THE THEORY OF WITHERING IN TEA MANUFACTURE*

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Introduction

Is withering necessary in tea manufacture?

Withering is the first step in the manufacture of black tea by orthodox method (Eden, 1958; Keegel, 1958; Harler, 1963) and it has been so for centuries (Harler, 1955). Yet we still do not know with certainty how important withering is in the manufacture of black tea.

The machines used in orthodox manufacture have been built to operate most efficiently with flush of about 55% moisture content. Hence, it can be said at the outset that withering is necessary in this type of manufacture for the purpose of physically conditioning the flush for subsequent steps in manufacture. However, one may wonder whether the flush is withered merely to suit certain possibly outdated machines which are not flexible enough to accommodate flush of other moisture levels, or whether flush is withered because withering itself imparts some desirable characteristics to the final product. The answer to our question is especially important today as the tea industry eagerly searches for new, continuous, methods of manufacture which afford far greater control than is possible with traditional procedures (Keegel, 1962a; Trinick, 1963; Sanderson, 1963a).

Before we can answer our initial question about the necessity of withering it is imperative that we determine exactly what changes take place in tea flush during the withering process and how these changes affect the character of the final product; black tea. This information is of the utmost practical importance also, because if we know exactly what is desired from withering, we should be able to evaluate rapidly and objectively the potential of new withering machinery and processes.

This paper is an effort to bring together existing information on withering. Much of the work in our laboratory in recent months has been concerned with this problem, especially as it effects quality in tea, and it is now felt that enough information is at hand to formulate a theory of withering in tea manufacture. The changes now known to occur during withering will be discussed first and then the way in which these changes may affect the character of the made tea will be explained. Finally, an attempt will be made to answer our first question, *i.e.* "Is withering necessary?".

The Practice of Withering

The practice of withering is aptly described in three recent books (Eden, 1958; Keegel, 1958; Harler, 1963) and it will only be described briefly here as it relates to the discussion following.

In present day orthodox practice, plucked flush is brought from the field to the factory where it is spread thinly (about one leaf deep) on some porous material, usually jute hessian or nylon nets. It is allowed to wither there undisturbed for approximately eighteen hours. In Ceylon, South India, and North India (Darjeeling) the moisture content of the flush is normally reduced during withering from about 78% to about 55% whereas in North-east India and East Africa the respective moisture contents are more usually 78% and 68%.

Withering in the former tea areas is carried out under partially controlled conditions, *i.e.* in withering lofts which are integral parts of the factories, whereas in the latter areas withering has been carried out under virtually uncontrolled conditions, *i.e.* in open leaf houses or chungs. These differences in practices combined with differences in the prevailing weather conditions are in large part responsible for the different mositure levels in flush which have come to be accepted as standard in various parts of the world.

The trend now is to use new withering equipment and processes; namely withering troughs, withering tunnels, and withering drums; which allow uniform and consistant withers regardless of the prevailing weather conditions. Evaluation of these innovations is today, of necessity, largely empirical based as it is on trial and error and the subjective opinion of tea tasters.

Physical Withering

The loss of moisturef rom flush which occurs during withering is called physical withering. This process is the most obvious one occurring during withering and in fact the word withering means to become dry and sapless.

The progress of the physical wither under different conditions is shown diagrammatically in Figure I. Tea flush is hygroscopic as is most plant material and it tends to lose moisture most rapidly during the initial stages of withering. This is shown by the three curves in Figure 1 relating to "Normal Withers".

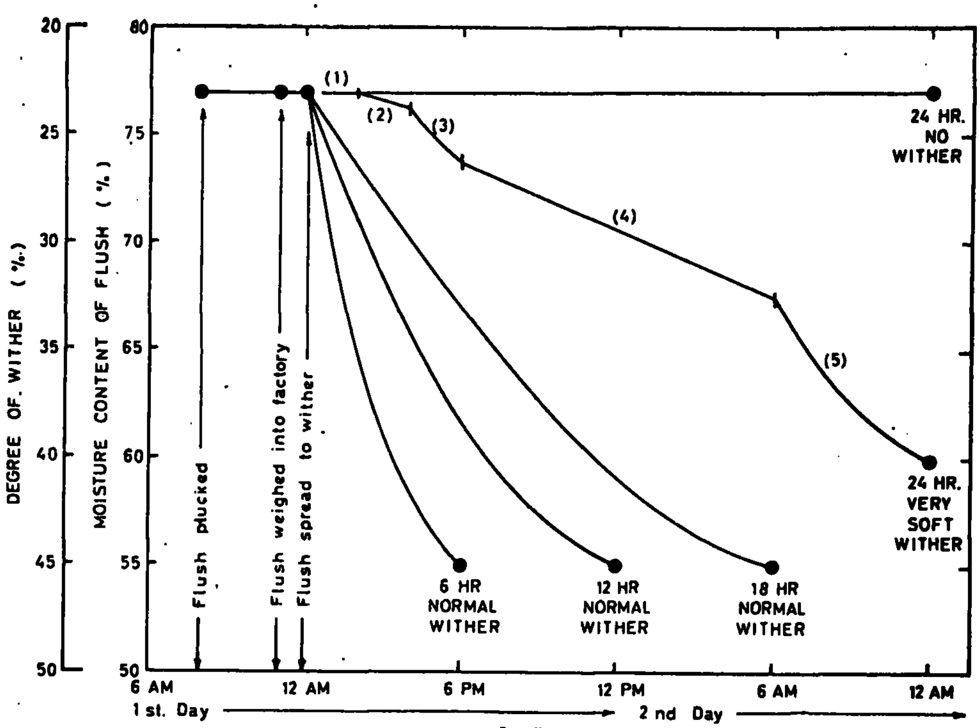

FIGURE 1. RECORD OF PHYSICAL WITHER UNDER DIFFERENT CONDITIONS.

The first three curves; labelled 6, 12, and 18 Hour Normal Wither; show records of physical withers under controlled conditions. The 18 hr Wither curve would be considered ideal in most cases under Ceylon conditions and teamakers spend much time trying to regulate their withering conditions to achieve this end. The 12 Hour Normal Wither curve would be typical of a good wither during periods of high quality and flavour. The 6 Hour Normal Wither is easily achieved in withering troughs or other rapid-withering machines but it would seldom, if ever, be achieved using orthodox procedures. The 24 Hour No Wither curve is obtained on very wet days when orthodox withering procedures without any means of control are in use. This situation is generally very undesirable.

The 24 Hour Very Soft Wither curve represents a hypothetical situation which might arise in a factory with only limited means of controlling withering conditions and it is included to show what can and does happen in most orthodox factories. On this day the flush was spread on tats wet because of rain and no wither was achieved until the surface moisture was removed; (1). It rained until 4 p.m. and the wither was consequently very slow because of the high relative humidity (R.H.) of the atmosphere; (2). From 4 p.m. to 6 p.m. the sun shone causing a fall in the R.H. and the wither was nearly normal; (3). Between 6 p.m. and 6 a.m. night-time conditions prevailed with low temperature and rather high R.H. resulting in a slow rate of whither; (4). From 6 a.m. to 12 a.m. of the second day favourable conditions prevailed, i.e. warm temperatures and low R.H., and the wither proceeded at a satisfactory rate; (5). However, after 24 hours the flush still contained 60% moisture (degree of wither is 40%) which is described as a very soft wither (Keegel, 1958).

As was stated in the introduction, withering is essential in orthodox tea manufacture to condition flush for the subsequent step of manufacture; *rolling*. Unwithered flush is turgid and it is not amenable to being rolled into the tightly twisted condition which is commercially desirable. Such flush breaks up in the rollers, juice containing valuable soluble substances is lost, and the resultant tea is described as being flaky in appearance and thin in its liquor. This aspect of withering has been acclaimed to be the chief factor in withering by at least two authorities in the field (Keegel, 1958; Child, 1960) and with some justification.

It has also been pointed out that moisture in flush which is not removed during withering must be removed later during the firing stage at some additional expense in fuel consumption (Trinick, 1962).

The importance of the above-mentioned factors must be conceded. However, they appear to be concerned entirely with technological problems in tea manufacture which a good engineer or an economist should be able to solve through the development of new machinery and processing methods. This might lead one to conclude that withering is not really necessary, but before we can finally answer our question we must also look at the chemical aspects of withering.

Empirical Evidence for Chemical Withering

It has been recognized for at least 60 years that, in addition to the obvious physical changes taking place during withering, chemical changes also take place (Mann, 1901; Bamber & Wright, 1902). Furthermore, strong presumptive evidence for a chemical wither comes from the observation that variations in withering practices can have an effect on the value of the made tea (cf. Trinick & Choudhury, 1963). More specifically, it has been shown that colour is increased by long withers (Evans, 1933; Wood, 1952; Keegel, 1955b), that quality is decreased by long withers (Evans, 1933; Wood, 1952; Keegel, 1954)., that cold night temperatures favour quality and the development of flavour (Keegel, 1955a), and that 'greenness' (probably similar to brassiness and clonal) in tea liquors is reduced by longer withers or higher withering temperatures (Wood, 1952; Keegel, 1955a, 1956).

In spite of the above mentioned evidence for chemical changes occurring during withering which have an important bearing on tea quality, the actual chemistry of withering has only recently begun to be elucidated in any detail. The following discussion will be, in the main, an exposition of our present knowledge on this subject.

The Chemistry of Withering

(*a*) *Changes in the level of polyphenol oxidase activity*.—The first report of a chemical change occurring during withering concerned polyphenol oxidase activity (Bamber & Wright, 1902; Mann, 1901, 1903, 1904). This enzyme is of considerable interest and importance in tea manufacture because it brings about the quantitatively most important change occurring during tea manufacture, namely the oxidation of the tea flavanols (cf. Roberts, 1962). I have recently reinvestigated this subject (Sanderson, 1964b) and my results may be outlined as follows:—

The activity of polyphenol oxidase in tea flush fluctuates after plucking and reaches a broad peak of activity after about 18 hours which corresponds with the normal withering period. Withering itself has little or no effect on these fluctuations, however, since they are nearly the same whether the flush is withering or not withering (stored in polythene bags). It is only after the moisture content of the flush is reduced to a very low level that the method of storage begins to affect the level of this enzyme's activity. These results are shown in Figure 2.

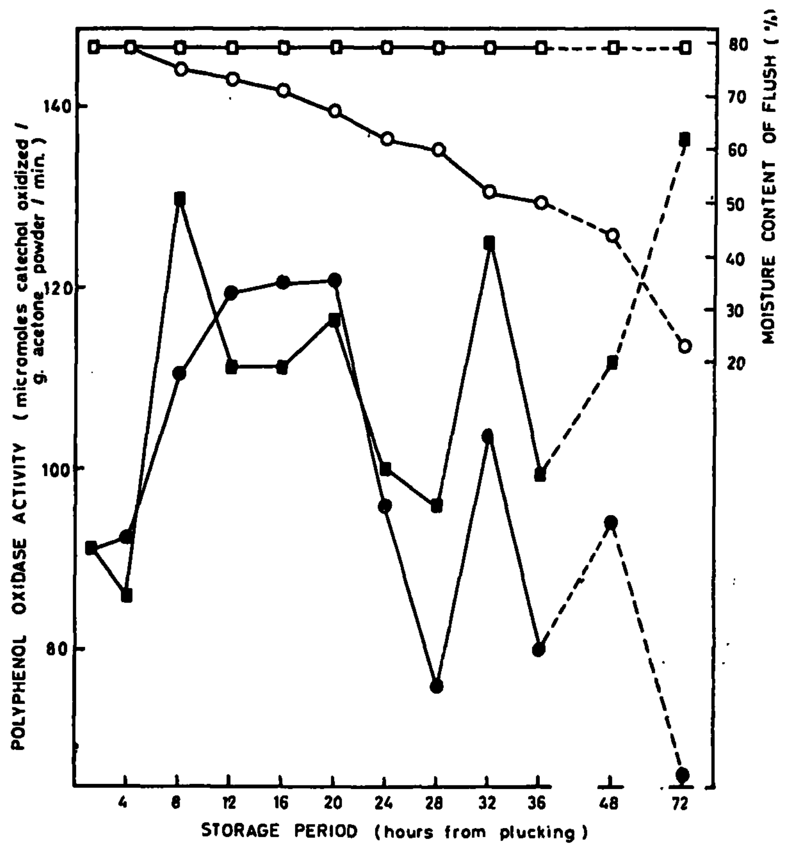

FIGURE 2. CHANGES IN POLYPHENOL OXIDASE ACTIVITY IN FLUSH OF TEA ON STORAGE AFTER PLUCKING AND THE EFFECT OF WITHERING ON THESE CHANGES

Legend: ●—● Polyphenol oxidase activity in withering flush.
■—■ " " " " non-withering flush
○—○ Moisture content of withering flush.
□—□ " " " non-withering flush.

The fluctuations are markedly affected by the temperature of storage (Sanderson, 1964b). It has been found that the rate of change in polyphenol oxidase activity is slower the colder the temperature of storage. The enzyme's activity continues to fluctuate, however, even at -15°C.

(*b*) *Changes in the level of free amino acids.*—An increase in the soluble nitrogen content of tea flush during withering was reported over thirty years ago by Evans (1929) and the observation that there was a loss of protein during the withering period was also reported later (E. A. H. Roberts, 1939). However, it remained for E. A. H. Roberts & Wood (1951) using semi-quantitative paper chromatography to show definitely that free amino acids were formed.

Recently, Bhatia (1962a, b; 1963) has used the increase in amino acids during withering to compare orthodox and faster new withering processes for their effect on chemical wither. This is the first known application of chemical methods to withering problems.

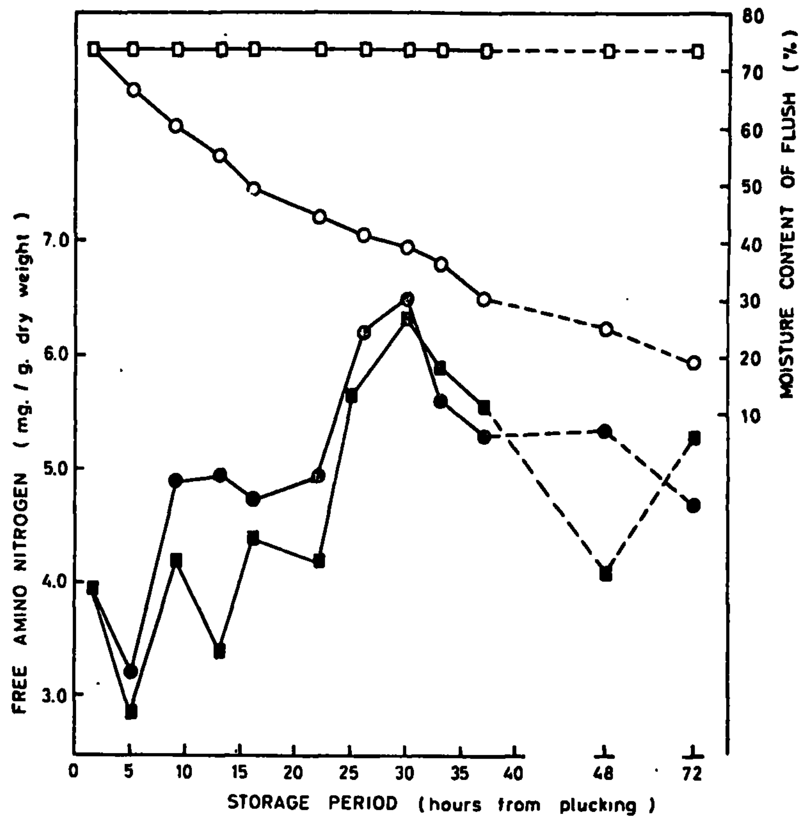

FIGURE 3. CHANGES IN THE LEVEL OF FREE AMINO NITROGEN IN FLUSH OF TEA ON STORAGE AFTER PLUCKING AND THE EFFECT OF WITHERING ON THESE CHANGES.

Legend: ●—● Free amino nitrogen in withering flush.
■—■ " " " " non-withering flush.
○—○ Moisture content of withering flush.
□—□ " " " non-withering flush.

We have confirmed the increase in free amino acids in tea flush during withering in our laboratory (Sanderson & G. R. Roberts, 1964, and unpublished results). Furthermore, we have found that the increase is not dependent on withering itself but rather it is a function of time only (Sanderson & G. R. Roberts, unpublished results). That is, the increase in free amino acids begins as soon as the flush is plucked and it proceeds at the same rate in flush which is withering and in flush which is not withering (stored in polythene bags). These results are shown in Figure 3.

Our finding that the level of free amino acids fluctuates throughout the storage period (Figure 3) indicates that amino acids are continuously being fed into and at the same time removed from a pool and it is only the size of the pool at the time of sampling which we measure. The metabolic fate of the amino acids being removed from this pool is not known at the present time, but it may be very important as regards the formation or destruction of quality in tea.

Bhatia (1962b) has reported that the increase in free amino acids is greatly affected by the temperature of storage; flush withered at 37.7°C for 24 hr was reported to have double the level of free amino acids as flush withered normally (presumably at about 27°C for 24 hr). Our finding that the enzyme responsible for the breakdown of protein to free amino acids in tea shoot tips, called tea leaf peptidase, has a very high optimum temperature at 50°C (Sanderson & G. R. Roberts, 1964) provides an explanation for the earlier finding.

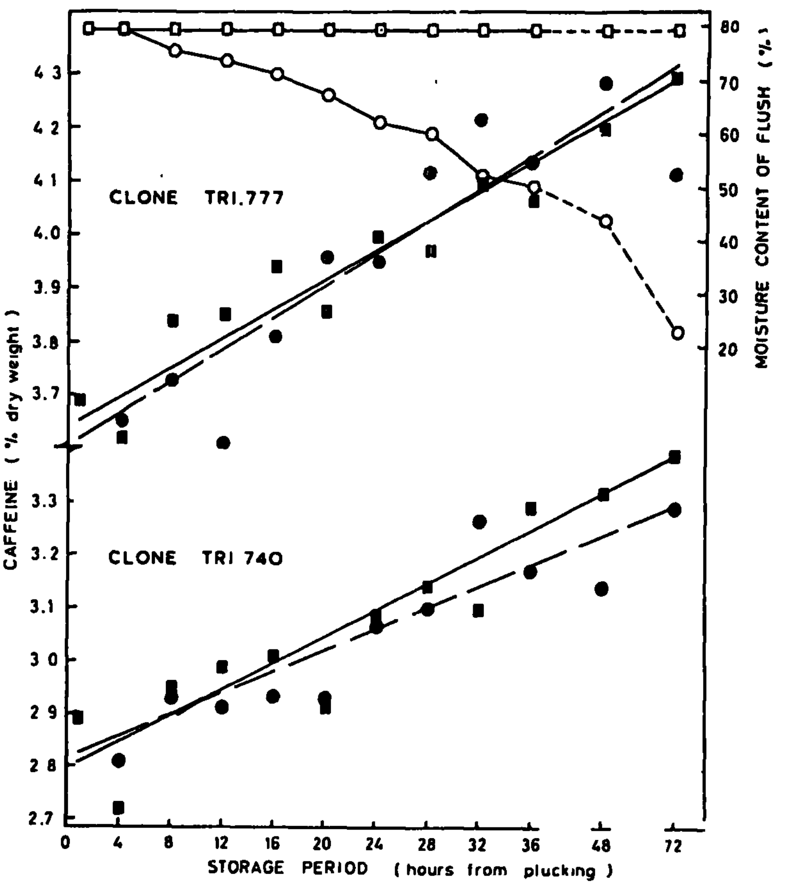

FIGURE 4. INCREASE IN CAFFEINE CONTENT OF FLUSH DURING STORAGE AFTER PLUCKING AND THE EFFECT OF WITHERING ON THIS INCREASE

Legend:
- ●—●—● Caffeine in withering flush.
- ■—■—■ " " non-withering flush
- ○—○—○ Moisture content of withering flush
- □—□—□ " " " non-withering flush

(*c*) *Increase in caffeine.*—Wood & Chanda (1955) were the first to report an increase in caffeine in tea flush during withering. These investigators later found that more caffeine was formed at 30°C than at 38°C and that only negligible amounts were formed at 16°C (Wood & Chanda, 1956).

Investigations in our laboratory have confirmed the earlier report and extended the earlier findings. I have found that the increase in caffeine under normal withering conditions is linear with time ($P < 0.001$) and that the increase is the same in flush which is withering and in flush which is not withering (stored in polythene bags). Finally, the rate of increase was the same in the two clones investigated, *i.e.* TRI 740 and TRI 777. These results are shown in Figure 4.

The source of the increase in caffeine has not been demonstrated, but it is likely that it is formed enzymatically from the free amino acids being produced at the same time. The synthesis of caffeine from amino acids has been clearly demonstrated in shoots of coffee plants (Anderson & Gibbs, 1962).

(*d*) *Increase in soluble carbohydrates* (*sugars*).—The changes undergone by carbohydrates during the manufacture of tea was first studied in any detail by Carpenter and his colleagues (Carpenter, 1931). These investigators reported the following data (Carpenter, 1931):

		Sugar Content
Fresh leaf	...	0.84%
Withered leaf	...	1.23%
Tea leaf	...	1.23%

Results of experiments in our laboratory which are still in their preliminary stages (Sanderson & Perera, unpublished results) have indicated a definite increase in soluble carbohydrates during the manufacture of black tea. This is shown by the data in Table 1. It is probable that this increase occurs during withering as found by the earlier investigators, but additional work is required before this can be stated with certainty. Further discussion of this investigation must be reserved until more information is available.

TABLE 1.—*Increase in Soluble Carbohydrates during the Manufacture of Black Tea*

Sample	Soluble Carbohydrates		
	Reducing Sugars	Non-reducing Sugars	Total Sugars
	(% dry weight)		
Clone TRI. 740			
Fresh flush	0.57	2.09	2.66
Made Tea	1.03	2.12	3.15
(% Increase)	(81)	(1)	(18)
Clone TRI. 777			
Fresh Flush	0.48	1.35	1.83
Made Tea	1.55	2.09	3.64
(% Increase)	(223)	(55)	(99)

(*e*) *Changes in the level of organic acids.*—Results of investigations still in progress (Sanderson & Selvendran, unpublished results) have indicated that there are marked changes in the levels of several organic acids during withering. The results shown in Table 2 are representative. Further discussion is reserved until more results are available.

TABLE 2.—*Changes in Organic Acids in Tea Flush during Withering*

Organic Acid	Acid Content of Flush			
	Experiment No. 1		Experiment No. 2	
	Fresh Flush	After 10.5 hr. Wither	Fresh Flush	After 29 hr. Wither
	(Millequivalents acid/100 gr. dry weight)			
Fumaric	0.27	0.45	0.37	0.33
Succinic	0.54	1.12	0.21	0.21
Oxalic	7.89	9.34	8.80	10.47
Malic	2.23	1.51	1.80	0.24
Citric	0.82	1.29	1.57	1.05
Unknown 1	0.19	0.36	0.09	0.30
Unknown 2	0.11	0.28	0.04	0.24

(*f*) *Increase in the permeability of cell membranes.*—Evans (1928, 1931) reported over thirty years ago that the permeability of the cell membranes in tea flush increased during withering. He showed that the permeability increased as the degree of wither increased and that flush stored under cover to prevent withering did not show a similar increase in permeability (Evans, 1931).

This subject was recently reinvestigated (Sanderson, 1964c) when it became apparant that this phenomenon might be of considerable importance in the formulation of a theory of withering. It has been possible to verify and extend the earlier results as shown in Figures 5 and 6. That is, the permeability of the cell membranes in tea flush increases as the flush withers, whereas flush stored so as to prevent its withering (stored in polythene bags) undergoes no appreciable change in membrane permeability during storage (Figure 5). The dependence of the change in permeability on withering was further demonstrated in studies with flush which was first stored for 20 hours under conditions which prevented any withering (stored in polythene bags) and which was then stored exposed to allow withering to take place. As soon as withering began (after 20 hours), the permeability of the cell membranes in the flush began to increase in the same manner as in flush which had been allowed to wither from the beginning of the experiment (Figure 5).

The effect of temperature on the permeability changes was also studied (Sanderson, 1964c). The results are shown in Figure 6. Extremes of temperature, namely 40°C and −15°C, caused marked increases in permeability even in the absence of any withering. Chilling temperatures (4°C and 10°C) appeared to increase the permeability appreciably but temperatures slightly above the ambient (31°C) had little or no effect as compared with storage at room temperature (25°C).

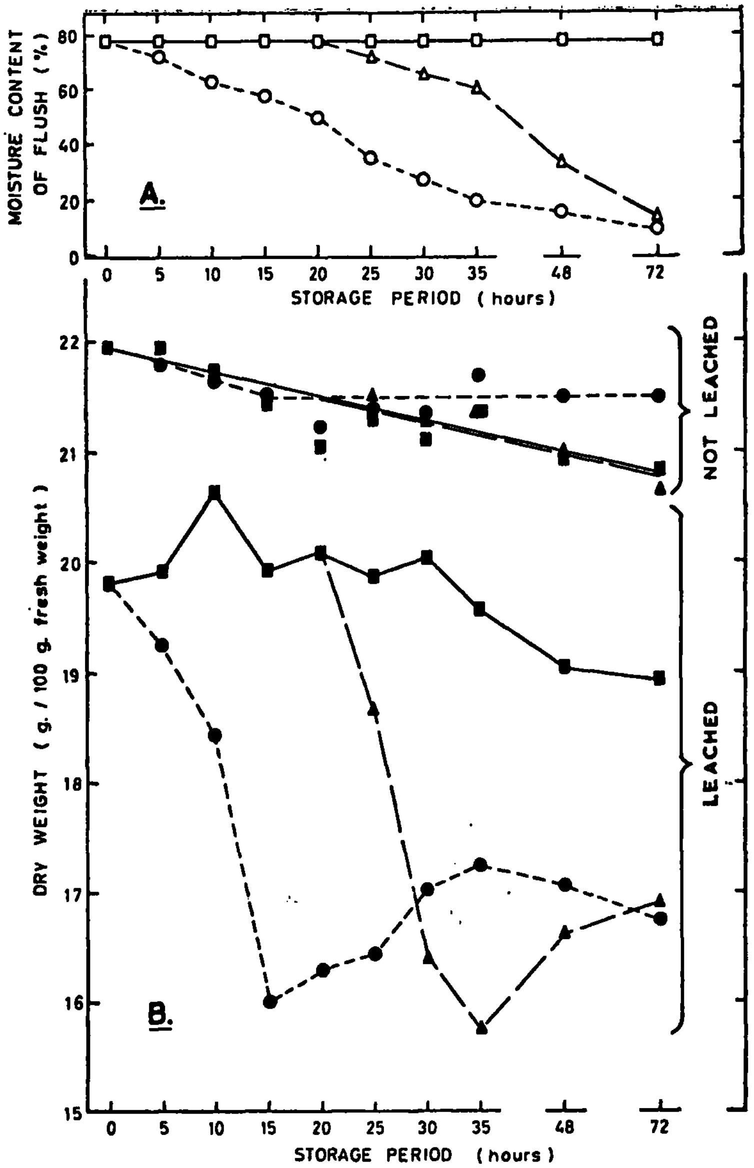

FIGURE 5. CHANGES IN THE PERMEABILITY OF MEMBRANES IN TEA FLUSH ON STORAGE AFTER PLUCKING AS SHOWN BY THE LEACHABILITY OF CELL CONTENTS AND THE EFFECT OF WITHERING ON THESE CHANGES.

Legend: A. Record of withering.

□——□ Flush stored in polythene bags (no withering).
○——○ " " exposed (withering).
△——△ " " in polythene bags until 20 th. hour (no withering); stored exposed after 20 th. hour (withering).

B. Record of dry weights of flush either leached or not leached.

■——■ Flush stored in polythene bags (no withering).
●——● " " exposed (withering).
▲——▲ " " in polythene bags until 20 th. hour (no withering), stored exposed after 20 th. hour (withering).

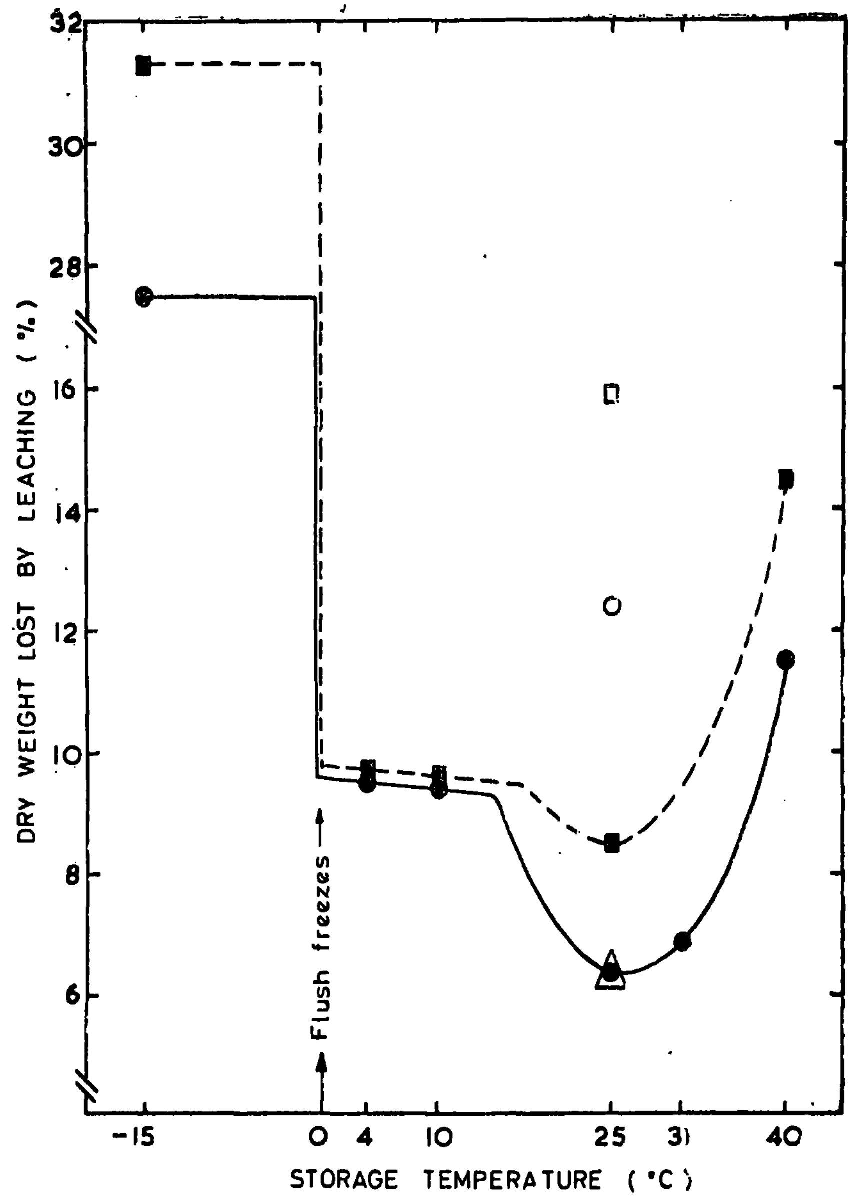

FIGURE 6. EFFECT OF STORAGE TEMPERATURE ON PERMEABILITY INCREASES OF CELL MEMBRANES IN TEA FLUSH AS MEASURED BY CHANGES IN LEACHABILITY OF FLUSH.

Legend:

Withering flush	Non-withering flush	Storage period
Δ (75.5 ± 1%)*		0 hours
○ (35%)	● (75.5 ± 1%)	21 hours
□ (12%)	■ (75.5 ± 1%)	45 hours

* Moisture content of samples is shown in parentheses.

(*g*) *Other changes.*—Changes other than those specifically described above are known to occur during withering. These include loss of dry matter due to respiration which can be seen from the decrease in dry weight of unleached samples of flush shown in Figure 5. A decrease in insoluble carbohydrates has also been reported (Carpenter, 1931) which is probably related to the increase in soluble carbohydrates described above.

These changes are not discussed in any detail here because insufficient information is available at present. However, the possible importance of these changes and others which are as yet undiscovered should not be over-looked.

It is noteworthy that the flavanols do not appear to undergo appreciable change during withering (E. A. H. Roberts, 1958). These substances which are so important in tea manufacture undergo change only after the flush has been damaged (such as by rolling) under normal circumstances. More will be said about this during the elaboration of our Theory of Withering.

The Theory of Withering

The changes known to occur in tea flush during withering were discussed above and they are summarized in Table 3. With this information we are in a position to formulate a Theory of Withering.

TABLE 3.—*Summary of changes now known to occur in Tea Flush during Withering*

Description of change	Importance of change in tea manufacture	Dependance of change on moisture loss
1. Loss of moisture.	Very important in orthodox manufacturing. Absolute importance is unknown.	—
2. Increase in amino acids.	Probably important for colour and quantity.	Independent
3. Increase in caffeine.	Probably increases value of tea.	Independent
4. Increase in soluble carbohydrates.	Unknown.	Unknown
5. Changes in level of organic acids.	Unknown.	Unknown
6. Changes in activity of polyphenol oxidase.	Probably important with slow fermenting clones or slow fermenting fields of seedling tea.	Independent
7. Change in permeability of cell membranes.	Probably important in obtaining even fermentation.	Dependent

Several chemical changes are known to occur during storage of plucked flush and they are all independent of physical withering (loss of moisture) except the increase in membrane permeability (see Table 3). We will first consider all of the chemical changes except the increase in membrane permeability which will then be considered separately.

We must make two assumptions on which to base our first principle. First, we must assume that the chemical changes occuring during withering have a real effect on the character of the made tea. This is fairly safe in view of the large amount of empirical evidence to support it (see section on Empirical Evidence for Chemical Withering). Furthermore, it must be assumed that by trial and error methods over a very long period of time orthodox methods of tea manufacture have been developed to produce the most desirable product from the consumer acceptance point of view and withering is an accepted part of orthodox tea manufacture. With this background and even without knowing exactly how these changes effect the character of tea, we can state our first principle:

Storage of flush for a period of time is necessary to allow chemical changes to take place whether a wither is desired or not if we wish to make a product with good traditional characteristics.

Practical considerations have lead Trinick & Choudhury (1963) to a similar conclusion.

Before proceeding it is worthwhile to speculate on how some of the chemica changes described above actually affect the character of black tea. First, the increase in polyphenol oxidase activity should improve the rate of fermentation. This is probably desirable but we must remember that it may be undesirable.

The breakdown of protein to free amino acids is probably important for several reasons. Free amino acids are known to be involved in non-enzymatic browning reactions; they are known to interact with polyphenols (Burton, McWeeny & Pandhi, 1963) and with sugars (McWeeny & Burton, 1963) in this way. These reactions are almost certain to occur in tea, especially during firing. Amino acids have been reported to be oxidizable in tea to yield aromatic substances which may contribute to flavour (Bokuchava & Popov, 1954; Nakobayashi, 1958; Wickremasinghe & Swain, 1964a, b) and it has already been pointed out that some amino acids are probably transformed to caffeine.

The soluble carbohydrates are likely to be involved in the production of the tea characteristic called quality. They probably also interact with amino acids in non-enzymatic browning reactions (McWeeny & Burton, 1963) as mentioned above to improve colour at the expense of quality.

The presence of caffeine in tea with its stimulating properties is probably the reason why people drink tea in the first place. It is doubtful that the level of caffeine in a particular tea will have much effect, if any, on its value at any one time, but it stands to reason that it will have an effect over a period of time.

For our second principle we must return to consider the increase in membrane permeability which is the one change found which is dependent on withering itself. To appreciate the importance of this change, we must recognize that the enzyme polyphenol oxidase and its substrates in fermentation (that is the chemical substances on which the enzyme acts), the flavanols, are spatially separated in the cells of the flush. While the basic evidence for a spatial separation (Li & Bonner, 1947) is not satisfactory, it is a well established fact that fermentation in tea flush will not proceed until the cell contents are mixed by breaking the cells (as in a mincing machine), by rolling (as in orthodox manufacture), or by killing the tissues with chloroform vapour (Sanderson, 1963b) or long periods of warm temperature (Sanderson, 1964c). In summary, there is every reason to believe that the enzyme of fermentation and its substrates are spatially separated in the intact tissues of the flush and that the separation is by means of cell membranes.

Now we can see why teamakers of Ceylon have come to regard a 45% wither (55% moisture in flush) as ideal. Reference to Figure 5 shows that at this moisture content the membranes in the flush are highly permeable which means that orthodox rolling will be sufficient to bring about good mixing of enzyme and substrate and a good fermentation can be expected under these conditions. It has been shown elsewhere that increasing the wither from 60% to 50% moisture content in the flush increases the rate of fermentation (Todd, 1954). The importance of uniform withers is now explained also, because only that flush at the correct moisture content has the correct permeability properties. Uneven withers will lead to uneven fermentation characterized by mixed infusions. Furthermore, we can now explain why newer and more drastic flush-processing machines such as the C.T.C. and rotorvane machines have a marked tendency to improve the teas of North-east India (Sanderson, 1963a). Because of climatic conditions prevailing there, withers are generally very soft, *i.e.* the moisture content of flush is generally reduced to only 68% or even less, and the permeability of the cell membranes does not increase sufficiently to allow adequate mixing of enzyme and substrates by orthodox rolling procedures. Therefore, more drastic treatment of flush is required and machines which cause a great amount of cell breakage are used to advantage.

Finally, we can now explain the cause of the peculiarities of non-wither teas. Brassiness (probably the same as greenness in liquors) in liquors is a defect associated with no-wither teas (such as Legg cut teas) and is due to the presence of appreciable amounts of unoxidized polyphenols in the made tea (Bhatia, 1961). Since the permeability of the cell membranes is at a minimum in unwithered flush, a cell must be physically broken before fermentation can proceed in it. Not every cell is broken with any manufacturing process in use today and, therefore, appreciable amounts of unoxidized polyphenols are present in these latter teas to their detirment.

We can now state our second principle:

Physical withering is necessary for good fermentation if we wish to use orthodox rolling. Leaf processing methods which cause a very high percentage of the cells in the flush to be broken can substitute for physical withering but at the expense of destroying the traditionally accepted appearance of the made tea.

Our third and final principle has to do with time and temperature. Most if not all of the chemical changes we have been discussing are temperature dependent. This means that the rate of change is affected by the temperature of storage. All of the changes are not affected in the same way, however, so a change of the storage temperature would be expected to alter the chemical state of the withered flush. In particular, the permeability of the cell membranes increases as the temperature of storage is decreased from 25°C (Figure 6) whereas the other changes discussed above become slower. It is important to realize, however, that a reaction proceeding slowly for a long period of time can give the same result as the same reaction proceeding rapidly for a short period of time. This means that any advantage to be gained from low temperature withering can be lost if the use of low temperature is accompanied by conditions which prolong the withering period. Also, advantages of short withers can be lost when high temperatures are required to bring about the rapid wither (*cf.* Keegel, 1962b). Time and temperature are closely inter-related in this instance and they must be considered together.

Two well established empirical observations are important here. First, quality and flavour are developed most noticeably during seasons characterized by dry atmospheric conditions and low night temperatures. The former climatic condition allows rapid withers (often a 55% moisture content can be obtained in less than 12 hours) and we now know that the latter condition favours an increase in membrane permeability with its attendant beneficial effects on fermentation. Finally, colour is developed at the expense of quality and flavour. It seems likely that the production of free amino acids during withering is responsible, in part at least, for this observation. As was suggested above, it is likely that amino acids interact with substances contributing to quality and flavour to form brown coloured substances. This would improve colour but diminish quality and flavour.

We can now postulate our third principle:

The length and temperature of the withering period will effect the character of the made tea. Low temperatures (about 10°C to 15°C) and short withering periods (about 12 hours) favour the development of quality and flavour while high temperatures (25°C to 35°C) and longer withering periods (20 to 30 hours) favour the development of colour at the expense of diminishing quality and flavour.

This principle is only a restatement of previously existing empirical knowledge but it is now strengthened by having some chemical basis.

The above three principles form the Theory of Withering. The theory in its present form is based on a consideration of the available information but much work remains to be done before a full understanding of all the factors involved will be possible. Some modification may be required in the future in light of new information and without doubt it will be possible to state the principles more precisely when more information is available.

Finally, it is important to emphasize that withering is only one stage in tea manufacture. The results to be expected from the correct application of the three principles of withering can only be realized if all conditions for the making of a good tea are favourable. For instance, the starting material must be right. The flush must be plucked and handled correctly and it must have the potential to make good tea in the first place (Sanderson, 1964a). Furthermore, subsequent stages of manufacture must be carried out correctly for it is possible to destroy potentially good tea at any stage of manufacture.

Summary and Conclusions

The chemical aspects of withering have been fully discussed and it is now possible to state that the chemical changes occurring during withering are of the utmost importance in determining the characteristics of the finished product.

A Theory of Withering has been developed from a consideration of all known information concerning withering, both empirical and scientific. The theory has been stated in the form of three principles as follows:—

Principle 1.—*Storage of flush for a period of time is necessary to allow chemical changes to take place whether a wither is desired or not if we wish to make a product with good traditional characteristics.*

Principle 2.—*Physical withering is necessary for good fermentation if we wish to use orthodox rolling. Leaf processing methods which cause a very high percentage of the cells in the flush to be broken can substitute for physical withering but at the expense of destroying the traditionally accepted appearance of the made tea.*

Principle 3.—*The length and temperature of the withering period will effect the character of the made tea. Low temperatures (about 10°C to 15°C) and short withering periods (about 12 hours) favour the development of quality and flavour while high temperatures (25°C to 35°C) and longer withering periods (20 to 30 hours) favour the development of colour at the expense of diminishing quality and flavour.*

In answer to our initial question, "Is withering necessary?", it can be said that withering is itself important in tea manufacture and it may even be considered to be essential in orthodox manufacture. We must conclude, however, that withering is not essential in the broadest sense because alternative processes for the orthodox rolling process can serve as a suitable substitute for withering.

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