MONOGRAPHS ON TEA PRODUCTION IN SRI LANKA
No. 7

FACETS OF TEA RESEARCH IN PRACTICE

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FOREWORD

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It is not often that practitioners of the Arts or the Sciences have the time or the will to convey to the public their findings in their areas of specialization. There was a time, especially in our Colonial past, when the heads of our Institutions did produce writings which sometimes came to be regarded as treatises on the subject. There are good examples of such endeavours in Agriculture, Irrigation and Archaeology.

It is therefore commendable indeed that Dr. R. L. Wickremasinghe, Director of the Tea Research Institute of Sri Lanka has found both the time and will to put down in a manner which would be of interest not only to the research student to whom in fact it is intended but also to the general reader his findings of a lifetime of work in Tea research.

The Tea Research Institute of which Dr. Wickremasinghe is now Head, has an enviable reputation internationally as an institution which has upheld the highest standards of integrity in scientific research. The people of Sri Lanka – and who amongst us can remain untouched by Tea, either as producer or consumer – have acknowledged the value of the work done by the Tea Research Institute. Particularly noteworthy have been its development of the vegetatively propagated clone and the improvements in technology which have contributed to the unique quality of Ceylon Tea. Dr. Wickremasinghe's book therefore, describing some aspects of Tea Research in practice should be of undoubted interest and value to all who are acquainted with Tea in one way or another.

Dr. Wickremasinghe clarifies for the layman the alluring terms of the Tea Taster – "bold", "neat", "stylish", "creamy" and so on – and gives us the bio-chemical reasons as to how the Tea we drink derives its characteristics of quality, strength, flavour and colour. He has a section on the therapuetic value of Tea which deserves to be widely known at a time when many beverages compete for the palate of the consumer. He concludes with a survey of the prospects for Tea products in new forms and a look at the future possibilities for Tea, which in a nation which is still dependant largely on earnings from Tea for its future prosperity, gives us hope for optimism.

I greatly appreciate the opportunity accorded to me of writing a Foreword to this valuable addition to our literature on Tea and express the hope that this example will stimulate other specialists in similar disciplines to publish their findings in their particular areas of work.

Signed **Bradman Weerakoon**
Secretary

Ministry of Plantation Industries

INTRODUCTION

Tea undoubtedly originated in China where its legendary history dates to as far back as 2737 B. C., although the earliest mention of tea is found in Erh Ya, an ancient Chinese dictionary of 350 B. C., and the first monograph on tea (Cha Ching) was published by Lu Yu in 780 A. D. Several centuries later, in 1559, tea (chai cattai) was brought to the notice of Europe by Gian Battista Ramusio, the noted Venetian writer, although the first reference to tea in England was by R. L. Wickham in 1615. At that time, coffee was the sole beverage known to Europe, and it was only in 1657 that the first tea packet was sold in Galways Coffee House in London. Subsequently, in 1684, J. I. L. L. Jacobson, a Dutch tea taster, penetrated the well-guarded and forbidden tea gardens of China, and at great personal risk, transferred some of the tea seeds to Indonesia and so was broken the monopoly of China in tea production. About 100 years later, in 1784-1789, tea drinking became widespread, and the first authenticated attempt to commercially cultivate tea in India followed the discovery by Major Robert Bruce, in 1823, of tea growing wild near the Sibsagar District in Assam, whence it found its way in 1839, to the Botanical Gardens, Peradeniya. Thereafter the story is well-known that following the devastation of the island's coffee plantations by *Hemilia vastatrix,* James Taylor, in 1867, demonstrated at Loolecondera that tea was a profitable alternative plantation crop.

Since that time production has steadily increased to the extent that it is now the major export commodity, and Sri Lanka stands second only to India in the world tea export market. Its position in relation to other tea producing and exporting countries for the period 1972-1974 is indicated in Table 1, from which it is seen that

TABLE 1

AVERAGE ANNUAL PRODUCTION AND EXPORTS OF TEA FROM DIFFERENT COUNTRIES FOR THE PERIOD

Country	**Production**	**Exports**
A. Net Exporting countries		
Far East and oceania	784	482
India	473	225
Sri Lanka	210	190
Indonesia	64	41

Country	Production	Exports
Bangladesh	28	22
Others	9	4
Africa	157	138
Kenya	54	48
Malawi	23	22
Mozambique	18	18
Uganda	22	20
Tanzania	13	10
Others	26	20
Near East	44	17
Turkey	44	17
Latin America	35	26
Argentina	27	20
Others	9	6

B. Producing - Importing Countries

Japan	91	
South Africa	2	
Iran	23	
Malaysia	3	
U.S.S.R.	74	
World Total	1213	663

Figures in 1000 metric tons, according to F.A.O., 1976.

34% of world tea was supplied by Sri Lanka during that period. The acreage under tea in Sri Lanka is about 270,000 hectares, distributed at elevations ranging from almost sea level to more than 2000 metres. Over 85% of this acreage is under relatively old tea, which has been raised from genetically heterogeneous seed, and referred to as "seedling tea". The remaining 15% or so is under vegetatively propagated tea, referred to as "clonal tea", which has been propagated from single node leaf cuttings, derived from selected "mother bushes" showing the desirable attributes of high yield, quality, resistance to pests and diseases, tolerance to drought, etc. Commercially cultivated tea is believed to have arisen by natural hybridization between at least three main types of tea, and controversy still exists among taxonomists as to whether it should be assigned to the family Camelliacea or Theaceae.

There are two main types of processed tea leaves, *viz.* "green" tea and "black" tea. In Japan, the famed tea ceremony (Cha-No-Yu), dating from the 14th-15th century, revolves round the former but green tea, although of greater antiquity, has now been outstripped in commercial importance by black tea. The differences between black and green tea lie in the choice of variety of tea used, and the conditions of processing. In black tea production the variety of tea preferred is *Camellia sinensis* var. *assamica*, which has comparatively large leaves, whereas the best green tea is made from *Camellia sinensis* var. *sinensis*, where the leaves are very small. Chemically, the major difference is that the ratio of astringent compounds to nitrogenous compounds is higher in var. *assamica* than var. *sinensis*. With regard to the differences in processing, the principal stages of manufacture of black tea are harvesting, withering, rolling, fermenting and grading. Profound chemical and biochemical changes occur during each of these stages, and these will be discussed later. In green tea manufacture, the main stages are harvesting, steaming or "pan firing", rolling, twisting and firing, and every effort is made to exclude fermentation. Two other types of tea, oolong and paochong, are made in Taiwan - these are akin to black tea, from which they differ mainly in the shorter period of fermentation, oolong being fermented for half, and paochong for quarter of the period generally used for the processing of black tea. The pickled tea of Burma and brick tea of Russia are also produced in small amounts to cater to local markets, while instant tea is the subject of active research at the present time. The teas produced throughout the world, even under the same processing conditions, differ from each other, depending on jat used, climatic and soil conditions, method of cultivation, type of fertilizer, applied, nature of shade, type of machinery available etc., and as was first observed by Lu-Yu in 780 A. D., it is still true to say that "there are a thousand and ten thousand teas".

CHAPTER 1

THE TEA TASTER AND THE COMPOSITION OF TEA

It is well-known that tea is a unique beverage, but only few are aware of the factors which contribute to this uniqueness. Included among these factors are the chemical composition of tea leaf and the fine details of processing to the final product, both of which are of equal importance–that it is to say, tea leaf of unsuitable composition cannot be made into a good tea, however careful the processing, and faulty processing cannot, under any circumstances, yield a good tea from even the finest leaf. It is, therefore, necessary to first know the chemical composition of the various parts of the tea bush, and the present state of knowledge is outlined in Table 2,

TABLE 2

CHEMICAL COMPOSITION OF TEA

		Green	*Mature*	*Mature*		
	Flush	*Stem*	*Leaf*	*Stem*	*Root*	*Seed*
Polyphenolic compounds	(++)	(+)	(+)	(+)	(+)	(?)
Amino acids	(++)	(+)	(+)	(+)	(++)	(+)
Organic acids	(+)	(+)	(+)	(+)	(?)	(+)
Caffeine, theobromine	(++)	(+)	(+)	(+)	(+)	—
Mineral elements	(+)	(+)	(+)	(+)	(+)	(+)
Saponins	(+)	(+)	(+)	(+)	(+++)	(+++)
Nucleotides	(+)	+	+	+	+	+
Non-saponifiable material	(+)	(+)	(+)	(+)	(+)	(+)
Lipids and fatty acids	(+)	+	+	+	+	+
Volatile compounds	(+)	(+)	+	+	+	+
Chlorophyll	(+)	(+)	(+)	(+)	—	—
Carotenoids	(++)	(+)	(+)	(+)	(+)	?
Proteins	(++)	(+)	+	+	(+)	(+)
Polysaccharides	(+)	(+)	(+)	(+)	(+)	?

Signs denote relative quantities.
Bracketed signs indicate that these have been closely studied.
? unknown.

from which it is seen that tea flush contains high levels of polyphenols, amino acids, caffeine and theobromine, carotenoids, and proteins, all of which play an important part in determining the unique tea character.

The ultimate criterion of a "good" tea is, however, the price it fetches at the tea auction, and this price is determined by market trends and the subjective assessment of expert professional tea tasters. In assessing the value of a tea, some of the properties which these experts take into consideration are appearance of the made tea, colour of the infused leaf, as well as colour, strength, quality, aroma and flavour of the liquor. Each of these properties needs to be considered separately, as they are each dependent on completely different sets of chemical and biochemical parameters. It will also be evident from what follows that the standards of the specialist taster are intimately related to the specialized biochemistry of the tea leaf.

Appearance of a processed tea

A processed tea which is described as "black" is more highly valued than one which is "brown", and it was found by chemical analyses that this difference in appearance was determined by the manner in which the leaf chlorophyll was broken down during processing. Chlorophyll is a large and somewhat complicated molecule with the structure shown in Figure 1, but, fortunately,

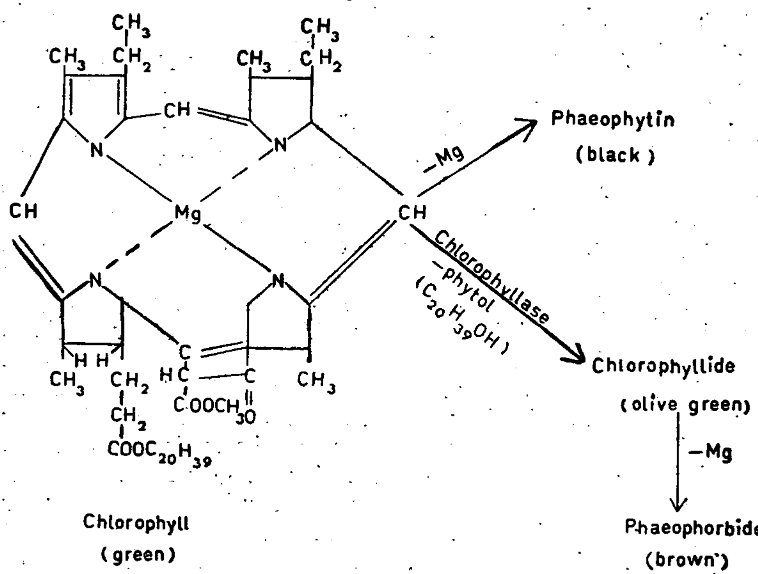


FIGURE 1—*Chlorophyll and its Breakdown products*

only three of its components need to be considered here. These three components are the central magnesium atom, the long attachment (C_{20} H_{39} side chain, commonly known as leaf alcohol or phytol), and the main skeleton, which is porphyrin. There are two possible ways by which this complicated molecule may be broken down during tea processing, and these are included in Figure 1. The first of these is loss of the magnesium atom to yield a compound known as phaeophytin, which is black in colour. This loss of magnesium occurs readily in the acidic conditions of fermented leaf, when it is heated to the temperatures used in "firing" tea. There is, however, an alternative method of chlorophyll breakdown, where an enzyme (known as chlorophyllase) removes the phytol to yield an olive-green compound known as chlorophyllide. This enzymic conversion occurs during rolling and fermentation, but on firing, chlorophyllide itself loses its magnesium atom to yield a compound known as phaeophorbide, which is brown in colour. It follows, therefore, that the appearance of a processed tea will depend on the relative proportions of black phaeophytin and brown phaeophorbide, a preponderance of the former yielding a black tea, and the latter a brown tea.

Based on the above consideration, it becomes evident that the two principal requirements for the production of a black tea are firstly, flush with high chlorophyll content (*i.e.* dark green in colour), and secondly, conditions where chlorophyllase activity is minimized. With regard to the former, it is common knowlege that dark green tea flush (*e. g.* low grown tea) yields a black tea, and that pale green flush invariably results in a brown made tea. Some of the conditions which determine the degree of greenness of tea flush are the climatic conditions, the presence or absence of shade trees, fertilizer application, and genetic characteristics of the tea clone. The effect of climate is evident in the observation that high grown teas have less chlorophyll than low-growns, due to the effect of lower temperature and of the quality of the light, especially when conditions are dry. Tea grown under shade is darker green than tea without shade, probably because the plant is obliged to produce more chlorophyll in order to compensate for the reduced availability of light. Lack of adequate fertilizer limits the amount of chlorophyll that can be made by the plant, resulting in the formation of etiolated, pale green, leaves. It is also a common observation that clones differ in their capacity for chlorophyll production, and that certain clones (*e.g.* DT 1, CH 13) always yield light green flush, irrespective of the conditions of growth, whereas other clones (*e.g.* TRI 2025, DN, DG) yield dark green flush in optimal conditions of growth. Given dark green leaf, careless manufacture, (*e.g.* excessive withering or rolling, over-fermentation, under-firing) can still lead to a brown made tea, and the taster's preference for a black tea therefore serves as a criterion of good manufacture. It is, however, observed that tea processed from mature leaves, which are dark green is, nevertheless, brown. The reason for this apparent discrepancy is the high chlorophyllase activity of mature leaves, which leads to a preponderance of brown phaeophorbide in the fired tea. The phenomenon of seasonal brownishness is also due to chlorophyllase activity, which is known to show seasonal fluctuation. Such seasonal increase in chlorophyllase activity may vitiate the results of good field practice and good manufacture, and it is fortunate that this phenomenon occurs only rarely. On the basis of the above considerations, an obvious way of increasing blackness would be to find an acceptable means of specifically suppressing the activity of chlorophyllase, but the search for such a compound has, up to now, been fruitless.

All of these observations serve to support the contention that the appearance of teas is influenced by chlorophyll content and chlorophyllase activity, and fit in neatly with the procedures necessary for making "tippy" teas. The colour of both silver and golden tips is due to the low content of chlorophyll in the bud, which precludes the formation of either black phaeophytin or brown phaeophorbide. In this connection, the suitablility of buds of clone TRI 2043 for the production of tippy teas is due, not only to their pubescence and length, but also to their negligible content of chlorophyll. Consequently the drying of these tips does not result in a black or brown appearance, but yields a silvery tip. In golden tip, the appearance is again due to the absence of chlorophyll breakdown products, but the burnished effect is due to a coating of golden coloured theaflavins, an important class of compounds which will be discussed later. In both silver and golden tip production, it is desirable that light coloured buds be used, and that the temperatures of drying be kept to the minimum possible, (certainly below that used for the firing of dhools), in order to minimize the formation of chlorophyll breakdown products. Exposure to sunlight, or ultra-violet light, will also be beneficial on account of their bleaching effect on the small amount of chlorophyll present in buds.

It will be evident, therefore, that the professional tea taster's preferences for appearance are not a mere fad, but an indirect, yet sound, way of ensuring good standards of cultivation and manufacture of tea growing under defined conditions. The effect of elevation in producing brownish teas is, of course, unavoidable, but here other desirable factors, such as quality, serve to offset the lack of blackness. As we shall see later, the vigorous growth that often accompanies a high chlorophyll content is, in fact, incompatible with quality.

Colour of infused leaf

The desired colour of infused tea leaf is, in tea taster's parlance, "Coppery", and increasing greenness detracts from the commercial value. Here again, chlorophyll and its breakdown products are important, but the additional effect of theaflavins and similar compounds (to be described later) is superimposed.

The greenish nature of infusions is due to the presence of chlorophyllide which has already been mentioned (Fig. 1) as a product of the enzymic breakdown of chlorophyll. Copperriness, on the other hand, is due to the absence of chlorophyllide, and the presence of theaflavins which, as will be seen later, are derived by the oxidation of polyphenols during fermentation. Various intermediate grades of "coppery-green" infusions are, as may be expected due to mixtures of chlorophyllide and theaflavins in varying proportions. It follows, therefore, that flush with a low content of chlorophyllide (*i.e.* low chlorophyll or low chlorophyllase activity) and high theaflavin content will produce teas which give coppery infusions, although the appearance of the made tea may be brown, *e.g.* as in high grown teas of good quality. The tea taster's preference for coppery infusions is, therefore, an indirect means of gauging the efficiency of theaflavin formation during manufacture, and a dull infusion is the penalty of over-fermentation or of insanitary conditions of processing, when the theaflavins formed will be either over-oxidized to other undesirable, muddy coloured compounds, or combine with microbial contaminants and become unavailable. It is here necessary to mention that certain tannins (identified as chebulagic acid and corilagin) are present in some clones of tea (*e. g.* TRI 2025), but absent from others (*e. g.* TRI 2023), and their formation in the bush is favoured by conditions of rapid growth, as in the low country. Tannins inhibit the activity of all enzymes including that which is responsible for the production of theaflavin (page 11) and hence infused leaf is greenish in their presence. The adverse effects of tannins, may, however, be neutralized by the addition of protein (*e. g.* gelatine) as described on (page 30), and is the basis of a method which has been developed for up-grading the quality of low-grown tea.

Quality

Great emphasis is laid on quality in the tea taster's assessment of tea, and this is rightly so, because quality is determined by a complex of parameters, the correct balance of which is essential for the unfolding of the quintessence of tea character. More remains to be learned of the nature of these parameters, but there is evidence that they include the relative amounts of the different polyphenols, theaflavins, polyphenoloxidase activity, and the contents of caffeine, protein, and an amino acid known as theanine.

All of these compounds contribute to quality in a positive way, but there are also other compounds which detract from quality, *e. g.* sulphur-containing amino acids, tannins, and certain aldehydes, and it is the overall effect of these competing parameters which is assessed by the tea taster. It is necessary that each of these factors be examined separately, and when this is attempted, the various theaflavins, polyphenoloxidase activity and catechins (a type of polyphenol) need to be considered together, because these are inter-related in the sense that catechins are oxidized to theaflavins by the action of polyphenoloxidase, in the presence of oxygen.

$$\text{Catechins} \xrightarrow[\text{+ Oxygen}]{\text{Polyphenoloxidase}} \text{Theaflavins} + CO_2$$

This is one of the most important and dramatic reactions which occurs in the processing of black tea. It begins as soon as the tea leaf is damaged in any way, (*e. g* rough handling, frost, mite attack, rolling) and continues throughout fermentation, as well as the first 5–10 minutes of firing. Some of the basic characteristics of the oxidation reaction are,

(1) Oxidation occurs only in the presence of oxygen and, therefore, air (which is composed of about 20% oxygen) is necessary for the reaction—experiments have shown that no theaflavin is formed in an atmosphere of nitrogen.

(2) Theaflavin formation is optimal at 28-34°C. Temperatures above or below this range result is decreased theaflavin formation and

(3) theaflavin formation is optimal at pH 5.8-6.2, which is approximately the pH of the leaf.

Apart from these three basic characteristics, there are, however, a number of other factors which influence theaflavin production, and a somewhat deeper insight into tea biochemistry and the nature of tea catechins, theaflavins and polyphenoloxidase is necessary for an appreciation of these factors.

Catechins and Theaflavins

Catechins are the raw material from which theaflavins are formed, and Table 3 lists the 6 catechins which occur in the flush plucked for processing. The relative amounts of these catechins show

TABLE 3

THE CATECHINS OF TEA FLUSH

		Amount in flush (% dry wt)
(—)	Epicatechin	1–3
(—)	Epicatechin gallate	3–6
(—)	Epigallocatechin	3–6
(—)	Epigallocatechin gallate	9–13
(+)	Catechin	1–2
(+)	Gallocatechin	3–4

variation with season, elevation, agricultural practices employed, maturity of leaf, etc., and their steep decrease as the flush matures is one of the reasons which makes mature leaf unsuitable for tea manufacture. Catechins themselves belong to a group of compounds known as "polyphenols", and the reason for the term "polyphenols" will become evident on glancing at the chemical formulae (Fig. 2) of phenol (carbolic acid), which is classified as a monophenol because it contains only 1 phenolic (OH) group, catechol

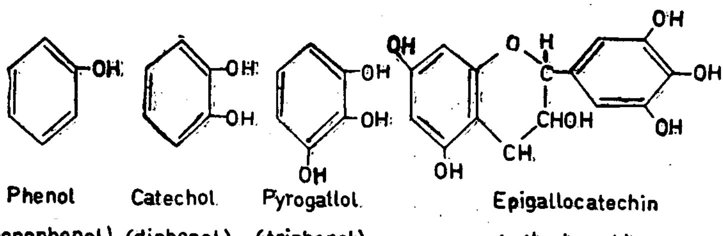


FIGURE 2—*Phenols and Polyphenols*

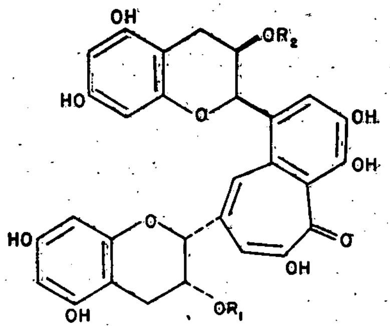
which contain 2 phenolic groups is a diphenol, while pyrogallol with 3 OH groups is a triphenol, and the catechins which contain several phenolic groups are designated as polyphenols. The reason for the prefix (-) epi is not discussed here, and the chemical nature of the other tea polyphenols, are likewise not considered, although it may be useful to learn that these are known as quercetin, kaempferol, quercetin–3–rhamnoglucoside (rutin), kaempferol-3-rhamnoglucoside, kaempferol-4-rhamnodiglucoside, leucoanthocyanins (2-3%), gallic acid, chlorogenic acid, p-coumaryl-quinic acids, theogallin (about 1%),ellagic acid, corilagin, chebulagic acid, and small quantities of 2 or 3 other compounds which have not, as yet, been identified. The total content of polyphenols in tea flush has been found to be 25-35% of the dry weight, and this extraordinarily high figure is an important reason for the uniqueness of tea.

Theaflavins are formed by the oxidation of pairs of catechins, and basic reactions which occur during the formation of theaflavins are as follows:

epicatechin + epigallocatechin + O_2 ——> theaflavin + CO_2 + $2H_2O$

epicatechin + epigallocatechin gallate
or
epicatechin gallate + epigallocatechin } + O_2 ——> theaflavin gallate + CO_2 + $2H_2O$

epicatechin gallate + epigallocatechin gallate + O_2 ———> theaflavin digallate + CO_2 + $2H_2O$



Theaflavin; $R_1 = R_2 = H$

Theaflavin gallate A; R_1 = 3,4,5-trihydroxybenzoyl, R_2 = H

Theaflavin gallate B; R_1 = H, R_2 = 3,4,5- trihydroxybenzoyl

Theaflavin digallate; $R_1 = R_2$ = 3,4,5-trihydroxybenzoyl

FIGURE 3—*Structure of Theaflavins*

The chemical formula of theaflavin (Fig. 3), which is given here for the sake of completeness, is somewhat complicated, and was unravelled in 1964 after the application of recently developed techniques of analytical chemistry. Leaving aside unnecessary organic chemistry, it will be seen that theaflavin formation requires the presence of both epicatechin (or its gallate) and epigallocatechin (or its gallate) and that oxygen plays a vital role in the reaction. It will also be seen that theaflavin may occur as such, or in combination with 1 or 2 molecules of gallic acid, as theaflavin gallate or theaflavin digallate respectively. In practice, the term "theaflavins" embraces all of these compounds, and the theaflavins content of a made tea may be between 0.3% and 1.8% on a dry weight basis, while that of a tea brew lies in the range 1–6%. *Quality is dependent on theaflavin content, with teas of good quality having a high theaflavin content.* Although the catechins themselves are not coloured, the theaflavins have a bright reddish colour, and play a major role in determining the brightness of infusions, and the colour and character of tea liquors.

Polyphenoloxidase

As mentioned earlier, the oxidation of the mixture of epicatechin and epigallocatechin to theaflavin requires the presence of the enzyme, polyphenoloxidase. This enzyme has been closely studied by numerous investigators and is, without doubt, of the greatest importance in black tea manufacture. In common with all enzymes, polyphenoloxidase shows optimal activity at a particular pH range (5.8 – 6.2) and a particular temperature (28-34° C). As the temperature is lowered below this range, the activity of polyphenoloxidase progressively decreases and the enzyme is inactive, but not destroyed, at freezing temperatures. On the other hand the enzyme is quickly destroyed at high temperatures, and this is the reason for the cessation of fermentation on firing, and the basis of green tea manufacture where the first step is destruction of polyphenoloxidase by either steaming for 30 seconds, or "pan-firing" by throwing the leaf into a hot, rotating pan. The effect of pH is evident in experiments where artificial alteration of the pH has been shown to reduce theaflavin production, mainly as a consequence of reduced polyphenoloxidase activity.

Apart from these factors, Copper is an essential constituent of polyphenoloxidase, and a deficiency of this element leads to reduced activity of the enzyme. Such a deficiency is unlikely to occur in areas where copper is sprayed for the control of blister blight, but in those areas where this practice is not necessary, it would be wise to make certain that copper deficiency is not limiting the activity of this enzyme.

Another factor which interferes with polyphenoloxidase activity is the tannin content of the flush. In the presence of tannin, this enzyme (a protein) is "tanned" in much the same way that the proteins in animal hides are tanned for the production of leather. Tanning of enzymes leads to a loss or reduction of their activity and would, therefore, curtail the extent of conversion of the catechins to theaflavin. It must be remembered that theaflavin itself is also capable of tanning proteins, although catechins are incapable of doing so.

Polyphenoloxidase is present in the flush as well as in more mature leaves, but the level of enzyme activity decreases progressively with increasing age of the leaf and the low polyphenoloxidase activity together with the low level of catechins in mature leaves (Fig. 6) are mainly responsible for the poor teas produced from coarsely plucked leaf.

The exact location of polyphenoloxidase is in the outer or epidermal layer of cells of the leaf, whilst the catechins are situated in a different stratum of cells known as the palisade layer, (Fig. 4).

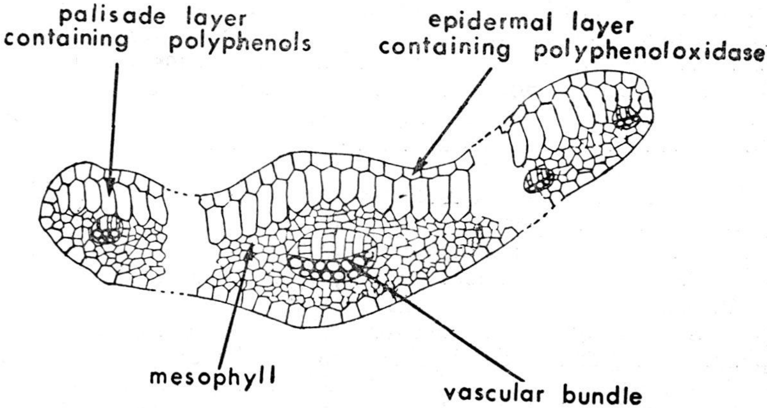


FIGURE 4—*Cross Section of tea leaf*

This spatial separation of the enzyme and its substrates (*i. e.* catechins) prevents their interaction. However, any damage to the leaf, (*e. g.* rolling, rough handling, frost, mite attack) causes a breakdown of the spatial barrier and the leaf turns brown due to the formation of theaflavins and other coloured compounds.

The *relative amounts* of polyphenoloxidase and catechins also play an important part in the development of quality. One of the primary reasons for this is that polyphenoloxidase activity is inhibited by the products (theaflavins) of its activity because, as stated earlier, theaflavins have the property of tanning the enzyme protein. It is possible to envisage three situations as follows:

(1) Enzyme is plentiful but epicatechin, or epigallocatechin, or both, are low - in these conditions, theaflavin formation will be limited by the low level of catechins and will cease as soon as one or the other of the catechins is fully oxidized,

(2) Catechins are plentiful but enzyme is low - in this case the small amount of enzyme initially present will rapidly lose its activity due to inhibition by the theaflavins formed, and the reaction will soon cease.

(3) Neither catechin nor enzyme limit theaflavin production, and this includes the optimal situation where the balance between theaflavin formation on the one hand, and the inhibition of polyphenoloxidase by theaflavin formed on the other, is so poised that theaflavin production is maximal.

The production of a bright "cream" is an index of quality, and the chemical rationale for this observation is that cream is a complex of several compounds, among which are theaflavins and caffeine, and that brightness is directly related to theaflavins content. It is of importance to note that theaflavins have a fiercely astringent taste, while caffeine is extremely bitter, but the mixture of theaflavins and caffeine results in a tea - like character.

Mention is also necessary of two other compounds in tea which play an important part in determining quality. These are theogallin, a polyphenolic compound, which accounts for about 1% of the dry weight of tea, and theanine, an amino acid, which occurs to the extent of 0.85-1.5% of the dry weight. Both of these compounds are unique to tea and have not been found in any other plant. Theogallin is a "depside", formed by the combination of two acids, *viz.* quinic acid and gallic acid, is chemically quite different to the catechins and theaflavins, and does not undergo any marked quantitative change during processing. Theanine is the major amino acid of tea, and its relative concentration is especially high in the best grades of green tea, the quality of which is dependent on theanine content. Finally it appears that *trans*-2-hexenal (an aldehyde) and sulphides, especially dimethyl sulphide (which has a cabbagy odour), are more abundant in low-grown than high-grown teas, and found to be detrimental to quality.

Colour and Strength

It has already been seen that the theaflavins contribute to quality and the brightness of tea liquors and infused leaf, but much of the colour, strength and "mouthfeel" is due to a heterogeneous group of compounds known as the "thearubigins" the exact composition of which is still imperfectly understood. They do not occur in green tea but comprise 9–15% of black tea, which is equivalent to as much as 30–60% of the solids in a black tea infusion. Molecular weight estimations indicated that the average value is about 700, and chemical studies have shown that thearubigins are a complex mixture of carbohydrate, oxidized polyphenols, and nitrogenous substances. Carbohydrates and nitrogenous substances have no colour by themselves, and it is likely that the strong colouriness of thearubigins is due to the augmentation of the natural colour of oxidized polyphenolic compounds as a result of their combination with carbohydrates and nitrogenous substances. This suggests the possibility of increasing colour by the addition of carbohydrate material (*e. g.* sucrose, maltose), amino acids (*e. g.* leucine) or proteins (*e. g.* gelatine) and all of these substances have, in fact, been found to have this effect. The addition of excessive amounts of these compounds may, however, adversely affect strength, and this is because the tea taster's assessment of strength is based on the tanning effect (astringency) of oxidised polyphenols on the taste receptors (which are protein in nature) in his mouth. If, therefore, the effect of these oxidised polyphenols is nullified by the prior addition of excessive amounts of gelatine (a protein) or leucine (a constituent of protein), it would be expected that strength will be diminished. On the other hand, some clones of tea (*e. g.* TRI 2024, TRI 2025, TRI 2043), especially in the conditions of growth of the low country, form very potent tanning compounds (chebulagic acid and corilagin), and the presence of these tannins is partly responsible for the strength, as well as "coarseness" and poorer quality, of low-grown tea. In these teas the addition of gelatine serves a dual purpose-firstly these potent tannins are partially neutralized resulting in a reduction of "coarseness", and secondly this partial neutralization of the tannins also prevents their inhibition of the activity of those tea leaf enzymes, *e. g.* polyphenoloxidase, which are necessary for the development of quality. Addition of gelatine during manufacture (page 30), therefore provides a means of up-grading low-grown tea by reducing part of the "coarseness" and improving the quality.

Flavour

Flavour, is one of the most interesting, valuable and sought after properties of tea, and a very great deal of research effort has been directed towards elucidating the chemical nature of flavour and the biochemical mechanism responsible for its seasonal appearance. It has been ascertained that tea flavour is a composite characteristic in the sense that it is due to the absence of substances that detract from, and the presence of substances which accentuate, its perception. Some of the factors which detract from flavour are the occurrence of potent tannins and this is one (but only one) of the reasons that flavour has not been detected in the low country, The absence of a sufficient quantity of theaflavin is another factor, and this is a likely reason for the fact that flavoury teas are only found among high quality teas. However, the occurrence of high quality without flavour emphasizes that there is an additional essential requirement for flavour, and this requirement is the composition of the volatile compounds present in tea. The proportion of volatile compounds in tea is quite small (about 0.01% of the dry weight), but this fraction has now been found to contain more than 300 different odoriferous substances, which includes several hydrocarbons (*e.g.* myrcene), aldehydes (*e. g.* acetaldehyde, hexenal), alcohols (*e. g.* ethyl alcohol), ketones (*e. g.* acetone), sulphides (*e. g.* hydrogen sulphide, dimethyl sulphide), acids (*e.g.* acetic acid), terpenes (*e. g.* linalool, geraniol). It is not proposed to give here a list of the numerous compounds that have been identified, but it needs to be emphasized that all these compounds were found to occur in flavoury, *as well as* in non-flavoury teas. The significant difference was that the *proportions* in which they occurred differed in the two types of tea. For instance, in flavoury teas, the proportion of volatile compounds of higher boiling point (linalool, *cis*-jasmone, theaspirone, β-ionone) to those of lower boiling point (dimethyl sulphide, butyraldehydes, *trans*-2-hexenal) was greater than that in teas without flavour. Evidently, excessive amounts of volatile compounds of low boiling point are deleterious to flavour, and their presence nullified the desirable effect of the compounds of higher boiling point. From these observations, it follows that the seasonal appearance of flavour could be due to the effect of dry, cold, windy conditions resulting in changes in the flush which encouraged the production of volatile compounds of higher boiling at the expense of those of lower boiling point. This was, in fact, found to be true, and the reason for this is a derangement of the normal metabolic processes in flush growing in the dry and cold climatic conditions conducive to flavour development. In normal flush, photosynthesis is actively proceeding with carbon dioxide being freely available to the leaf, and the chloroplast in an active state. In the flavour season, however, the desiccating wind, cold nights, and bright, cloudless days, subject the tea bush to the combined stresses of dehydration, high light intensity, and cold, which result in a breakdown of the photosynthetic mechanism due to closure of the stomata, disorganization of the chloroplast due to desiccation, and lack of water for the transport of essential nutrients from the root. In these conditions the chief site of metabolism shifts from its normal location inside the chloroplast to a position outside the chloroplast, and the composition of volatile compounds consequently changes in a diıection that gives rise to flavour. It appears that about a fortnight of the appropriate weather conditions are necessary for this shift to occur, and the occurrence of rain causes the immediate disappearance of flavour because of the rapid recovery of the desiccated chloroplast, and the resumption of normal intra - chloroplast photosynthesis. The mechanism of this shift to flavour development is shown in Figure 5, where it is seen that in normal conditions of growth, photosynthesis results in the formation of acetic acid, which is then transformed *via* mevalonic acid to volatile compounds, In flavour conditions, on the other hand, disorganization of the chloroplast leads

FIGURE 5

CHEMICAL MECHANISM OF FLAVOUR DEVELOPMENT

Flavour	*No flavour*
Leucine	Acetate
↓	↓ (–> Compounds deleterious for flavour (*e.g. trans* – 2 – hexenal))
Mevalonic acid	Mevalonic acid
↓	↓
Mixure of volatile compounds required for flavour	Mixture of volatile compounds, containing those which detract from flavour
Site of reactions Outside leaf chloroplast	Within leaf chloroplast

to retardation of photosynthesis, and flavour compounds are then derived from the amino acid, leucine, rather than from acetic acid. This change of precursor to leucine results in an alteration of the composition of the aroma complex which leads to flavour, particularly because some of the compounds derived from acetate are deleterious to flavour.

Flavour is then due to a non-functioning chloroplast and may be regarded as a pathological condition. Other factors which hasten damage of the chloroplast, *e. g.* mites in Sri Lanka, green fly in Darjeeling would, therefore, indirectly contribute to the onset of flavour. This elucidation of the mechanism of flavour biogenesis opens exciting vistas for the artificial induction of out of season flavour.

Finally, flavour is dependent on the presence of compounds with extremely low "threshold values", *i. e.* a minute quantity of a particular compound may make the difference between flavour and no flavour, and the accentuation of the effect of these compounds may well be vital for the perception of flavour. It is well-known that common salt serves to accentuate the flavour of several foods, and that mono-sodium glutamate and inosinic acid-5-phosphate are used to bring out the flavour of soups and meat, and there appears to be no reason to ignore the possibility that substances with a similar activity occur in tea, and a promising compound in this connection is theanine, which is itself a derivative of glutamic acid.

CHAPTER 2

BIOCHEMISTRY AND MANUFACTURE

The two main types of processed tea are black tea and green tea, and as stated earlier, the difference between these two is that black tea manufacture gives full rein to the oxidation of polyphenols by the polyphenoloxidase present in the flush, whilst in green tea manufacture the first operation is the heat destruction of polyphenoloxidase by steaming (Japan) or pan firing (China). It follows, therefore, that the primary difference between black tea and green tea is that the former contains a mixture of the native unoxidized polyphenols, together with theaflavin and other oxidized polyphenols, whereas green tea contains unoxidized polyphenols only. A large excess of unoxidised polyphenols is, by itself, undesirable on account of the "metallic" taste that these would engender, and it follows that tea clones containing low levels of polyphenols are necessary for the manufacture of good green tea. These clones (*e. g.* Yabukita, Tamamidori, Miyoshi and Natsumidori) are all of extreme China jat, with very small, dark green leaves. This property of being dark green is important for green tea because here, as in the case of black tea, the desired black appearance is the result of the conversion of chlorophyll to phaeophytin during processing. In fact, the finest and most highly valued green tea in Japan, known as Gyokuro or "Pearl Dew", is carefully grown under artificial shade to produce a leaf containing almost three times as much chlorophyll as that grown under normal conditions. Other less costly green tea grades are the popular "Sencha", and the coarse "Bancha".

Apart from low polyphenol and high chlorophyll content, the other desired property of leaf for green tea processing is a high content of nitrogenous compounds, especially amino acids and protein. It is for these reasons that clones which have been selected for black tea production mainly on account of their relatively high levels of polyphenol and polyphenoloxidase are not very suitable for green tea production, because they yield a product which is too astringent, and also require a longer period of steaming or pan firing for enzyme inactivation. This longer period of heat treatment is itself undesirable in that it leads to stewing of the leaf as well as loss of chlorophyll. A comparison of the chemical composition of various green teas from Japan, China and Sri Lanka are shown in Table 4, from which it is evident that the Sri Lanka tea (processed after steaming leaf from St Joachim, Ratnapura) contains an excessive amount of astringent polyphenols, and a

TABLE 4

COMPARISON OF VARIOUS KINDS OF GREEN TEA

	Polyphenols	Amino acids
Gyokuro .. .. (Japanese finest grade)	132	48
Sencha .. .. (Japanese popular grade)	229	21
Chinese green tea	258	18
St Joachim Estate .. .. (Sri Lanka)	413	17

(All values expressed as mg/g dry wt.)

relatively low content of amino acids. The results also suggest that Sri Lanka leaf may be more suitable for processing to pan-fired Chinese green tea than foı steamed Japanese tea.

Reverting to black tea it is of interest to discuss the principal changes occurring in the various stages of black tea processing *viz*, growth of the tea bush, plucking, handling of the leaf, withering, preconditioning, rolling, fermenting, firing, grading, packing, tasting and storage.

Growth of the tea bush

Propagation of tea from seed is no longer practised, and has been replaced by vegetative propagation with its attendant advantage of ensuring immutability of the desirable characters of the mother bush from which the original leaf cuttings were taken. Selection of the mother bush may be on the grounds of high yield, production of a desirable tea, resistance to a particular pest or pathogen, hardiness, rapid growth, suitability of the bud for tip, or a combination of one or more of these factors. Selection of the appropriate mother bush is, therefore, of paramount importance, and is based, at present, on observation in the field, followed by time-consuming field trials to assess the performance of the selected cutting. It would obviously greatly expedite clonal selection if chemical analysis of the chosen mother bush were to provide an index of its potential value. With this aim in view, several chemical parameters are being screened as a possible alternative to clonal trials, and some of these parameters, listed in Table 5, indicate the possibility of predicting the performance of clones in a relatively quick, but rational, manner.

TABLE 5

PARAMETERS FOR CLONAL SELECTION

Parameter	*Remarks*
Polyphenoloxidase activity Catechins Caffeine Theogallin Theanine	High levels improve quality of made tea.
Tannins	Low level necessary for quality and flavour.
Leucine	High level improves flavour.
Chlorophyll S-containing amino acids Linolenic acid α-alanine	Low levels conducive to development of flavour.
No. of branches Root hormones Leaf area	High level indicates increased yield.
Root/Shoot ratio	High ratio suggests increased yield and drought resistance.
Saponin	High level indicates tolerance to shot-hole borer.
Chebulagic acid	Absence indicates tolerance to shot-hole borer.
Uptake after application of fertilizer	High uptake indicates good response to fertilizer.

An important requirement for the growth of leaf cuttings is the provision of hormones for the rapid formation of roots which can absorb the required nutrients from the soil. The nature of these hormones is, as yet, largely unknown, but the spraying of nursery plants with tea root extracts has been found to cause a remarkable increase in root growth. It remains to be seen whether this advantage in the nursery continues throughout the life of the mature tea bush, but it has already been observed that nursery plants treated with tea root extract, are more resistant to drought conditions during the critical first year of growth in the field. It is likely that improvement of nursery plants, especially with respect to increasing the root system, will be of great use.

A plant regulator, the effect of which has been evaluated in the nursery, is Ethylene in the form of its chloroethylphosphonic acid (Ethrel). In this case the level of application is of critical importance *e. g.* levels which are too high lead to stunted nursery plants with very dark green leaves. When applied at the correct level, however, there is stimulation of root growth, and the effect of greening of foliage is evident. In the field too, Ethrel application causes increased greening, and this effect may be useful in the low country, where the black appearance of the processed tea is of prime importance.

The use of radioactive isotopes has revealed that the products of photosynthesis in the flush are retained therein, and that the flush is additionally nurtured by the roots as well as by the mature leaves in the upper half of the bush, which transport at least part of their photosynthate to the growing flush. The more mature leaves towards the base of the bush, however, transport photosynthate to the roots, and are, therefore, essential for the healthy growth of the bush. The use of radioactive isotopes has also shown that the important amino acid, theanine, is biosynthesized in the root from precursors transported thereto from the mature leaves. After biosynthesis, theanine, together with other nutrients, is transported from the root directly and exclusively to the growing flush. It follows therefore, that the different parts of the bush support each other in a complementary fashion, and that the activities of each are useful to the other. However, the excision of any part of the bush, as in pruning, sets in motion compensatory reactions which lead to a reallocation of metabolic functions for the maintenance of the plant.

Plucking

It has already been discussed that the composition of flush differs from that of mature leaves, and that this is the reason for the production of superior teas from carefully plucked leaf. Quantitative comparisons of some of the important constuents, *viz.* polyphenoloxidase activity polyphenol, amino acid and caffeine contents are shown in Figure 6, whilst other differences are depicted in Table 2, (page 4).

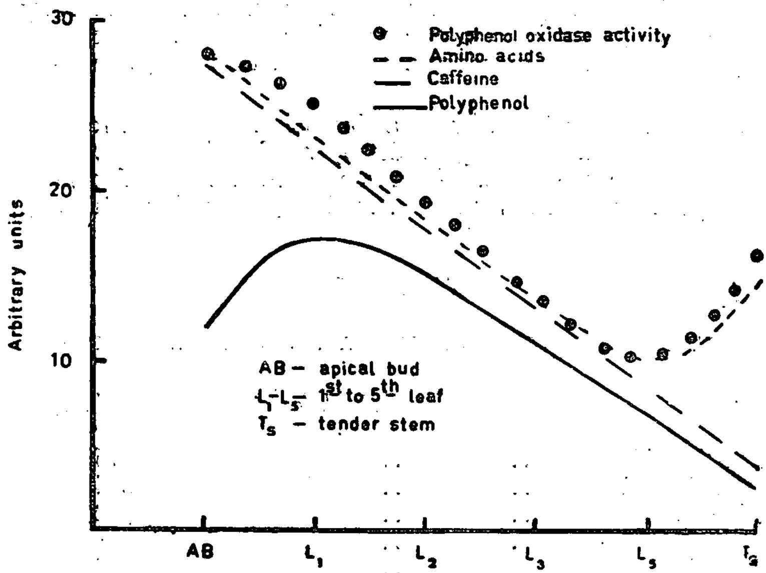


FIGURE 6—*Comparison of polyphenols, amino acids, caffeine and polyphenol oxidase in tender stem and leaves of different maturity.*

Handling

The spatial separation of enzyme and substrate in the intact leaf (Fig. 4) prevents the onset of fermentation and other biochemical reactions, which are an essential part of black tea processing. Rough handling of the plucked leaf will lead to a breakdown of these separating barriers and result in premature fermentation. In green tea processing such premature fermentation would make it impossible to manufacture an acceptable product.

Withering

It was, at one time, erroneously believed that the sole purpose of withering was to reduce moisture content and produce a leaf which was sufficiently limp for rolling. It is now known that several biochemical changes of great importance occur during withering. The majority of these changes is completed in 6-10 hours and it may therefore be true that prolongation of the wither beyond this period is necessary mainly for loss of moisture. Among the many important biochemical changes which occur during withering, the following have been substantiated :

1. Increase in polyphenoloxidase activity. There is a 2–3 fold increase in polyphenoloxidase activity which has been found to be due to the synthesis of new enzyme during withering. This increase in enzyme, which occurs independently of loss of mois-

ture, is of great importance for rapid fermentation, and every effort should be made to ensure conditions which are favourable for protein synthesis, *e. g.* the avoidance of high temperatures.

2. Breakdown of proteins to amino acids. This is a reaction which has been studied in great detail, and found to be catalysed by the enzyme, peptidase. As a consequence, the total content of amino acids increases remarkably during withering (Table 6),

TABLE 6

CHANGES IN THE LEVELS OF AMINO ACIDS DURING WITHERING

	Fresh leaf	*Withered leaf*
Aspartic acid	109	176
Glutamic acid	215	394
Serine	68	102
Asparagine	28	116
Glutamine	30	53
Tyrosine	4	28
Threonine	20	43
Alanine	20	35
Valine	8	50
Leucine + isoleucine ..	11	84
Phenylalanine	2	41
Theanine	930	625
Total	1445	1747

(Values expressed as mg/100 g dry weight)

and these amino acids play a vital role in the development of colour, flavour and bouquet of tea liquors. Especially remarkable is the formation during withering of asparagine, leucine and isoleucine, phenylalanine and tyrosine, as these amino acids are hardly detectable in unwithered flush. The occurrence of these amino acids, may, in fact, be used to differentiate an unwithered tea (*e. g.* Legge cut) from an orthodox manufactured tea. Apart from this, leucine plays a central role in the development of flavour (page 17).

3. Breakdown of chlorophyll. The breakdown of chlorophyll begins during withering, and progresses during the various stages of proceedings, and Table 7 shows that the amount of chlorophyll

TABLE 7

CHANGES IN CHLOROPHYLL AND ITS BREAKDOWN PRODUCTS DURING BLACK TEA MANUFACTURE

	Chlorophyll	*Phaeophytin*	*Phaeophorbide*
Flush	31	0	0
Withered leaf	27	0	0
Fermented 1 hr	27	0	0
Fermented 2 1/2 hr	18	+	+
Fired tea	0.15	+++	+

(Arbitrary units)

in fired tea is very low indeed. The breakdown products of chlorophyll and their effect on the appearance of made tea have been discussed earlier.

4. Increase in Caffeine. The amount of caffeine increases during withering, due partly to the enzymic synthesis of this alkaloid, and partly to its release from complex molecules which contain the caffeine molecule in their make-up. It is well-known that caffeine is important for the physiological activity of tea (see Chapter 5).

5. Increase in simple carbohydrates, *e. g.* glucose.

6. Changes in carotenoids. Products derived by the oxidation of carotenoids are of great importance for flavour, and play a decisive role in the valuation of a tea.

7. Changes in levels of organic acids. Several organic acids (oxalic, malic, citric, isocitric, succinic, quinic, shikimic), have ben identified in tea and these, with the exception of oxalic acid, are of importance for the metabolic activity of the plant. There is a notable reduction in the levels of succinic and malic acids during withering.

8. Increase in permeability of cell membranes. The increase in cell wall permeability facilitates the mixing of the contents of the separate cells, and consequently, promotes the efficiency of the reactions occurring during rolling and fermentation.

9. Increase in micro-organisms. Freshly plucked tea flush contains micro-organisms on the leaf surface, and the nature of these micro-organisms changes with climatic conditions. There

is, however, a marked increase (several hundred to several thousand fold) in the number of these micro-organisms during withering. This increase is especially remarkable in the case of the fungi present on wet leaf, and is one reason for the poor character of "rain teas".

Changes 1–7 are mediated by one or more enzymes, and the conditions during withering must, therefore, be regulated in order to prevent destruction of these enzymes, *e. g.* the application of excessive heat by the introduction of hot air, or the generation of heat by piling the leaf for long periods, or by overloading tats or troughs. Futhermore, enzymes require a certain amount of water for their activity, and too rapid a rate of withering would desiccate the leaf and impair enzyme activity. The increase in permeability (change 8). is a non-enzymic reaction, controlled by changes in the cell membrane due to loss of water during withering and this increase is of great importance in tea manufacture. With regard to the increase in micro-organisms (change 9) during withering it is unfortunate that insufficient attention has been paid to its effect on processing. It has been found that the micro-organisms on low-grown tea are mainly fungi (Aspergilli, Penicillia), and that these also occur on the flush of high-grown tea during wet weather. However, the onset of the dry, cold weather, during the flavour season results in a dramatic disappearance of the fungi and their equally dramatic replacement by a yeast-like organism, which may be pink or white, This change is comparable to that in other crops, *e. g.* grapes, where vintage wines are produced only during the dry season from grapes which have a "bloom" and a population of surface micro-organisms which are quite different from that in the wet season. It is possible that the presence of fungi on the surface of the flush and their rapid proliferation during withering are detrimental to the made tea characteristics, and every effort is necessary to keep the factory and leaf handling as hygienic as possible. In practice, spraying flush with either sodium propionate solution containing 0.5 g propionate per kg of flush, or glycerol solution containing 0.5 g glycerol per kg of flush, improved the valuation of the made tea. This improvement in valuation is probably due to the suppression of microbial growth by sodium propionate or glycerol. In this context, one of the advantages of the practice of using a short withering period during the flavour season is reduction of the time available for multiplication of the leaf surface organisms.

Preconditioning of withered leaf

The necessity for preconditioning becomes evident when it is recalled that polyphenoloxidase is located in the epidermal layer of the leaf cells and that the catechins are situated below this layer of cells (Fig. 4). Each cell of these discrete layers has its own complement of polyphenoloxidase or catechins respectively, and haphazard maceration of unwithered leaf, which is brittle and turgid, may be expected to disrupt only some of the cells, whilst leaving others intact. In such conditions the enzyme or catechin in the intact cells would not be released and remain unutilized during fermentation. On the other hand light preconditioning of limp, withered leaf leads to disruption of the separating walls between the epidermal cells resulting in the condition which is diagramatically represented in Figure 7, and rupture of the epi-

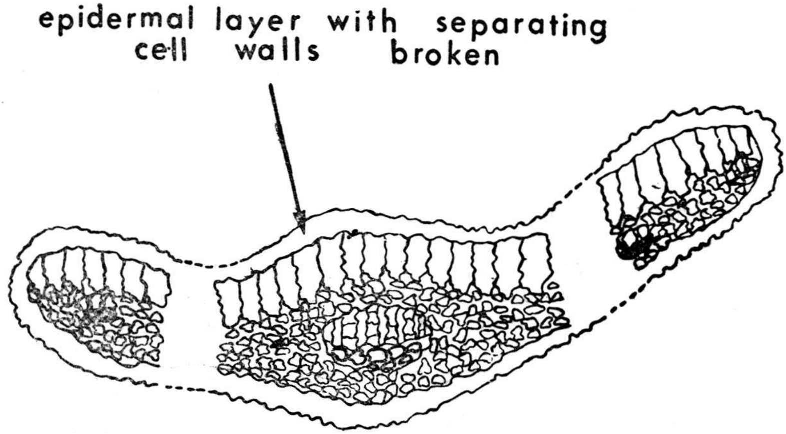


FIGURE 7—*Effect of preconditioning on withered leaf*

dermis at even one point would release the entire content of available enzyme. Careful preconditioning is therefore, seen to be a *sine qua non* for realising the full enzyme potential of the leaf.

Rolling

Some of the biochemical and chemical changes initiated during withering and continued during preconditioning, proceed at an accelerated rate during rolling. The reasons for this acceleration are rise in temperature, and maceration of the leaf which leads to intimate mixing of reactant systems. Perhaps the most important of these reactions is the enzymic oxidation of catechins to theaflavins by polyphenoloxidase, and the effect of preconditioning on this reaction has already been emphasized. Several other reactions are also initiated during rolling *e. g.* the breakdown of chlorophyll by chlorophyllase, the sequence of reactions leading to the formation of compounds responsible for flavour and colour of liquors, non-enzymic reactions contributing to colour, the release of compounds which inhibit enzymic reactions, and other reactions described in the following section. The employment of CTC or Legge cut machines results in a more efficient and rapid distintegration of the leaf mass than does orthodox manufacture, but one of the consequences is the brown appearance of the made tea. The reason for this browning is the rapid enzymic breakdown of chlorophyll, which leads to the formation of phaeophorbide on firing (Fig. 1). In orthodox manufacture, on the other hand, chlorophyll and chlorophyllase are allowed to mix only gradually and at a slower rate, and this gives time for the enzyme inhibiting compounds (theaflavins, tannins) to interact with and inhibit chlorophyllase activity, and so favour the production of a blacker tea. The maceration of the leaf during rolling also initiates another reaction, which is of importance in determining flavour. This is the reaction resulting in the formation of *trans*-2-hexenal, which is deleterious to flavour and the formation of this compound is discussed in more detail in the following section on fermentation.

Fermentation

The principal reactions which occur during fermentation may be divided to 2 groups (a) those which are enzyme-dependent and (b) those which are purely chemical and independent of enzymes. Among the former are theaflavin and thearubigin formation, the full development of aroma and flavour, the continuing breakdown of chlorophyll, and changes in carotenoids, organic acids and nucleotides, whilst some of the non-enzymic reactions are interaction of oxidized polyphenols and sugars with amino acids, tanning of enzymes and other proteins, and reduction of number of micro-organisms.

The reaction which has been studied most intensively is the formation of theaflavins, and the principal findings have been described earlier. To briefly recapitulate, it was found that catechins, oxygen and polyphenoloxidase were required for theaflavin formation, and that the unsuitability of coarse leaf for the processing was due to their low content of both catechins and polyphenoloxidase, (see Fig. 6). The requirement of oxygen is obtained from air which contains ample (20 %) oxygen, but the utilization of this oxygen is dependent on the thickness of spread of the dhool. If the dhool is spread too thick (more than 3 inches) the passage of air through the fermenting dhool will be restricted and the carbon dioxide which is found during fermentation will replace the oxygen, and so retard fermentation. Apart from restricting oxygen circulation, thickly spread dhool will also become over-heated, which would favour the rate of chemical reactions which are unfavourable to the enzymic changes occurring during fermentation, *e. g.* tanning of enzymes. On the other hand dhool which is spread too thinly (less than 2 inches) will tend to cool and dry too quickly, and result in a slowing down of fermentation, because water too is an essential requirement for enzyme activity, *e. g.* dry polyphenoloxidase will not react with dry catechins. In addition drying also leads to concentration of the tea constituents and a consequent drop in pH. Furthermore, it is well established that there is an optimal concentration of substrate for each enzyme reaction, and that at levels higher or lower than this concentration, the rate of the reaction falls. On drying, therefore, the level of substrate may become too high for reaction to occur.

As seen earlier (page 16) flavour is the result of the correct balance between compounds which are "good" and "bad" for flavour. Two compounds which are in the "bad" category are *trans*-2-hexenal and dimethyl sulphide. Production of the former begins as soon as the leaf is damaged in any way, *e. g.* rough handling of leaf or rolling. Its formation is unavoidable and dependent on the linolenic acid content of the leaf, from which it arises by enzymic oxidation. Light rolling without undue maceration of the leaf will reduce its formation, and this is one of the reasons for the low *trans*-2-hexenal content of Darjeeling second flush teas, which are of flowery BOP grade. One may go further and suggest that part of the unique Darjeeling flavour is due to its low content of *trans*-2-hexenal. The low linolenic acid in Dimbula and Uva flush produced during the flavour season is responsible for the low *trans*-2-hexenal content of these valuable teas. In this context it would be of interest to determine the effect of processing flush, obtained from Dimbula and Uva during the flavour season, according to the conditions used in Darjeeling, *viz.* hard wither, light rolling, short fermentation, and high (about 200° F) firing temperature. The other compound which is "bad" for flavour is dimethyl sulphide, which has a "cabbagy" odour, and is formed by the enzymic hydrolysis of the amino acid, methionine. The level of this sulphide in low-grown teas is relatively very high, and this makes it difficult, if not impossible, to make a tea with flavour in the low country by conventional methods of leaf processing.

The breakdown of chlorophyll to chlorophyllide continues during fermentation, proceeding rapidly at first, but slowing down as the production occurs of compounds (theaflavins, quinones) which inhibit chlorophyllase activity. It follows, therefore, that conditions which favour the rapid formation of such inhibitory compounds will yield blacker teas. Conversely, ths slow or inadequate formation of these compounds will reduce blackness, *e. g.* as in over-withered teas or low temperature during fermentation. It must be mentioned that the presence of tannins (chebulagic acid, corilagin) in certain clones of tea, *e. g.* TRI 2025, DG, TRI 2027, TRI 2016, TRI 2024, will cause inhibition of activity of all enzymes, including chlorophyllase and polyphenoloxidase, so that the production of blacker teas will, in this instance, be at the expense of quality.

Carotenoids, the group of yellow pigments found in association with chlorophyll in all leaves, also undergo changes during fermentation. One of these changes, which is probably non-enzymic, is the oxidation of carotenoids to β-ionone. This compound, which is responsible for the aroma of violets, is an important component of "good" tea flavour, particularly because β-ionone itself is further oxidised to compounds known as theaspirone and dihydroactinidiolide, both of which are also "good" for tea flavour. Another of the "good" compounds formed during fermentation is linalool (and its oxides), and this may be derived from either acetate or leucine via mevalonic acid, as depicted in Figure 5.

The change in colour of fermenting dhool from green to brown is due to a variety of reactions *viz.* the breakdown of chlorophyll, the formation of theaflavin, as well as a host of non-enzymic chemical reactions. Important among the last group of reactions are the interactions between amino acids and proteins on the one hand, and carbohydrates, quinones (including theaflavin), aldehydes (*e. g.* acetaldehyde) and ketones (*e. g.* acetone) on the other. Included here are the group of compounds known as "thearubigins" (page 14), which impart the reddish tint to tea liquors. Trials have shown that the addition of protein (*e. g.* 30-40 g gelatine per 225 kg withered leaf), or amino acid (*e. g.* leucine at 3–8 g per 225 kg withered leaf) or carbohydrate (*e. g.* sucrose at 250-500g per 225 kg withered leaf) caused an useful increase in the valuation of made teas. It needs to be emphasized that the formation of thearubigins involves utilization of theaflavins, and their increased formation will be at the expense of part of the quality.

The aroma ("nose") of fermenting dhool is the result of interaction between amino acids and quinones which results in the formation of fragrant aldehydes. The aroma of fermenting dhool is, therefore, an indication of the state of oxidation of catechins and, consequently, an excellent subjective assessment of the progress of theaflavin formation and quality development.

Yet another change occurring during fermentation is a reduction in the number of micro-organisms which, as mentioned earlier, show an increase during withering. The reason for the reduction during fermentation is the "tanning" of the microbial protein by theaflavins and other polyphenolic compounds, and it will be readily seen that excessive microbial growth during processing will reduce the content of valuable free theaflavins, and therefore yield a tea of negligible quality.

Firing

The most well-known effects of firing are arrest of fermentation and reduction of the moisture content to about 3%, which is the level suitable for storage. Less well-known, are (1) the acceleration of enzymic reaction during the early stages of firing, (2) the formation of phaeophytin and phaeophorbide, (3) the loss of about 40% of the volatile compounds in the dhool, (4) the formation of aldehydes, ketones, theaspirone, etc., (5) the "tanning" of proteins by polyphenols (6) reduction of micro-organisms, (7) non-enzymic browning reactions, *e. g.* caramelization, (8) formation of thearubigins. Considering each of these in more detail, it needs to be recalled that enzymic reactions play an important part in fermentation, and that enzymic reactions show a progressive increase in rate as the temperature is raised, until that point of temperature is reached when the enzyme is destroyed. In the early stages of firing, the temperature of the moist dhool reaches a level at which enzymic reactions, *e. g.* theaflavin formation occur at a very rapid rate, and it is likely that about 20% of the theaflavin of processed tea occurs during the early stages of firing. However, as the dhool dries, its temperature rises rapidly and attains a level at which enzymes are rapidly denatured or destroyed, or rendered inactive by the loss of water during firing.

The application of heat is necessary to convert the brown dhool to the black tea of commerce, because in the unfired dhool, the loss of magnesium from chlorophyll is prevented by a lipoprotein which protects it from the action of acid. When heated, this lipoprotein is coagulated, and chlorophyll is then exposed to the action of acids. The necessity for moisture is strikingly demonstrated by the fact that fermented dhool which has been freed of moisture in the cold by freeze drying does not turn black when fired in the conventional way. These results suggest that excessive drying during fermentation may be expected to reduce the degree of blackness of a tea, and provides an explanation for the observation that moistening the dhool before firing leads to increased blackness.

A high proportion (about 40%) of volatile compounds, responsible for the aroma of tea, are also lost during the initial stages of firing, because the water that is being removed carries with it essential oils and other volatile compounds. It must, however, be remembered that this considerable loss of volatile compounds is not altogether undesirable, as included among the compounds lost are some which are deleterious to tea aroma, *e. g.* dimethyl sulphide, *trans*-2-hexenal. At the same time, chemical changes occur which generate the formation of compounds which are essential for good tea aroma, *e. g.* β-ionone, theaspirone, dihydroactinidiolide. The correct balance of volatile compounds is struck during firing, and serves to emphasize the importance of this stage of tea processing for the development of tea flavour.

Apart from tea aroma, the astringency of tea is also markedly influenced by firing. It is well-known that unfired dhool has a harsh metallic taste, which is lost during firing. One of the main reasons for the harshness of unfired dhools is the effect of theaflavins and other polyphenolic material which have a fiercely astringent taste. On firing, however, these compounds are partly "neutralized" by the proteins of tea in a manner essentially similar to the tanning of the proteins of animal hides by tannins during the manufacture of leather. Another important function of firing is sterilization of the dhool by destruction of the micro-organisms present in the unfired dhool. Micro-organisms too contain a high content of protein and their uninhibited growth would soon lead to an excessive amount of protein, which would lead to an "over neutralization" of the astringent material and result in a "flat" tea. This is, of course, in addition to the undesirability of having a product with a high count of micro-organisms, which would impart a "sour" characteristic to the tea.

Both the neutralization of harshness, and the destruction of micro-organisms are chemical processes, and another important class of reactions in this category is the group of non-enzymic browning reactions. Common examples of the occurrence of this type of reaction are the brown colour formed on heating a solution of impure sugar and the browning of fried potato chips, where the colouration is due to the effect of heat in causing the chemical combination of sugars and amino acids to yield a product which is brown in colour. However, sugar and amino acids are not the only compounds which interact to give such brown coloured products, and tea contains a number of other compounds *e. g.* polyphenols, various aldehydes and ketones, which behave in the same manner as sugars. Mention has already been made (page 30) that these reactions take place during fermentation, but the rate of this type of "non-enzymic browning " is accelerated at the elevated temperatures employed during firing.

Grading and Packing

Grading is the process of separating the fired tea into particles of different sizes by the use of mechanically oscillated sieves fitted with mesh of various sizes. The grade is defined, on the one hand, by the mesh size of the sieve through which the tea passes, and on the other, by the size on which it is retained. In Sri Lanka, a tea passing through a No. 10 sieve and retained by a No. 18 sieve, is designated as a B. O. P., but this grade specification is entirely artificial, and varies from country to country. Excessive sifting is a procedure to be avoided, as it tends to erode the film of fermentation products on the dried leaf, which leads to an undesirable "greying" of the tea. It is also necessary to prevent excessive uptake of moisture by the thin layer of tea on the sieves, and for this reason the relative humidity of the air in sorting room should not exceed 70%. For this same reason, teas must be sorted daily, and the various grades stored in air tight bins until a sufficient quantity has accumulated to pack an invoice. The respective grades in the bins are then bulked and mixed, and the tea packed in plywood chests lined with aluminium foil and paper, and sealed with similar material. During all of these stages, every precaution must be taken to minimize exposure to elevated temperatures, light and moisture, as these conditions drastically reduce the storage life of tea.

Storage of tea

Several changes occur during the storage of black tea, some of which are purely chemical and others biological. These commence shortly after the tea has been fired, and are beneficial during the first few weeks of storage, but detrimental thereafter. One of the reasons for the initial improvement was correlated to an increase in theaflavin content, which, however, fell off on prolonged storage. This loss of theaflavin on storage is accompanied by losses of amino acids, sugars, pigments, some volatile compounds and other substances which determine the flavour and astringency of tea. These changes are accelerated by moisture and heat, and it is for this reason that storage in cool, dry conditions is essential. In this connection, it has been found that the development of rancidity is most rapid in ultra-dry conditions, whereas browning reactions occur in moist conditions, and micro-organisms thrive in very moist conditions. The results of detailed investigations suggest that the optimum moisture content for black tea is in the region of 3 to 5%, and it is therefore important to ensure that tea is dried to a moisture content in this range, and maintained at this level during transit and warehouse storage. Optimal conditions would also include maintenance of a temperature below 30°C.

TEA TASTING

The tasting and valuation are carried out by trained professionals who have a broad knowledge of the requirements of he tea market with respect to grade, appearance, taste and aroma of the finished product. Valuations are dependent on the prevailing demand for the different tea characteristics, with some countries preferring a strong liquoring tea of black appearance, and others laying emphasis on quality rather than appearance. In assessing a tea, the taster uses a number of terms, the more common of which, abstracted from a draft of the British Standards Institution, are given below:

Appearance of the tea

Attractive	Well-made, uniform in colour, size and texture. Pleasing to the eye. Not necessarily good quality tea.
Black	Leaf black in colour. Properly withered leaf gives black tea.
Bold	Large, loosely rolled.
Brownish	Leaf brown in colour. May be due to under-withered leaf fired at too high a temperature, or to coarse leaf, or to CTC action.
Choppy	Descriptive of a milled heavy leaf. ("milled" — cut on a tea mill).
Clean	Free from fibre, dirt or extraneous matter.
Crushed	Untidy and dusty.
Dusty	Containing an undue percentage of dust.
Even	True to grade, consisting of pieces of approximately equal size.
Fibrey	Containing a noticeable proportion of torn stalk or fibre.
Flakey	Flat, open, untwisted. Usually light.
Grainy	Small, clean, granular. Having the appearance and, to some extent the texture of sand.
Grey	Results from oversorting and cutting whereby the outer leaf varnish is scratched and broken.
Hairy	(as Whiskery) - containing a high percentage of fine, hairy fibre.
Large	Applicable to any tea which is large for its species.
Leafy	Large, unbroken, intact (*e.g.* Formosa Oolong).
Light	Abnormally light-weight.
Neat	Well-manufactured, even, attractive.
Open	Very loosely rolled, flat, untwisted. Applicable principally to large leaf.
Powdery	Very fine, light dust, the particles of which tend to cohere.
Shelly	Cup-shaped, light, Flakey with the 'edges turned up.'
Small	Applicable to any tea which is small for its specie.
Spongy	Loosely manufactured, springy, compressible.
Stalky	Containing an abnormal amount of stalk.

Stylish	Attractive, well-manufactured, sometimes containing tip.
Tippy	Containing a high percentage of tip, either golden or silver.
Twisted	Leaf which has become curled as a result of thorough withering and heavy rolling.
Uneven	Untrue to grade, irregular to size. Indicative of bad sorting.
Well-made	(as attractive)–Uniform in colour size and texture. Pleasing to the eye. Not necessarily good quality tea – as denoted by "Stylish".
Whiskery	(as "Hairy") – containing a high percentage of fine, hairy fibre.
Wiry	Large, twisted leaf, long and stiff. Tends to cling together like scraps of wire.

Infused leaf colour

Bright	Light and attractive, denoting a good tea.
Coppery	Suggestive of new penny colour. Found only in the finest teas. The quintessence of infusion colour.
Dull	Dark, dingy, murky, unattractive.
Greenish	Containing a proportion of semi-fermented leaf.
Mixed	Containing one or more colours at variance with the general tint.
Reddish	Reddish-brown being the predominating tinge.

Taste

Aroma	Denotes that the infusion and the liquor have one of a number of smells in a concentrated form. Flavour is an aroma.
Bad Leaf	Taste resulting from presence of foreign leaf. Applies particularly to inclusion of leaves from shade trees.
Bakey	(as "Toasty") – a degree of burn, produced by slight over-firing. Reminiscent of burnt chocolate.
Brisk	"Pointy", lively, with some degree of pungency.
Burnt	Excess of firing, tending to mask other characteristics. Not always detrimental. Sometimes referred to as over or highly "fired".

Cedarwood	"Woody" character, suggestive of cigar boxes.
Cheesy	Faintly suggestive of overripe Camembert cheese, or slightly rancid butter.
Chesty	A character imparted to the tea by unseasoned battens or the wood of a tea chest-similar to "Cedarwood".
Clean	Free from unpleasant character, but possessing no particular attribute.
Clothy	Suggestive of the small of sackcloth. Contracted normally from contact with unseasoned withering tats.
Coarse	General term, indicative of the combination of poor grade tea and faulty manufacture. Rough, lacking fullness and roundness.
Common	General term for inferior tea. Typical description of low-grown tea. Having little to commend it but at the same time showing no specific detrimental character. Bought leaf.
Cooked	Burnt to such an extent that all other tea characters are hidden. Definitely unpleasant and thoroughly objectionable.
Creamy	Round, smooth. Describes the type of tea which, when cooling down, produces precipitate known as "Cream".
Dry	Lacking juice and sap. Having a tendency to dry up in the mouth.
Dull	(as "Muddy") – Without unpleasantness but uninteresting.
Earthy	Advanced degree of "hay flavour", suggestive of rotten soil.
Flat	(as "Tired") – having lost character and briskness as a result of being kept too long.
Flavoury	Delicate, aromatic character associated usually with a particular district.
Full	Having roundness and pronounced tea character. Mature, rich, ripe, smooth.
Grassy	Similar to weediness, but reminiscent of grass rather than other types of vegetable growth. It is best described by likening, it to the taste one gets from chewing freshly-plucked grass.
Harsh	(as "Raw") – bitter, immature, unfinished.

Malty	Suggestive of malt, caramel, toffee; Assam character chiefly, but found not infrequently in tea from Ceylon. A character akin to maltiness is produced by a slight degree of over-firing.
Meaty	Full-bodied, thick. Implies that the useful property of the tea so described is backbone rather than quality.
Mellow	Smooth, finished, settled. Having no harshness or rasp as a result of immaturity.
Metallic	Either an intrinsic character suggestive of metal, or contamination from various metals.
Mouldy	Definitely and indisputably mouldy. Strongly reminiscent of mildew or bad walnuts.
Muddy	(as "Dull") – without unpleasantness but uninteresting.
New	Having not had sufficient time to mellow.
Old	Having lost, through age, those attributes which may originally have commended it. Flat.
Out of Condition	General term, descriptive principally of mould, but may be applied more loosely to other detrimental characters.
Plain	Clean and innocuous, but lacking flavour, body and tea character.
Pointy	Brisk, alive, vital. Akin to pungency, but not possessing the degree of bite implied in this term.
Pungent	Having bite and astringency, but without bitterness.
Quality	Denotes a preponderance of desirable attributes.
Rainy	Applicable to tea produced in India during the monsoon. Thin, weedy, mushy, full of moisture. Usually plain and light.
Raw	(as "Harsh") – bitter, immature unfinished.
Smoky	Suggestive of contact with smoke from coal fire.
Soft	Lacking bite and briskness.
Sour	Having the tang either of sour milk or of rotten fruit.
Spicy	Having dry character suggestive of spices (*e.g.* cinnamon, cloves, mace, myrrh, frankincense, etc.)
Stewy	Unpleasantly strong and thick as a result of over infusion.

Strong	Possessing a powerful tea character, but not necessarily thick.
Sweaty	Disagreeable and nauseating taste, reminiscent of perspiration.
Sweet	(as "Clean") – free from unpleasant character, but possessing no particular attribute.
Synthetic	Artificial flavouring. Applies particularly to use of chemicals. (The characters produced by inclusion during manufacture of jasmine or gardenia are "synthetic" in the sense that they are unnatural to tea, but since these flavours are recognised and accredited, they are never referred to as such).
Tainted	A tea having a foreign aroma. May result from bacterial infection or from contact with a foreign body, *e.g.* oranges, onions, kerosene.
Thick	Having body, but not necessarily strength.
Thin	Lacking body, but not necessarily flavour.
Tinny	A character imparted to tea stored in an unseasoned sample tin. Also applied to a very similar flavour which sometimes occurs naturally.
Tired	(as "Flat") – having lost character and briskness as a result of being kept too long.
Toasty	(as "Bakey") – a degree of burn, produced by slight over-firing. Reminiscent of burnt chocolate
Under-infused	Washy and watery as a result of too little time being allowed for infusion.
Washy	Thin, watery, little tea character.
Weak	Thin and tasteless as a result of too little tea being used.
Weathery	Unpleasant character. Rains tea. Sometimes referred to as "Prune" character.
Weedy	Suggestive of herbs or the acrid juice from vegetable matter.
Wood-fired	Reminiscent of charcoal or wood fires. The character is actually produced by firing in this manner.
Woody	Suggestive of saw-dust or freshly-cut timber.

CHAPTER 3

THE BIOCHEMICAL RELATIONSHIP OF PESTS AND PATHOGENS TO TEA

The relationship between the host plant and its predators is a subject which has aroused interest in recent years, but received little attention in the case of the tea bush. Apart from its academic interest, it is potentially of great practical value for evolving rational methods for the control of predators and pests, especially at a time when even trace amounts of pesticides are being banned by consumer countries on account of the harmful cumulative effects of their residues on human well being and the environment. At the present time, the host-plant relationship existing between the tea bush and the insect predator, *Xyleborus fornicatus*, is the only one which has been extensively studied, and the results suggest that the prolifera-tion of this insect could be controlled without recourse to the use of chlorinated hydro-carbons.

Xyleborus fornicatus

Xyleborus fornicatus, the shot-hole borer beetle of tea, was first detected in 1892 at Craighead, and has been a major pest of mid-grown tea ever since. A close study of its life history revealed that tea bushes are attacked by the female adult and that these attacks cause a significant reduction in the vegetative harvest of tea, and also predispose the bush to invasion by other pests, notably termites. The results of intensive studies during the past half century have provided the following salient findings :-

(1) The pest was most active in the elevation range of the mid-country, *i.e.* 150 m to 1300 m,

(2) Certain clones of tea (TRI 2025, TRI 1114, TRI 777, QT 1/5 NL 4/2 DG 39, CH 13) were more susceptible to attack than others (TRI 2023, TRI 2151, TRI 2024, TRI 2027, TRI 2016, DG 7, DT 1).

(3) *X. fornicatus* attacks tea stems, particularly those of pencil thickness (10 mm) covered with streaky, reddish-brown bark,

(4) Stems covered with bark were preferred to those stripped of bark,

(5) Nodes were preferred to internodes.

(6) Bushes were most susceptible to attack at 12 – 24 months after pruning.

(7) The female adult beetle carried spores of the ambrosia fungus (*Monacrosporium ambrosium*) in a buccal pouch (mycangium) and inoculated these spores on to the walls of galleries formed by boring into the stem. These spores germinated in the galleries, and the beetle laid 15 – 20 eggs on the fungal mycelium. The eggs hatched out into larvae within a few days and moulted several times in the course of the next 3 – 4 weeks to give rise to pupae, which finally changed to the adult beetle 4 – 8 days later. Male adult beetles were found to be smaller (1.5 mm x 0.9 mm) than females (2.25 mm x 1.5 mm), and both were yellowish at first, but in a few hours the colour deepened until the females were entirely black; the males took much longer to attain their colour, which was finally of a lighter tint than the female. The parent female lived in the gallery for about 3 weeks after the broods had emerged, at which time (*i.e.* 7 – 8 weeks after the entrance of the parent beetle) the female offspring emerged from the stem and flew off to infest another tea stem; males were dwarf and flightless and did not leave the gallery.

In an attempt to explain some of these findings, detailed chemical analyses were carried out of segments of tea bushes of different clones of tea growing at varying elevations. The results indicated that the preference of the beetle for tea growing at 150 m to 1300 m (*i.e.* mid-country) was due to the ambient temperature (23 – 26°C) in this region of Sri Lanka being favourable for the development of the beetle and its associated fungus. The beetle did not thrive at higher elevations because the temperature range was too low, whereas at lower elevations, conditions were too hot for their proliferation.

The clonal preference of *X. fornicatus* in the mid-country region were found to be dependent on the availability of a sterol known as α – spinasterol which is present in all parts of the tea bush from root to growing tip. This sterol is abstracted from the tea stem via the ambrosia fungus, and transformed in the beetle to moulting hormones, which are essential for the development of larvae to pupae. It was found that clones which are susceptible to infestation (*e.g.*

TRI 2025) contained more α – spinasterol than tolerant clones (*e.g.* TRI 2023). Apart from this higher α – spinasterol content, susceptible clones contained less of a class of compounds, known as saponins, than tolerant clones. This finding is of significance because two well-known properties of saponins are their ability to bind sterols to form a complex from which the sterol is not available to the beetle, and their inhibition of the growth of fungi. Hence the saponin level is a key factor in determining the susceptibility of tea clones to infestation by *X. fornicatus*, and indicates that it would be possible to control shot-hole borer beetle by increasing the saponin content of the tea bush. One of the methods of effecting this increase is by spraying saponin solutions, and it is therefore, fortunate that both tea seeds and tea roots are rich in saponins. Tea roots, especially feeder roots, were found to contain about twice as much saponin as tea seeds and would appear to be a more suitable source of saponins than tea seeds. However, tea roots also contain a very high level of the amino acids, theanine and arginine, which prevent the binding of sterol by saponin and may, therefore, be expected to render ineffective their use for the control of the beetle. This difficulty has, however, been overcome by adding Copper to the tea root extract, because Copper has the property of forming complexes with these amino acids and removing them from the sphere of action. These findings may be summarized as in Figure 8.

FIGURE 8

FACTORS AFFECTING FORMATION OF MOULTING HORMONES

Sterol + Saponins ⇌ Sterol – Saponin complex

theanine or arginine

↓

Insect moulting hormones
(essential for pupation)

A second method for increasing the saponin content is to supply the tea bush with the material from which it synthesizes saponin. One such material is acetate, and it has been found that the simple addition of a small quantity of potassium acetate (0.3 grams per bush) to the normal NPK tea fertilizer resulted in a reduction of the degree of infestation by shot-hole borer. As expected, the effect of this acetate addition was most inhibitory to the development of the beetle larvae to pupae.

The foregoing considerations regarding saponin levels account for the varying susceptibility of different clones of tea to *X. fornicatus,* but do not explain the observed preference of the beetle for the pencil thick stem, and particularly the nodes in this portion of the stem. Further investigation revealed that this preference was due to the moisture content (61–63%) of the pencil thick stem being critical for successful infestation; the green stem above this region had a moisture content more than 61 – 63%, and the more mature stem below had less moisture. One of the reasons for the particular attraction of the *node* was found to be its higher content of α – spinasterol as compared to the internode region. The effect of age from pruning on infestation was found to be due to the high content of saponins during the early post-prune months, whereas the reduction in attack during the later post-prune months is attributed to the low moisture content in the frame of the bush.

In summary, the study of the host plant – pest relationship between tea clones and *X. fornicatus* illustrated that host preference was dependent on ambient temperature, moisture content of the stem, and the availability of α – spinasterol. The finding that saponins reduced sterol availability has suggested practical means of controlling the beetle pest, without recourse to the use of organochlorine insecticides.

Red Mites

Red Mites attack tea only during the dry season, and disappear as soon as the rains appear. This behaviour is reminiscent of the incidence of tea flavour, and suggested that flavour and red mite infestation may have something in common. This was, in fact, found to be true, the common factor being the carotenoid, rhodoxanthin. This red carotenoid is responsible for the colour of the mite, and appears in tea flush only during the flavour season as a result of the shift of metabolic pathways due to the disorganisation of the chloroplast as described earlier (page 17) The requirement of this carotenoid by the mite is possibly for its reproduction, although this has not been fully established. It is of interest to note that the red mite abstracts rhodoxanthin from the tea leaf by piercing the chloroplast and this damage of the chloroplast may provide the conditions necessary for flavour development (page 17), and so lend support to the contention of those who maintain that there is some correlation between flavour and mites. It may also be mentioned here that the belief of some Darjeeling planters that greenfly induces Darjeeling flavour may be due to a similar role of greenfly in damaging the leaf chloroplast structure. In the case of yellow and purple mites, it is tempting to assume that their colour is due to the commonly occurring yellow and purple carotenoids, but evidence for this assumption is lacking.

"Dimbula Disease"

"Dimbula Disease" is not caused by a pest or pathogen, but is, nevertheless, included here to illustrate another biochemical relationship. The observed symptoms of tea bushes affected with Dimbula Disease are profuse production of flowers and seeds, followed by chlorosis, progressive defoliation, and ultimate death of the bush. No pathogen could be isolated from these bushes, and various hypotheses have been proposed to account for this condition, *e.g.* aging of the bush, water logging, lack of aeration of the root system, decay of the root system, soil characteristics etc., but no evidence in support of any of these hypotheses is available.

A comparison of some of the chemical constituents in different segments of healthy and diseased bushes gave the data shown in Table 8, which indicate that there is an accumulation of amino acids, saponins and nitrogen, in the collar region of diseased bushes, suggesting that the flow of nutrients through this region of the bush is restricted. The occurrence of this restriction was confirmed by observing the passage of a coloured dye absorbed by the roots – in healthy bushes the colour spread throughout the frame of the bush and was apparent in the leaves as well, whereas in the diseased bush it moved only up to the collar and did not progress beyond this region. Apart from this restriction to flow in the collar, the results in Table 8 also show a very low moisture and K content in feeder roots, indicating that these have decayed in efficiency, with a consequent reduction in capacity to absorb moisture and nutrients. On the basis of these findings it appears that Dimbula Disease is caused by a sequence of events as follows – a restriction to the flow of nutrients in the collar region of the bush – starvation of the leaves, due to deprivation of nutrients from the root – defoliation – decay of feeder roots deprived of nutrient from the leaves – reduced uptake of nutrients from the soil – starvation of the bush – death. It is seen that the first step in the disease is the restriction in the collar region of the bush, which is probably an effect of age. The practical application of these findings is the inference that the only cure for Dimbula Disease is hard pruning of the bush below the level of the area of restriction, *i.e.* a rejuvenation prune. This measure will, of course, be useful only if it is taken at the first appearance of symptoms of disease, before decay of the feeder roots has progressed beyond the stage of their rehabilitation.

Studies of the relationship between the eelworm and different tea clones have shown that there was a sharp increase in polyphenols when roots of resistant clones were infested by this nematode, whereas in susceptible clones, there was a reduction in the free polyphenol content. These findings suggest that a detailed study of the relationship between polyphenols and eelworm infestation may yield results of practical value.

TABLE 8

COMPARISON OF SEGMENTS OF NORMAL AND DIMBULA DISEASED BUSHES

	Moisture		*Amino acid*		*Saponin*		*Nitrogen*		*Potassium*	
	H	*D*	*H*	*D*	*H*	*D*	*H*	*D*	*H*	*D*
Feeder Roots	72	31	35	1.3	13000	1280	0.55	0.79	1.03	0.53
Lower Root	50	58	4.5	3.7	28000	10500	0.53	0.74	1.14	0.44
Upper Root	50	55	3.3	3.9	3200	1800	0.54	0.68	0.94	0.50
Collar of Bush	55	50	1.5	4.1	1500	6000	0.56	0.70	0.91	0.56
Mature Stem	58	45	1.5	1.4	400	300	0.42	0.45	0.53	0.54
Tender Stem	54	46	1.1	1.3	400	800	0.56	0.66	0.50	0.51

H — **Healthy bush**

D — **Dimbula Diseased bush**

CHAPTER 4

THERAPEUTIC VALUE AND BY-PRODUCTS OF TEA

Therapeutic value

Apart from water, tea is the most popular beverage in the world, and one reason for its continuing popularity is that no harmful properties have been associated with tea over the period of more than 45 centuries since the time of its discovery. Recent evidence indicates that tea drinking is, in fact, beneficial to human well-being, and that the unique chemical composition of tea distinguishes it from brews prepared from a variety of other vegetable materials *e.g.* camomile, mate, etc., which are loosely referred to as "teas."

Nutritionally, tea brews contain marginally useful amounts of proteins (1 – 2%), carbohydrates (4 – 5%), amino acids, lipids, and vitamins. The mineral content of tea is about 5%, and many of the minerals identified (*e.g.* potassium, magnesium, calcium, manganese, zinc, iron) are essential to human health. In respect of these, tea drinking provides significant amounts of the daily requirements of potassium and manganese, but only a small proportion of the requirements of the other minerals. Tea brews also contain 2 – 3 parts per million of fluoride, and it has been estimated that tea drinking can contribute a substantial proportion of the human requirement of fluoride which is necessary for the prevention of dental caries, although over-sugaring of tea tends to nullify this beneficial effect.

Numerous pharmacological effects are claimed for tea, and many of these have been attributed to caffeine and polyphenols. It is important to realize that excess of either of these compounds individually may be harmful, but their occurrence in combination nullifies the undesirable effects. Caffeine has the effect of dilating the blood vessels, resulting in an increase in the rate of respiration and in the amount of work which can be performed by the muscles without elevating the pulse rate or blood pressure. It also has a diuretic effect on the kidneys, stimulates gastric secretion and mental alacrity, and relieves mental fatigue. Excessive doses of caffeine can invoke anxiety and an unpleasant gastric sensation, but tea drinking does not result in these side effects because the concomitant presence of polyphenols in tea, modifies the pharmacological action of caffeine.

Investigations in Russia have shown that tea polyphenols possess the property of strengthening the walls of blood vessels and regulating their permeability, and these desirable effects are ascribed to the presence in tea of a compound designated "Vitamin P ". Several well authenticated reports have also been published on the usefulness of tea in preventing heart disease, and here too the evidence suggests that the active principle is polyphenolic in nature.

Other effects claimed for tea are anti-inflammatory action, normalization of thyroid hyperfunction, radioprotective effect and antibacterial properties. Considering each of these in turn, the anti-inflammatory action is believed to be due to polyphenols, and the time-honoured practice of treating burns with brewed tea leaves is an empirical recognition of its efficacy. The normalization of hyperthyroid function, which leads to thyrotoxicosis and goitre, has been attributed to the activity of the gallocatechin fraction of the polyphenol mixture, and it has also been claimed that tea affords protection against the development of leukaemia after exposure to radiation. Infusions of tea have been shown to act bacteriostatically on typhoid, dysentery, and cholera bacilli, and for this reason, tea has been used in Russia for the treatment of several bowel diseases caused by bacteria.

Some harmful effects have however, been attributed to tea, and these relate to carcinogenesis, and an alleged correlation between tea drinking among expectant mothers and the subsequent incidence of anencephalic births. The majority of claims for carcinogenic effects are based on epidemiological investigations of doubtful validity, and on the results of injection into mice of the chemically isolated polyphenolic fraction of tea. Apart from the unnatural method of administration of the tea, the separation of the polyphenolic fraction from the other constituents of tea, notably caffeine, introduces another abnormal factor and the findings do not, therefore, provide evidence that the drinking of normally brewed tea is, in any way, hazardous because, as mentioned earlier, the pharmacological effects of caffeine or of polyphenols *per se*, are modified in tea in such a way as to eliminate their individually harmful effects. The claim that has been made of a correlation between tea drinking and anencephalus is questionable, because the evidence adduced does not justify the conclusion of a direct relationship. The consensus of opinion would therefore favour the view that tea is a pleasant and stimulating beverage, possessing nutritional and pharmacological properties which are beneficial to health.

By-Products of tea

At the present time, black tea is the only product of commercial importance from the vast acreage in Sri Lanka which is cultivated in tea. There is, however, no reason to continue with this almost traditional practice, and diversification of the product to other forms of tea, *e.g.* instant, carbonated and green tea, and tea wine is a pressing need. These, however, are not discussed here as they may be considered to be primary products and, therefore, outside the purview of this resumé, and the true by-products obtainable from the different parts of the tea bush are shown in Table 9.

TABLE 9

BY–PRODUCTS OF TEA

Source	*By-products*
Tea Leaf	Caffeine, Pigments, Antioxidants, Protein, Cellulose
Tea Seed	Saponin, Oil, Protein, Pipecolic Acid
Tea Bark	Tannins
Tea Root	Saponin, Theanine, Growth Hormones

Caffeine

The most obvious source of caffeine in a black tea producing industry is waste or refuse tea, which accounts for 3 – 4% of black tea production. Tea waste contains 1.5 – 3.5% caffeine, and the commonly used methods for extraction of the alkaloid is by the use of solvents. Trichloroethylene, carbon tetrachloride, benzene, alcohols, and various mixtures of these have been used for this purpose, and are the subject of several patents. However, competition from synthetic caffeine has made inroads into this once profitable industry, and it seems that the future of natural caffeine processes will depend on the profitable utilization of the residue after caffeine extraction, perhaps for the recovery of protein.

Pigments

Russian workers have developed methods for the extraction of vitamin-containing food dyes from non-standard tea leaf. The three different coloured compounds extracted were green, yellow and brown, corresponding to chlorophyll, partially oxidized, and fully oxidized polyphenols, respectively. Similar coloured compounds are also present in waste tea, but it does not appear that these dyes are being used to any great extent in the food industry. As in the case of caffeine, synthetic dyes appear to be used in preference to natural products.

Antioxidants

The catechins in tea are very useful antioxidants and may be used for the prevention of the development of rancidity in oils. Their activity is due to the affinity of catechins for oxygen, which preferentially attaches itself to these polyphenols rather than to the fatty acid moieties in the oils.

Protein

Tea waste, as well as brewed tea leaves, contain 20 – 30% of protein which may prove to be an useful adjunct to animal and poultry feeds. Furthermore, about half of this protein is extractable with dilute alkali and this soluble protein could be of great value for the fortification of human foods. This application of waste tea is, perhaps, one which needs to be studied in the greatest detail in the context of the current shortage of inexpensive protein supplements.

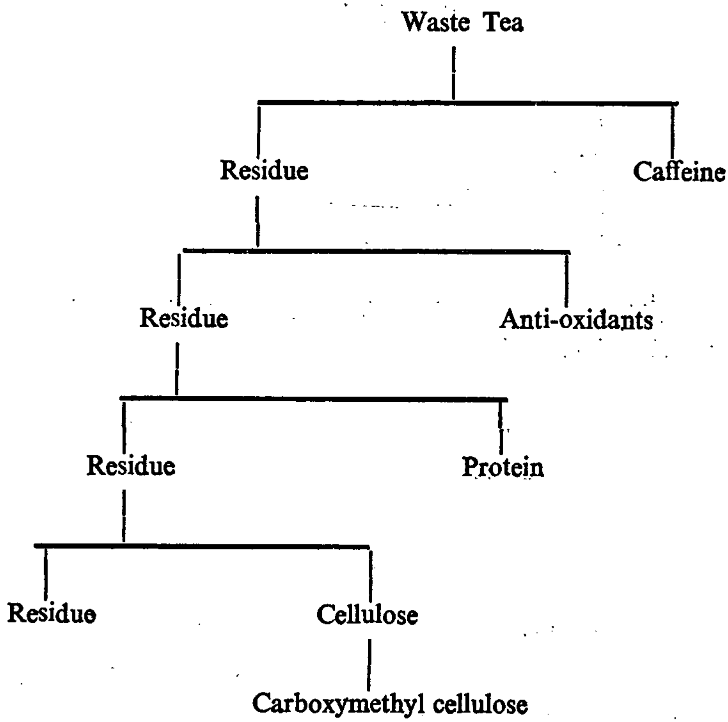
Cellulose

The residue after protein extraction contains about 20% cellulose and 5% pectin, and these products too may find uses as such, or after chemical transformation to other products.

It is evident, therefore, that several by-products are obtainable from waste tea or tea leaf, but it is doubtful whether the extraction of any one of them would, by itself, be a profitable commercial enterprise. It is likely, however, that the successive utilization of the residue from one process for extraction of a different compound, might pay dividends. A possible flow scheme, using waste tea as raw material, is envisaged in Figure 9. In this scheme about 50% of the available material in waste tea would be gainfully exploited.

FIGURE 9

BY–PRODUCTS OF WASTE TEA

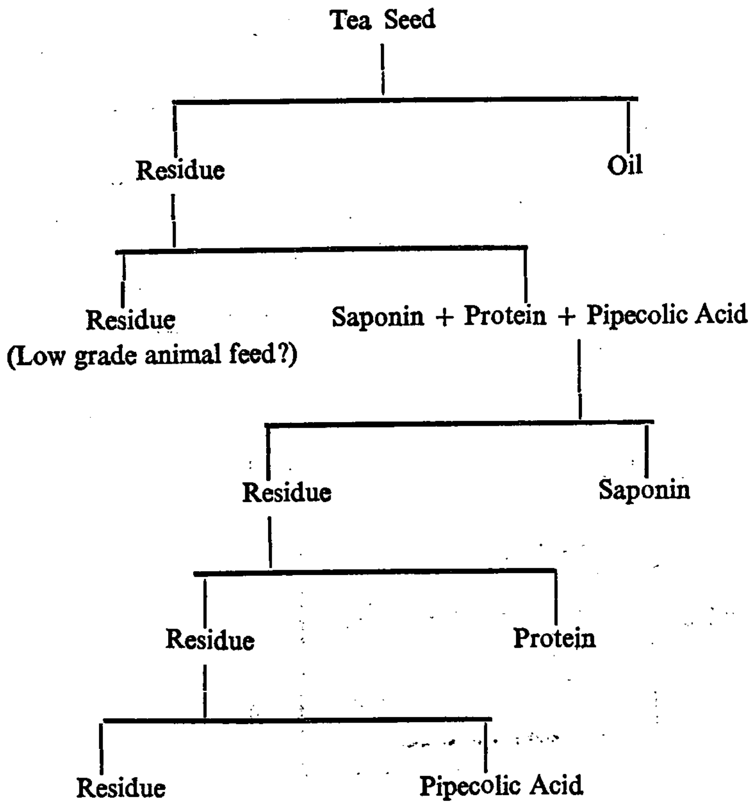


Tea Seed

Mature tea seeds have been found to contain several products of potential use and here again, as in the case of waste tea, exploitation of all the possible products is necessary for commercial feasibility, and a suitable scheme for the processing of tea seed is shown in Figure 10. Considering each of these products separately, tea seed oil is an edible oil having properties very similar to those of olive oil, and is considerably less "saturated" than coconut oil. It may, if required, be also used for soap or margarine production. The soluble protein from tea seed is eminently suitable as an additive to human food (*e.g.* bread, buns, biscuits); the amount of soluble protein obtained is about half of the total protein content of tea seed, but its amino composition indicates that it is of high nutritive value. With regard to the saponins, these may be used as detergents, but their potential for the control of insect pests (*e.g.* shot-hole borer) may prove to be its principal application.

FIGURE 10

BY–PRODUCTS OF TEA SEED



The fourth constituent of mature tea seed, L-pipecolic acid, is present in only small quantity, but it is a product of some value, being sold at a price of about U.S. $40 per gram. The final residue containing about half the protein in an insoluble form may find use as a low grade additive to animal and poultry feed, although this possibility needs further investigation. It is noteworthy that immature tea seeds do not contain any saponin or oil, but have a remarkably high content of L–pipecolic acid.

Tea Bark

Tea bark contain tannins, the nature of which are similar to those occurring in myrobalans, which is widely used for the tanning of leather. It has been demonstrated that tea bark is effective in leather production, where it yields a product comparable to that obtained by the use of imported wattle tannin. It is likely that the most expeditious source of tea bark would be prunings.

Tea Roots

Tea roots contain high levels of saponin, theanine and growth hormones, all of which are of potential value, but the raw material for this purpose will become available only during uprooting prior to replanting. Theanine is a compound of great academic interest as its occurrence in tea is unique, but it could also find practical uses as an enhancer of green tea flavour and as a hydrogen bond breaker. The exact nature of the growth hormones remains to be elucidated, but these too would be valuable by-products of the tea bush, on account of their plant growth promoting properties.

CHAPTER 5

INSTANT TEA AND REFLECTIONS OF THE FUTURE

Instant Tea

Consumer preferences for tea have remained remarkably static over the centuries, although some changes have occurred in the recent past, and particularly so in the manner of presentation, where bulked tea packages are now losing ground to black tea in the form of individual tea bags. This change is largely due to the growing world demand for the factors of convenience and ease of disposal. For these same reasons, and following the popularity of instant coffee which was developed at the end of World War II, there was a surge of activity during the mid-1950's in instant tea production. The early instant tea processes used the methods which had been developed for instant coffee production, but it soon became evident that the differences in chemical composition of tea brews necessitated modifications in the basic steps of extraction, concentration and drying which had been successfully used for processing instant coffee. An additional factor needing consideration in instant tea production is the popularity of cold water soluble instant teas in the United States of America, where this product, particularly in the form of iced tea mixes, accounts for over 40% of all tea products sold in that country. On the other hand, much of the instant tea sold outside the United States is soluble in hot water only, but this accounts for only a small proportion (less than 5%) of total tea sales. The popularity of these hot water soluble tea has not grown at anywhere near the rate of cold water soluble teas, probably because there is hardly any advantage with respect to convenience between tea bags and hot water soluble instants.

Processes for instant tea production have been protected by patents, which are too numerous to describe here, but in all innovations the first requirement is to prepare a suitable extract of the starting material, which may be green tea leaf, fermented leaf or fired tea. Exhaustive extraction of all the tea solids is undesirable as this imparts a "stewed tea" characteristic, which persists in the final product. At the same time, too light an extraction would render the process uneconomic as a consequence of useful tea solids remaining unutilized. Care must therefore be exercised to ensure that the correct balance is struck between excessive extraction and the optimal level of extractable tea solids. Several extraction processes have described, some of which are (a) countercurrent extraction, (b) percolation systems, (c) percolation, followed by extraction at a high temperature and high pressure of the residue from the first extraction, (d) extraction with hot water followed by squeezing the residue in a hydraulic press.

Subsequent to extraction, many patents incorporate a process for recovering the delicate aroma of tea from the extract, followed by concentration of the aroma, and addition of this concentrate to the final dried tea powder. It appears, however, that no satisfactory method has yet been developed which provides a true tea aroma, the reason being that it is difficult to obtain a concentrate with the correct quantitative distribution of the numerous chemical compounds which are essential for the delicate flavour characteristic of tea.

In the case of hot water soluble instant teas, the next step is concentration of the extract to provide 30 – 40% of tea solids, because this is a requirement for final drying to a powder. This concentration is generally achieved by removal of water under reduced pressure at an elevated temperature, and several types of equipment have been designed for this purpose. Numerous reactions occur during this process, among which are almost complete loss of the volatile compounds responsible for tea aroma, and a variety of chemical reactions which detract from the desired characteristics of tea. It is therefore necessary to effect the concentration step in conditions which minimize these undesirable consequences, and this is achieved by minimizing the temperature and time of vacuum concentration, or by a process known as freeze concentration.

Final drying of the concentrate to the instant tea powder has been effected by a variety of processes, *e.g.* spray drying, vacuum belt drying, foam mat drying or freeze drying, although spray drying is, at present, the most widely used method.

Cold water soluble instant teas are more difficult to prepare and require additional processing steps. The main problem here is solubilization of the tea cream (page 14) without removing too much of the tea quality. This requires great care, because as mentioned earlier (page 14) there is a direct relationship between quality and cream formation. Among the methods for cream solubilization described in the patent literature are oxidation of the cream, treatment with sulphites, the use of enzymes, and gel filtration techniques. It is necessary to emphasize here that tea cream may be considered to lie at the heart of tea quality, and attempts at cream solubilization must always be of a mild nature.

Reflections on the future

A great deal of knowledge regarding the agricultural aspects, chemistry and technology of tea has been amassed, but several fields of investigation still remain open. One such field is the development of methods for prolonging the storage life of processed teas, which would result in the preservation of quality and flavour for periods of up to at least one year. A complementary requirement is the development of packaging techniques which would eliminate the dependence of the Sri Lanka Tea Industry on plywood, which is expensive and, sometimes, hard to procure. In this connection, one could envisage that the application of encapsulation techniques, whereby each individual particle of tea is individually wrapped in some innocuous material, would not only improve the storage properties of tea, but also eliminate the dependence on plywood chests. In addition, new forms of tea presentation, *e.g.* high quality instant tea powders with solubility in either hot or cold water, tea concentrates, carbonated tea and iced tea mixes are convenience beverages which have a bright future in selected markets. Another technological requirement is for the development of processes for exploiting the by-products obtainable from waste tea and from various parts of the tea bush, as this would add to the viability, and enhance the profitability of the Tea Industry.

The development of techniques for increasing yields of tea is another requirement. Vegetative propagation of selected clones of tea has already had a significant impact in this area, but the methods of clonal selection itself are, at present, time-consuming and laborious, and alternative methods need to be evolved for the rapid evaluation of the potential of clonal material. A dynamic study of the genetic characteristics of clonal tea should be a part of this programme.

The relationship of the tea plant to its pests and pathogens is another area of study which may be expected to pay rich dividends. Evidence has already been obtained that control of shot-hole borer beetle may be achieved by simple and inexpensive measures which do not involve the use of costly insecticides with their attendant environmental hazards. These studies should certainly be extended to study the relationship of the tea bush to attack by blister blight and by termites.

Methods for the optimization of uptake of the fertilizer applied to tea would confer great economic benefits, and requires a concerted effort, involving a study of the physical properties of the soil, the use of isotope techniques, the biochemistry and physiology of the uptake of nutrients, as well as soil microbiology. It is evident, therefore, that although much has already been achieved, research on tea offers great scope and opportunities for investigation in the future.

GLOSSARY

Aldehyde : A class of chemical compounds which contain a special grouping of atoms, common examples of which are formaldehyde and acetaldehyde. Many of them are volatile compounds possessing a marked odour, which may vary from unpleasant to pleasant.

Amino acid : A class of organic acids which are the building blocks of protein. They are essential for the nutrition of all living organisms where they occur either in the free form or in combination as proteins. Over a hundred naturally occurring amino acids are known, although only about 25 of these are found in proteins.

Caffeine : Caffeine is one of a group of compounds known as alkaloids, which contain nitrogen, have basic properties and are found only in plants. Other examples of alkaloids are nicotine, morphine and quinine. As a class, these compounds have a bitter taste and are pharmacologically active.

Carboxymethyl cellulose : A derivative of cellulose, much used in the soft drink industry.

Carotenoid : A group of naturally occurring compounds of which more than sixty are now known. They are insoluble in water, but dissolve in fats. They are found in all leaves and several fruits. Examples are β-carotene, which is converted to Vitamin A in the liver, and lycopene which is responsible for the red colour of tomatoes.

Catechin : A very important constituent of tea, described on (page 10).

Catechin gallate : A very important constituent of tea. It is the gallic acid derivative of catechin.

Chebulagic acid : A tannin found in tea as well as in material used for tanning leather. A very astringent compound which is more abundant in low-grown than high-grown tea, and partly responsible for the poor quality of the former.

Chlorophyll : The green pigment of plants which is essential for trapping the energy of sunlight. This energy is locked in the sugars and other carbohydrates of plant, and this property of chlorophyll is essential for the sustenance of all forms of life.

Chlorophyllase : An enzyme which occurs in all leaves and causes the biological degradation of chlorophyll.

Chlorophyllide : A compound formed by the breakdown of chlorophyll by chlorophyllase (page 6).

Chloroplast : The structure in the leaf which contains chlorophyll and certain other compounds. This is a very important component of leaves and is the site at which the carbon dioxide in the atmosphere is converted to sugars and other carbohydrates.

Corilagin : A tannin similar to chebulagic acid (see above).

Depside : A compound formed by the combination of two acids. Theogallin is an example, formed by the combination of gallic acid and quinic acid.

Dihydroactinidiolide: A chemical compound which is important for good tea flavour. It is formed during fermentation and firing of black tea as a result of the degradation of β-ionone.

Dimethyl Sulphide : A chemical compound which has a harsh odour, reminiscent of cabbages. This compound detracts from tea flavour and is more abundant in low-than high-grown teas.

Encapsulation : A technique for coating particles, oils, or other material with a protective layer, which prevents deterioration of material in the capsule, *e.g.* cod liver oil pills.

Enzyme : Enzymes are proteins which catalyze the reactions occurring in living organisms. All but a very few of the reactions carried out by living organisms are enzyme-catalysed, and all organisms produce enzymes. Enzymes are responsible for building up large compounds or breaking them down to their constituents, and thousands of different enzymes are known. Common examples are papain, chlorophyllase and pepsin.

Epidermal layer : The outer layer of cells of living organisms, also known as the epidermis (see Fig. 4).

Etiolated : The pale, yellowish condition of plants growing in the absence of sunlight. The plants are characterized by a lack of chlorophyll, and show a tendency to elongation in their attempt to grow out of their dark environment and reach light.

Fatty acid : Organic acids, which are derived from the breakdown of fats. Common examples are acetic acid, palmitic acid, stearic acid, which differ from inorganic acids, (*e.g.* hydrochloric and sulphuric acids) by their containing one or more carbon atoms in their chemical constitution.

Flush : The young and tender leaves of plants. Tea flush refers to the unopened terminal bud and two adjacent leaves borne at the tip of tea shoots. Also referred to as "two and a bud", they are the ideal unit for processing to good black tea.

Gallic acid : A commonly occurring acid, found in coffee, tea, nut galls, and a number of tannins.

epi-Gallocatechin and epi-gallocatechin gallate : The major polyphenolic component of tea, described on page 10.

Geraniol : A sweet smelling chemical compound found in small, but important quantities in tea. It is the chief constituent of Geranium oil.

Glutamate – (mono-sodium) : The active constituent of Ajinomoto, used to accentuate meaty flavours.

Hexenal : (trans -2-): A constituent of tea flavour. Excess of this aldehyde is considered to be detrimental to tea flavour.

Inosinic acid – 5-phosphate : A chemical compound which enhances the flavour of meats and soups.

β-Ionone : A sweet-smelling compound which is an important constituent of tea flavour. It is formed by the decomposition of certain carotenoids during fermentation and firing. It is the main constituent of the aroma of violets.

Jasmone (cis-) A sweet-smelling compound which is an important constituent of tea flavour. Occurs in jasmine flowers.

Jat : Variety of tea. High jat tea is the large-leaved Assam variety, low jat is the small-leaved China variety.

Leucine : An amino acid, which is converted during withering and fermentation to compounds (*e.g.* linalool), which are of importance for tea flavour. Leucine is also part of the complexes responsible for the colour of tea liquors. It is an essential requirement for the growth of plants and animals.

Linalool : A very important constituent of tea flavour. It is the principal component of oil of bergamot, which is used for the preparation of scented teas.

Linolenic acid : The principal fatty acid of tea leaf. It is converted during rolling and fermentation to *trans* – 2 – hexenal, which detracts from tea flavour.

Lipid : A class of fatty compounds which are insoluble in water, but soluble in solvents such as ether and chloroform. They include the waxes, oils and fats. Their oxidation in air during storage of tea leads to the formation of compounds which detract from tea flavour.

Lipoprotein : Complex containing protein and lipid in combination. This complex protects the cholorophyll molecule from the action of acids. This protective, effect is lost during firing due to disorganization of lipoprotein as a result of coagulation of the protein at the high temperature during firing.

Mesophyll : The cells which lie in the middle portion of the cross-section of a leaf. They are bounded above by the upper epidermis and upper palisade layer of cells, and bounded below by the lower epidermis (see Fig. 4).

Methionine: An amino acid which contains sulphur. Excess of this amino acid is harmful to tea flavour. It is, however, essential for the growth of plants and animals.

Mevalonic acid : One of the key compounds of plant metabolism, which may be derived from either acetate or leucine. On further metabolism it is converted to essential oils, carotenoids, or sterols, all of which are important in tea and other plants.

Minerals or Mineral elements : The inorganic constituents of plants and animals *e. g.* Nitrogen, Potassium, Phosphorous, Calcium, Copper, Manganese, Magnesium, Molybdenum, Boron. They are essential for the healthy growth of plants. Some are required in large quantities and others in trace amounts.

Mycelium : The vegetative portion of fungal growth, as distinguished from spores, which are the reproductive portion.

Non-Saponifiable portion : Those constituents of plants or animals which are unaffected by treatment with caustic soda or other alkali. These include the sterols and other compounds. Chlorophyll and oils, on the other hand are broken down by alkali. The breakdown of oils leads to the formation of soap and glycerol.

Nucleotide : An important and complex group of chemical compounds containing a nitrogenous base (*e.g.* adenine), carbohydrate (*e.g.* ribose) and phosphate. They are essential for the growth and multiplication of plants and animals.

Palisade Layer : The layer of elongated cells which lie adjacent to the epidermis in a cross-section of the leaf (see Fig. 4). In the tea leaf, the important group of polyphenolic compounds is located in the palisade layer.

Pan-Firing : The first stage in the processing of Chinese green tea, where the tea leaves are thrown into a heated pan or a hot rotating drum. The purpose of this practice is to prevent fermentation by inactivating the tea enzymes.

Peptidase : An enzyme which breaks down proteins to their constituent amino acids. In black tea processing, this enzyme plays an important role during withering.

Phaeophorbide : A brownish coloured breakdown product of chlorophyll. Excess causes the brownish appearance of teas.

Phaeophytin : A breakdown product of chlorophyll, which is black in colour. The black appearance of teas is due to phaeophytin.

Photosynthesis : Process by which the energy of sunlight is trapped by the chlorophyll of green plants and used to build up complex materials from carbon dioxide and water. This process is the basis for the sustenance of life on earth.

Phytol : A constituent of the chlorophyll molecule. It is also known as leaf alcohol.

Polyphenols : A group of related compounds which play a predominant role in making tea a unique beverage. These compounds are described in some detail in pages 9-12.

Tannin : A group of very astringent compounds which bind themselves to protein. They are responsible for the tanning of hides in leather production, where they combine with the hide protein. Tannins also combine with enzymes because these are proteins. The tanning of enzymes leads to inactivation or reduction of enzymic activity.

Theaflavin : The golden coloured product formed by the oxidation of polyphenols by polyphenol oxidase during the fermentation stage of black tea manufacture. It is essential for the quality of liquors, the copperriness of infused leaf, and the brightness of liquors. It does not occur in green tea.

Theaflavin gallate and Theaflavin digallate : Theaflavin with one and two molecules respectively of gallic acid in chemical combination.

Theanine : An amino acid of tea. This amino acid has not been detected in any other plant. Theanine is important for quality.

Theaspirone : A sweet-smelling chemical compound which is important for good tea flavour. It is derived from β-ionone.

Theobromine : A compound similar to caffeine. The amount of this alkaloid in tea is much less than that of caffeine. Theobromine, like caffeine, has important pharmacological properties.

Theogallin : A polyphenol of tea. The amount of theogallin in tea is high, but it has not been detected in any other plant. There is some correlation between theogallin content and quality of black tea.

Vascular bundle : The vascular bundle of leaves consists of those vessels through which materials are conducted through the plant, *e.g.* from leaf to root and *vice versa*. The veins of the leaf indicates the position of the vascular bundles in this part of the plant. They may be compared to the veins and arteries of animals.

Polyphenol oxidase : A key enzyme in balck tea processing. It converts the polyphenols to other compounds which determine the quality, colour, and part of the flavour of black tea lquors. However, it plays no part in green tea processing.

Polysaccharide : A large molecule consisting of a number of carbohydrate molecules joined together in chemical combination. Well known examples of polysaccharides are starch and cellulose, where the carbohydrate involved is glucose.

Porphyrin: A complex skeleton (see Fig. 1). which is found in chlorophyll, as well as haemoglobin.

Protein : A large molecule consisting of a number of amino acids joined together in chemical combination. All enzymes are proteins, but all proteins (*e.g.* casein) are not enzymes.

Quinone : A highly reactive compound formed by the oxidation of a polyphenol.

Rhodoxanthin : A red coloured compound belonging to the group of carotenoids.

Saponin : A class of compounds which froths on shaking with water. They are especially abundant in tea seeds and tea roots. They have the property of combining with sterols.

***α*-Spinasterol :** The major sterol of tea. It is an essential requirement for the development of the shot-hole borer beetle. Other examples of sterols are cholesterol and ergosterol.

Substrate : The compound, or class of compounds, on which enzymes act. The substrate of polyphenol oxidase is polyphenol. Each enzyme has a specific range of substrates, *e.g.* polyphenoloxidase has no action on proteins, sugars, fats, etc.

Volatile compounds : Compounds which evaporate and become gases. Volatility increases as the temperature is raised. More than 300 different volatile compounds have been identified in tea. These play an important role in determining the aroma and flavour of tea. They, therefore, also determine the valuation of a tea.

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