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Spices—a review of problems and challenges

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This paper will review present and future technical problems in the use of spices, and indicate areas in which there is a need for new research and development studies. It is written from the viewpoint of a member of staff of the Tropical Products Institute, which has two roles to play in the field of spices. Firstly, the Institute has a responsibility to assist the less developed countries to reap the maximum benefit from their renewable natural resources. Secondly, it attempts to assist importers and consumers on problems of continuity of supply and quality of raw material. I will, therefore, be paying particular attention to the problems of primary production.

From the producer aspect, the cultivation and export of spices is of considerable significance. The production of paprika, certain spice seeds, and herbs is a substantial industry for some developed countries in the temperate zones. In many tropical countries, spice production has an even greater role in the economy. Spices are frequently the only cash crop for many farmers in a number of countries in the Third World. The export of spices is very important as a means of obtaining foreign exchange in such countries. Several very small countries are heavily dependent upon spice exports; Grenada and its nutmegs are a prime example. Some of the larger Third World countries also place a considerable emphasis on spice exports. These include India, Indonesia, and China.

In spite of the continuing importance of spices to the economies of many Third World countries, relatively little attention has been devoted to production improvement in recent years; India is perhaps the notable exception. There exists a considerable scope for work on spices by a number of disciplines and, not least, by chemists and biochemists. Perusal of the literature shows that studies of the chemistry of spices between about 1920 and 1960 were at best sporadic and rarely systematic. There are many areas in which an original and useful contribution to knowledge is still possible.

Major problems

Some of the major problems in the subject area call for interdisciplinary action. There are three closely interrelated major areas of concern.

- Achieving improvements in primary production—yields—to ensure a better profit margin for the farmer.
- Ensuring consistent quality of spices supplied to the importer and consumer; and, for certain aspects of quality, achieving higher standards. These last relate to health and safety regulations in the major importing countries.
- Ensuring a continuity of spice supply to consumers. This involves the establishment of new production areas as supplies from traditional sources dwindle.

Improved yields

Production profitability for the farmer is a key factor, and improvements in spice supply and quality will be greatly influenced by advances in this area. While retail packed spices may appear to be comparatively expensive items to the household, production is rarely highly profitable to the farmer in a Third World country. There are two reasons for this. First, in the majority of such countries production is based on numerous small farmers who obtain poor yields. This arises from cultivation of poor yielding strains or the prolonged exploitation of old stock, and from losses through diseases. The cultivation of pepper in India is a prime example of this problem. Even though con-

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siderable effort has been devoted by Indian researchers to the selection of superior cultivars, implementation has been slow. The bulk of Indian pepper is still obtained from very poor-yielding, old vines.

Secondly, there is usually an extended chain of intermediaries between the farmer and the point of export. Each of these takes a cut in the transactions. They, rather than the farmer, make the real profit. Simplification of the marketing chain would be of considerable benefit to the farmer, but this is much easier said then done. Farmers' cooperative marketing ventures have been established in some areas, but experience has shown that these can frequently be very difficult to operate effectively. For many areas, one cannot foresee any radical improvements in internal marketing for years to come.

The most effective means of aiding the farmer, therefore, lies in improvement of crop yields. This requires programmes to select superior cultivars and to determine the optimum cultivation regimes. In these exercises the chemist and flavourist will need to collaborate closely with the agronomist, since it is essential to ensure that the optimum choice is made between yield, disease resistance, and final product quality. It is important for the agronomist to appreciate that very high yields are not always commensurate with high quality. Ginger is a good example of this problem.

Product quality

Traditional quality evaluations involve an assessment of the principal quality determinants, that is, the character and strength of the flavour. For spices such as turmeric and *Capsicum* products it also includes the colour value. These are determined both by subjective and analytical tests. Other factors of importance for some spices include fibre and/or fat contents and, in many cases, physical appearance.

Over recent years, some of these quality attributes for certain spices have deteriorated. One of the contributing factors is that radical changes in social attitudes and economic structure have occurred in some producer countries. Many farmers are now not prepared to carry out traditional spice preparation operations, which demand much care and effort. There is, for example widespread dislike of preparing clean-peeled ginger. In Sri Lanka, it is likely that production of traditional cinnamon quills will become rarer, and that the bulk of future exports will be comprised of roughcut, unscraped cinnamon bark. This trend will only be reversed if the farmer can be offered greater financial incentives to maintain product quality.

Another recent problem comes from the establishment of buffer stocks in some spice-exporting countries. Such stocks were established to control, to some extent, periodic fluctuations in supply and price levels. Jamaican pimento quality appears to have suffered in this way, owing to loss of volatile oil during prolonged storage. A similar problem could arise in the future with pepper, since the member countries of the pepper community are debating a proposal for the establishment of buffer stocks. Studies of the optimum procedures and duration of long-term storage under local conditions are clearly necessary, and would benefit both the producer countries and the consumer.

More recent quality criteria for spices, however, are of greater concern and importance. Standards relating to safety and hygiene of foodstuffs have progressively become more stringent in the major Western countries, and they now embrace spices. The hygiene and safety requirements differ somewhat from country to country, but generally cover limits for contamination by insects, rodent pellets, etc.; residual pesticide levels (less than 0.1 part per million); heavy metal content; bacterial loads and the presence of fungal toxins. (US regulations demand less than 20 parts per billion of aflatoxin and the total absence of salmonella and shigella microorganisms.)

Among these cleanliness requirements, the prevention and treatment of microbiological contamination is likely to receive the greatest attention in the immediate future. Infection of spices by bacteria and fungi mainly occurs between the time of harvesting and completion of drying. On attaining a moisture content of 12% or below, propagation of bacteria and fungi is usually inhibited. Bacterial contamination occurs by contact of the spice with soil, dirty bags, etc. Mould growth is fostered by slow or inadequate drying. These contamination problems can often be minimised by simple modifications to traditional handling techniques. However, for the majority of spices, prevention of contamination will be impossible to achieve in practice, since production is based on small farmers for whom there is no incentive, either financial or visible, to change methods.

Pimento provides a good example of the problem. In Jamaica, the major source of the spice, production is mainly on a plantation basis. The berries are traditionally sun-dried on concrete platforms. Studies by TPI have shown that the berries are effectively sterile on harvesting, and that subsequent contamination can be minimised by avoiding contact with soil and by drying on simple racks in the sun, or by artificial driers. While these innovations could be readily introduced within the relatively well-organised Jamaican production situation, it is difficult to imagine their adoption in the other main source of the spice, Central America. In Honduras, Guatemala, Mexico, and Belize, the harvest is predominantly obtained from wild forest trees, largely by individual collectors. Berries are harvested, placed in a sack, and often carried for several days until a suitable dry patch of level ground is found in a clearing where sun-drying can be undertaken.

Since there are certain intrinsic problems to achieving prevention of contamination with many spices, the problem will have to be solved at the point of export or on receipt in the importing countries. Various treatments are used at present. These include washing and redrying, which is quite effective for removing surface contamination, and sterilization by ethylene oxide. Other techniques under investigation include ionizing radiation. Questions have been posed, however, about the possible side-effects of some of these sterilization treatments. Chemical treatment has been under scrutiny owing to possible problems of toxic residues and of spice flavour deterioration; while fears have been expressed that ionizing radiation might result in detrimental quality changes in some spices—for example, by photolysis of piperine in pepper. Devising effective sterilization techniques for spices is a challenging area, in which the chemist and flavourist will play an important role.

Before leaving the subject of safety aspects, I should mention the question of heavy metal content. Abnormally high levels of lead, zinc, and copper are occasionally found in consignments of some spices and herbs; and the causes of this problem are not clearly understood. Turmeric, for example, is a periodic offender with excessively high lead levels. In the past, this problem would have been interpreted as arising from adulteration practices of some producers. Polished turmeric would be dusted with lead chromate to achieve a better surface colour. The question which we must now ask is whether the problem arises from adulteration or by natural absorption of lead during the growth of the rhizome. Heavy metal uptake by some spices and herbs in relation to cultivation regimes demands greater study.

Spice supply and relocation of production

The spice supply situation is dynamic rather than static, and periodic problems of oversupply and shortages occur. There are a number of causes for these cycles, but I will restrict comment to shortages where a need for development of new supply areas is desired. Turmeric provides an example of where there is a single, dominant supplier to the market—India; and where a poor harvest results in a world shortage. For this spice, the development of alternative sources of comparable quality material would greatly ease the situation.

Ginger furnishes an example of where preferences are expressed by consumers for the characteristics of certain sources for use in particular applications, and where supply problems exist for certain types. Production of both Jamaican ginger, valued for its fine flavour, and of Nigerian ginger, valued as a raw material for distillation and extraction, has declined dramatically. It is questionable whether there will be a recovery. The decline in production in both countries has arisen from social and economic changes. In Jamaica, the competition of the tourist industry for labour has been a factor; in Nigeria, policies of the Marketing Board and the development of the oil industry have contributed to the decline.

In cases such as these, there is a challenge to establish production of comparable material elsewhere, perhaps in areas where the land and people are poor, and spices would provide alternative or new crops. This would not only benefit the local farmer, but could also ensure long-term continuity of supply to the market.

Finding solutions to problems

These problems call for improvement in cultivar selection, preparation, handling techniques, and means of tackling contamination. To progress in these areas, it will be necessary to better understand what constitutes quality, the metabolism of the plant, and the influence of the various stages of production and handling. For many, if not most, tropical spices, available information is scanty and systematic, interdisciplinary work is badly needed.

A key factor to achieving progress is greater fundamental knowledge of the biochemistry and chemistry of the principal quality determinants, and the devising of reliable methods for their monitoring. For spices, these principal quality determinants are one or a combination of the following.

- Content and composition of the volatile oil. (The majority of spices and herbs)
- Content and composition of any pungent principles. (*Capsicum* products, pepper, and ginger)
- Content and composition of any pigments. (Paprika, capsicums, and turmeric)

Our first task is to obtain greater information on the relationships of the composition of these constituents to quality. For spices in which the volatile oil is important, the advent of gas chromatography has facilitated progress in relating volatile oil composition to flavour character. Much remains to be done, however, in making fine distinctions between the characteristics of spices from diverse geographical sources, and of the causes of the differences.

For spices where pungency is important, we have some way yet to go before acquiring both full chemical information and adequate tools for the task. Over the past 15 years, we have learned that the pungency of Capsicum products, pepper, and ginger is produced not by a single compound, but rather by a mixture of related compounds. These are known as capsaicinoids in chillies, piperanoids in pepper, and gingerols in ginger. Furthermore, it has been demonstrated that the constituent members of these groups differ somewhat in their individual pungency values. In the cases of pepper and ginger, some of the pungent principles are labile.

These findings have made us appreciate that there are considerable limitations to the standard physicochemical methods employed to assess the pungency of these spices. To make accurate pungency assessments, it is necessary to identify, synthesise, and to determine the absolute pungency values of these compounds, and of any transformation products. Instrumental techniques must also be devised that will permit resolution of the individual pungent principles and a determination of their relative abundance in samples. Gas chromatography and high-pressure liquid chromatography techniques are being investigated as tools for this problem.

Acquiring more information on the relationship of spice composition to quality characteristics and the devising of superior analytical techniques is, however, only the first stage in product improvement. The spice received and analysed in laboratories of importing countries is the product of a series of transformations, each of which may have a significant influence on final product quality. The factors which contribute to final product properties are as follows.

- The dominant factor is usually the intrinsic characteristics of the cultivar grown. This is widely understood, but there is still much scope for cultivar selection programmes with many spices.
- The stage of maturity at harvest is often the second most important factor, but this is frequently less well understood. Improvements to product quality could probably be achieved for a number of spices by modifying traditional harvesting times.
- The procedures employed for spice preparation and drying can have a considerable modifying influence on product properties. This is often not well understood by producers or consumers.
- The dried product handling and storage regimes are also significant. This is better understood by importers and consumers than by producers.

When striving to make improvements in spice quality, it is, therefore, necessary to identify the relative importance of these various factors; and to monitor changes in the content and composition of the principal quality determinants through all stages of production and handling.

Below are a few examples of the significance of these factors, and of cases where chemical knowledge has made a contribution to product development.

Nutmegs serve as a good example of where instrinsic cultivar differences are the dominant influence on final product characteristics. In the spice trade, nutmegs are categorised according to their geographical origin: East Indian or West Indian. The two types differ in their flavour characteristics. Preferences are expressed by some consumers for one or the other in certain applications. West Indian nutmegs are principally obtained from Grenada, but the original planting stock came from the East Indies. Preparation practices are broadly similar in both sources, and the flavour differences are attributed to evolved cultivar differences and perhaps to environmental effects. Detailed analysis of the volatile oil, the flavour determining component, has shown that quantitative rather than qualitative differences exist between East and West Indian nutmegs. The most significant distinguishing features are the relative proportions of individual monoterpenes and aromatic esters. West Indian oils are low in alpha-pinene, safrole, and myristicin but contain higher amounts of sabinene. The reverse holds for East Indian oils and the myristicin content can be very high: up to 13.5% compared to below 1% in West Indian oils. The monoterpene balance in the West Indian oils accounts for the characteristic turpentine-like note; while the higher myristicin safrole content in East Indian oils is considered to be responsible for the stronger and characteristic flavour of the spice from this geographical source.

The significance of maturity at harvest and the benefits obtainable from its careful control have been demonstrated with ginger. The contents of the volatile oil, pungent principles, and fibre are very important in assessing the suitability of the rhizome for particular processing purposes. The variation in the relative abundance of these components has been carefully studied by the Australian industry. Young, tender rhizomes, lifted 5 to 7 months after planting, contain a mild flavour and a low fibre content. At this stage the rhizome is preferred for the preparation of preserved ginger. As the season progresses, the relative abundance of the volatile oil, pungent principles, and fibre steadily increases. At 8 to 9 months after planting, the volatile oil and pungent principle contents reach a maximum. Thereafter, their relative abundance falls as the fibre content continues to increase. The Australian industry has applied this knowledge to good effect. When a dried ginger with a high extractives content is required for use as raw material for ginger oil or oleoresin preparation, rhizomes are lifted at 8 to 9 months of age. Material from the later harvest is used for the preparation of the ground, dried spice.

This work on ginger has stimulated a reappraisal of maturity effects on several spices, and a questioning of whether traditional harvesting times should be modified to provide products with specific desired characteristics. Similar variations in volatile oil and pungent principle contents according to berry maturity have been found with pepper; this has explained the high extractives content of Sri Lankan pepper. In Sri Lanka, pepper farmers often pick their berries earlier than in other countries in order to avoid theft from the vine or to obtain ready cash. This early harvesting corresponds to the period when the extractives content is highest.

Recent studies in India have also suggested that the curcumin content of turmeric is strongly influenced by the stage of maturity at harvest, and that a better quality product could be obtained by closer control of harvesting time. It is rather surprising that these studies were not done much earlier, since the influence of maturity on the volatile oil and pigment contents of a closely related species, *Curcuma xanthorriza*, had been reported in 1939. Studies of maturity effects with other spices might also prove to be of practical value.

The influence of preparation and handling techniques on final product quality has also been demonstrated with ginger. For example, investigations of the chemistry of the gingerols has shown that undesirable transformations of these pungent principles can occur under relatively mild conditions during drying of the spice. If a product with a high pungency is required, careful control of the drying temperature is necessary, and it is preferable that the fresh rhizome be dried sliced rather than whole, since this reduces drying time.

The physical form of ginger preparation also has a significant influence on volatile oil content. The oil cells are located close to the skin of the rhizome and can be damaged during peeling. This results in a loss of oil and also in some changes in the balance of oil constituents in the final product. Therefore, when a dried ginger with a high volatile oil content is required, the rhizome should not be peeled.

Vanilla furnishes an example of where detailed biochemical studies have led to radical developments in preparation methods. Green vanilla pods are substantially odourless when harvested, and the flavour is not developed until enzyme action is stimulated by the curing process. The traditional curing procedures developed in Mexico and Reunion involve complex operations of killing the bean, sweating, sunning, and conditioning, which are very labour intensive and take up to six months to complete. During the late 1940s, the United States Department of Agriculture Federal Experimental Station in Puerto Rico undertook a very thorough investigation of the biochemistry of vanilla flavour formation, which provided a foundation for development of modified preparation procedures. Subsequently, accelerated mechanical curing methods have been devised by the McCormick Co. in the United States and by the Vanilla Research Institute in Madagascar. These methods have reduced labour input and preparation time considerably.

Future challenges

I will now list some gaps in knowledge for some individual spices. These are varied in nature and importance, but they serve to illustrate the potential for further work.

Pepper, capsicum products, ginger–the pungent spices

The principal need here has already been mentioned: the requirement for a full characterisation of the pungent principles and reliable methods for their analysis. Progress on these subjects will permit a better assessment of the significance of the various stages involved in production on the final spice quality. For ginger and pepper, a closer examination of post-harvest effects on pungency would be of considerable value. For *Capsicum* products, which include chillies, capsicums, and paprika, a study of qualitative and quantitative differences in the capsaicinoids could be of interest for chemotaxonomic purposes. These three spices also contain volatile oil, which contributes to the overall flavour, and further studies of their oil composition would be of interest.

With black pepper oil and ginger oil, the characterisation of the composition according to geographical source and correlation with acknowledged flavour differences is still imperfect. Furthermore, the influence of differing preparation procedures on volatile oil composition and flavour is still unclear. For example, Brasilian black pepper is considered to be blander in flavour than Asian pepper. Is this due to cultivar differences or to the fact that artificial driers are used in Brasil while traditional sun-drying is practiced elsewhere? In the case of ginger, both Australian and Indian material possess a pronounced lemony note when fresh, but when dried it is much stronger in the Australian product. Is this simply a consequence of more carefully controlled drying procedures in Australia?

Relatively, little attention has been devoted to study of the volatile oil of *Capsicum* species. The limited information available relates to the larger fruited varieties of *C. annuum;* and there is some controversy over the occurrence of pyrazines, which one group claims is responsible for the characteristic aroma.

Turmeric

This spice requires a greater study of the changes in pigment content and composition during maturation, and during the various treatments employed for preparing the spice. One of the greatest practical challenges with this spice is to devise a cheap but effective alternative to the boiling step of the preparation operation. The fresh rhizomes are usually boiled for an hour or more, prior to sun-drying. This is believed to help in evenly distributing pigment throughout the rhizome, and gelatinising the starch, which accelerates subsequent drying and resistance to insect attack. Turmeric is a relatively low-priced spice, and the need for expensive firewood during preparation reduces production profitability. An alternative approach would be highly desirable. The volatile oil present in turmeric has received some attention; but studies of the relationship of its composition to spice flavour, and of the effects of preparation procedures are needed.

Pimento

This spice is a product of the Caribbean region. Its flavour is mainly imparted by its volatile oil. The oil composition and the variations according to area have been fairly well documented for the Jamaican spice. However, very little information has been published on the characteristics of the Central American spice, which possesses a rather different flavour. Pimento also contains some pungent principles, which contribute to the flavour, but these have not yet been fully characterised.

Cloves

The characteristic flavour of this spice is produced by the steam-volatile oil. The chemistry of the volatile oil has received sporadic attention, but there has been little published information in recent years. Several aspects have yet to be fully explained. These include a thorough study of the relationship of volatile oil composition to flavour properties; changes in composition during maturation of the bud and during storage; and qualitative and quantitative differences in composition between different sources of the spice.

The question of the relative importance of the cultivar and of storage changes on flavour are currently of interest in Indonesia. This country consumes over 50% of the world production of cloves. The spice is used as an ingredient in locally manufactured cigarettes. In recent years, Indonesia has been attempting to achieve self-sufficiency in clove production, since imports from Madagascar and Zanzibar are a drain on foreign exchange. However, consumers find the flavour of the locally grown cloves less acceptable than that of the imported spice. The reasons for this flavour difference have not yet been established, but we believe that changes in the volatile oil composition, particularly ester hydrolysis, during the period of storage and shipment of imported cloves are responsible.

Cinnamons and cassia

The chemistry of the cinnamons and cassias has been a subject of fairly extensive, if somewhat uneven, attention since the nineteenth century. The characteristic flavour of these spices is mainly determined by their steam volatile oils. True cinnamon *(C.verum)* has been studied most extensively, Chinese cassia *(C.cassia)* rather less, while Vietnamese cassia *(C.loureirii)* and Indonesian cassia *(C.burmannii)* have been only superficially studied. In all four cases, varying gaps in knowledge exist. These include the relationship of volatile oil composition to flavour character; changes in composition during maturation, preparation and storage; and variations in composition between different sources of a given spice.

For example, even with true cinnamon, no studies of volatile oil composition differences between Ceylon and Seychelles cinnamon, which possess very different flavours, have been published recently. In the case of Chinese cassia, information is largely limited to the cassia oil of commerce, obtained by distillation of leaves and twigs. Little data is available on the spice oil composition.

Vanilla

Vanilla remains an active field of interest to the chemist. Some 170 aromatic components have now been listed in the literature. Of these numerous components only about 25 are present in concentrations greater than 1 ppm in the beans. However, the Bourbon type of true vanilla is the only one which has yet been studied in any great depth. Comparable studies of Mexican true vanilla and of Tahitian vanilla *(V. tahitensis)* and Guadeloupe vanilla *(V. pompona)* are awaited.

Cardamom

Cardamom is an interesting spice in that the colour of the fruit capsule is regarded an an important quality criterion by some consumers, particularly in the Middle East, although it contributes nothing to the flavour. The flavour is imparted by the volatile oil present in the seeds. This association of capsule colour with quality has arisen from the fact that colour fading closely parallels loss of flavour by evaporation during storage. Hence a premium is offered for cardamoms possessing a uniform deep green colour, and producers are striving to develop methods for retarding colour fading.

The chemistry of the pigments present in the capsule has received little attention. The major pigment is assumed to be chlorophyll, and fading is thought to be analogous to that of peas and other green vegetables. Consequently, a number of treatments have been tried to retard cardamom colour fading. The most promising involves washing the capsules in aqueous sodium carbonate. Further studies are required on this subject, and should include investigation of pigment composition.

Other spices and herbs

Many additional examples of needs for research could be given for other spices and herbs which are important in international trade. However, it might be of interest if I listed some rather less well-known spices, which are of significance in regional trade, and where there are interesting problems for the chemist.

"*False cardamoms.*" Numerous species are closely related to the true cardamom. These include the *Amomum* species of Asia and the *Afromomum* species of Africa. In general, the information available on these spices is very limited. With the Asian *Amomum* species, the flavour is mainly imparted by the volatile oil, which is thought to be qualitatively similar to that of true cardamom. The compositions of a number of these spices have yet to be definitively established. The Bengal cardamom, *Amomum aromaticum*, for example, appears to have been examined last by the Schimmel Co. in 1897. The *Afromomum* species of Africa are particularly interesting in that a number contain pungent principles in addition to volatile oil. The "Melegueta pepper" or "Grains of Paradise" *(Afr. melegueta)* has recently been shown to contain pungent principles related to those of ginger. A dispute exists, however, over whether gingerols or paradols predominate. Pungent principles are also present in the Madagascan cardamom *(Afr. angustifolia)*, but these have not been identified.

Xanthoxylum alatum or "Chinese pepper" is another spice, grown in the Himalayas, which possesses an interesting combination of volatile oil and pungent principles. This also has not been examined in any depth.

False nutmegs. Papuan nutmeg *(Malabrica argentea)* and Bombay nutmeg *(M. malabrica)* are additional interesting oddities that have received comparatively little attention.