and by migration from packaging materials (Spencer, 1969).

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