

RELATION OF TEMPERATURE AND HUMIDITY TO MADE TEA

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The part that temperature and humidity play in the manufacture of tea and the influence of these two factors on its liquoring characteristics have long been recognised. Even before the leaf is plucked from the bush, temperature and humidity initially determine to a great extent what the properties of the final product are likely to be. We know, for instance, how temperature and humidity variations of the atmosphere can appreciably alter the characteristics of a tea, particularly high-grown quality.

The marked improvement in quality during dry weather up-country is not merely due to slow growth — growth is equally slow in wet weather. Nor can it be entirely a question of temperature because temperatures in wet weather may be just as low as during dry periods. The conclusion is inescapable that low humidity makes some important contribution to the enhancement of the desirable qualities inherent in the bush.

Temperature by itself is equally important, as indicated by the progressive improvement in quality from sea-level to higher altitudes where ambient temperatures are lower. Further evidence of the close relationship which exists between temperature and liquoring properties is provided during the dry weather when atmospheric temperatures fall to very low levels. At such times, flavour is conspicuous and disappears as soon as the night temperatures rise.

In the light of this evidence, which is common knowledge, we may be justified in concluding that, leaving aside the effect of manuring, shade and other factors, climatic conditions have a most marked effect on the nature of the final product. It is more than probable that the way in which these conditions influence the made tea is by their connection with the actual temperature of the leaf. If we assume that green leaf is a wet body, and transpiration is taking place all the time, the temperature of the leaf on the bush would not be widely different from the wet-bulb temperature of the surrounding air. Attention must therefore be directed to the importance of the wet-bulb temperature in our reckonings. Its influence in all stages of manufacture as well will be seen as we consider each process in turn.

Altitude of Factory

One of the earliest experiments conducted and reported in connection with this aspect (Palmer, 1934), concerned the manufacture of medium-grown leaf at a higher elevation. The object was to determine whether such leaf manufactured in a factory at an elevation of 5,200 ft would compare sufficiently favourably with the same leaf manufactured in a factory at an elevation of 3,800 ft to justify a combined factory being built at the higher elevation.

The results were quite conclusive, teas manufactured at the higher elevation being preferable in quality and brighter in cup. During favourable weather

conditions a slight sign of flavour was noticeable, whilst teas manufactured at the lower elevation did not possess flavour and were poor and plain in comparison. The presence of flavour alone put the former teas into a different class and the infused leaf was also brighter. Although they did not come up to the same standard as high-grown leaf manufactured at the higher elevation, they lost many of the characteristics of the teas manufactured at the lower elevation and tended to acquire those of high-grown teas, despite a difference of only about 4°F between the two factories.

It was considered that the only factor which was responsible for the improvement of the teas was elevation, and that the results justified the building of an amalgamated factory at the higher elevation.

Manufacture of leaf grown in the low-country has been done from time to time at St Coombs (elevation about 4,000 ft). It has been observed that although the low-country character was not entirely eliminated, in almost all instances quality was present in the manufactured teas. Recently Clone TRI 25 grown near sea-level and manufactured at St Coombs (Keegel, 1961) gave a tea with little flavour and fair quality and could almost have passed as a high-grown tea. Nevertheless in respect of these two characteristics it did not compare favourably with the same clone grown at St Coombs.

The main factor producing these results could hardly have been anything but temperature. There are therefore sufficient grounds to believe that air-conditioning in factories at low elevations would be beneficial, not merely in rolling rooms but during withering as well. Whether it can be economically achieved is doubtful.

Further evidence of the effect of altitude and temperature has been provided by the manufacture at St Coombs of leaf grown in the Nuwara Eliya district (elevation about 6,000 ft). Despite the fact that the leaf was manufactured on an experimental scale, which kept temperatures relatively low in the rollers, in the region of 80°F, the higher ambient temperatures during withering and fermenting caused a loss of the Nuwara Eliya character. The teas gained in colour with a corresponding loss in quality.

Pre-manufacture Influences

Before the actual processes of manufacture commence, considerable damage to quality could take place from the time the leaf is plucked off the bush till it is spread for withering. If leaf is closely packed or exposed unduly to the sun, the heat generated by the mass of leaf, as a result of respiration, is prevented from escaping and under severe conditions could cause reddening of the leaf. If the leaf is partly bruised—no leaf is entirely free from bruising by handling—the high temperatures cause premature fermentation at a rapid rate besides having a detrimental effect on the quality of the tea. According to Tocklai (Evans, 1931) temperatures up to 140°F may be recorded in the middle of a plucking basket, and at this temperature leaf would redden in as little as 10 minutes.

Despite every precaution taken, leaf arriving at the factory could attain temperatures approaching 90°F, depending on the ambient temperature, so that neglect in packing leaf properly and transporting it in the quickest possible time would result in much higher temperatures and a loss of quality. Though the leaf may not redden, the rise in temperature brought about by the heat generated would cause certain changes to take place in the leaf, which would be detrimental to quality.

The same effect may be produced after leaf is withered, because heaping of the leaf for any length of time causes heating and reddening. It is for this reason that badly ventilated lofts and hot-house conditions are also condemned. If the heat produced in respiration is not dissipated, a set of conditions is created in a withering loft which is not very dissimilar from those in a plucking basket. The conscientious tea-maker, aware of the ill-effects of excessive heat, goes to a great deal of trouble in maintaining the coolest conditions possible in withering.

In experiments to study the effect of low temperatures on fresh and withered leaf (Norris, 1944), the results revealed that subjecting the fresh leaf to low temperatures improved the quality considerably, and that freezing brought about a still further improvement. Subsequent withering of such leaf at ambient temperatures destroyed this gain in quality. On the other hand, leaf that had been first withered at normal temperatures and then exposed to cool conditions failed to produce a tea of the same standard as that obtained after the cooling of unwithered leaf.

These results again go to show that though some improvement may be effected by low-temperature conditions in manufacture, the all important factor is the temperature of the leaf prior to its manufacture. The effect of altitude is therefore no mystery since, as long as transpiration is taking place from the leaf, its temperature would rarely rise above the wet-bulb temperature of the air. On this hypothesis, even under the warmest conditions up-country, leaf before it is plucked would be at a considerably lower temperature than at sea-level. In the height of a drought, when quality and flavour are at their best, leaf temperatures at night may be only a few degrees above freezing point, and in the day time with rapid evaporation probably not more than 50°F. Such conditions of course are never prevalent in the low country.

Withering

The effect of temperature and humidity in this process has been studied in some detail. It has been found that at temperatures as low as 50°F the resultant teas were appreciably improved in quality (Keegel, 1954). One striking feature was the marked improvement in the colour of the infused leaf. At 100°F, a period of 2 hours was sufficient to cause the infused leaf to be duller than at normal temperatures (Keegel, 1951).

Further work on low-temperature withering (Keegel, 1955) also revealed that 'cold' withering is not of much benefit to leaf really lacking in quality. Trials carried out in monsoonal weather did not give such promising results as those obtained at other periods that were favourable to the production of quality.

Cold withering has also been investigated by other workers. Hall and Glen Dickson (1934), enquiring into the causes which governed flavour, came to the conclusion that high-elevation flavour was brought about by cold dry weather and enhanced by wind in the presence of low humidities. From an analysis of general atmospheric conditions prevailing in three different districts during flavoury and non-flavoury periods, they put forward a tentative theory that the critical temperature to which the thermometer must fall at night before high-elevation flavour becomes pronounced is 55 to 60°F. Close observation over a considerable period confirmed this and also that the lower the temperature dropped, the better the flavour the next day.

They accordingly set out to see if they could get similar results by artificially withering medium-grown leaf at temperatures below 60°F. In a specially conditioned shed they worked with a temperature of 40°F, but this low temperature

combined with a high humidity necessitated a prolongation of the period of wither to 24 hours and even then they were not able to get a satisfactory wither. Nevertheless, despite this shortcoming and other difficulties encountered in rolling and firing because of the relatively small amount of leaf handled, the liquors were found to have definitely improved quality over normal manufacture and nearly always possessed some flavour. The infusions were also brighter.

When however they tried to improve the wither by first withering in a normal manner and then completing it in the cold shed, no improvement resulted. Neither did they get such good results as completely cold-withered leaf when the wither was first done under cold conditions and finished off in the lofts.

To get a deeper understanding of the influence of temperature in withering one must also consider the ambient relative humidity, which controls two very important factors that affect quality—namely, the temperature of the leaf and the period of wither. For instance, it was found that at temperatures as high as 90°F, quality was quite definitely impaired at a wet bulb temperature of 80° but not when the latter was lowered to 70° (Keegel, 1956). It was also observed that the detrimental effect of high temperatures could be reduced if withering is completed in a short time.

The success achieved by some factories by 'forcing' a wither could be partly attributed to large volumes of air circulating freely, which promote the evaporation of water from the leaf, thus keeping its temperature reasonably low. Should evaporation of water be restricted or prevented, the temperature of the leaf is raised above the ambient wet-bulb temperature and quality suffers. Unpleasant characters, such as dullness and softness, are also brought about, and the teas might even taste sweaty and stewy.

Since both the dry-bulb and wet-bulb temperatures increase when air is heated, and experimental evidence suggests that a wet-bulb temperature of over 80°F is harmful, irrespective of the hygrometric difference, little can be done under low-country conditions to prevent the loss of any inherent quality the leaf may possess. At higher elevations, because of the lower atmospheric temperatures that are prevalent, air for withering could be heated to a greater extent, and a dry-bulb temperature of even 90°F could be employed at certain times without a serious detrimental effect. Forcing a wither by the use of heated air, even during the flavoury season, has been found to be preferable to extending the wither by natural means (Keegel, 1960). Nevertheless, the evidence is conclusive enough to show that, provided withering is not delayed, low temperatures are preferable from the standpoint of quality.

An example of the harmful effects of high-temperature withering is provided in the experience obtained from withering in drums in East Africa (Hutton, 1959). The original idea was to wither the leaf in the shortest possible time by the employment of temperatures of over 100°F. It was found that these high inlet-temperatures had quite a detrimental effect on quality. It is not surprising that this result was obtained because day-time ambient temperatures were often above 80°F and exhaust temperatures in the drum in the region of 85°F. Under these conditions, leaf in the drum would have not been less than 80°F at all stages of the process.

In the light of this experience, inlet temperatures were lowered to 85°F and, though the wither had to be extended, a noticeable improvement in quality was obtained. The results were so conclusive that the idea of accelerating the wither at very high temperatures has been abandoned, and longer periods at lower temperatures are now the recommended method for using the drum.

Rolling and Fermenting

Rolling is directly involved in the rate of fermentation. Considerable heat is produced during the process, partly due to friction and partly due to the chemical changes which take place. Since fermentation begins as soon as the leaf is crushed, the conditions of rolling must have a more marked influence on the quality of the product than the conditions under which the dhool is fermented on racks or tables. It is in this context that we have to examine the influence of temperature in fermentation.

According to investigations carried out by Mann on Darjeeling teas (Evans, 1930a) the earlier stages of fermentation in the rollers are of special importance because the production of essential oils, to which the flavour of tea is very generally ascribed, takes place at this period. The time of maximum formation of these oils depends to a great extent on temperature, and the rate at which fermentation continues after the dhools are separated would also depend on temperature. There is no doubt that the temperature developed in the rollers may be considerably higher than is desirable and lead to a serious loss of quality.

In some preliminary experiments carried out on a single dhool (Keegel, 1957), the results bore out practical observations that for equal periods, no matter of what length, a lower temperature produces better quality. It was also noted that the higher the temperature the better the colour, but that at temperatures above 90°F or thereabouts, no further improvement in colour takes place.

In more accurate comparisons made subsequently (Keegel, 1958) where three different temperatures, namely, 70, 80 and 90°F, were investigated, the first results were confirmed—teas fermented at 70°F were the best in quality. Shortening of the period at higher temperatures failed to preserve quality and, if carried too far, produced a greenish liquor, not entirely acceptable to the trade. Flavour is also affected in a similar manner to quality by high temperatures (Keegel, 1959).

The question then arises as to what is the lowest limit to which temperature may be reduced without seriously interfering with the fermenting process and without producing a tea lacking in the essential characteristics. The three main essentials are colour, strength, and quality and they are all developed during fermentation. A tea is not of much value if any two of these characteristics are absent. We need not consider low-country teas because primarily they sell for their appearance.

Experiments conducted in Indonesia (Leniger, 1941) have revealed that, at a temperature of 50°F, the characters of tea are not developed at the same extent as at a higher temperature, however prolonged the fermentation may be. The use of chilled rollers in Ceylon (Norris, 1931) also showed that fermentation proper took place only after the leaf was exposed to the higher temperature in the rolling room. But as a result of the lower temperatures in the rollers, the teas were preferable in quality and strength to those rolled in the normal way. The average rolling temperatures compared were 66° and 83°F and the room temperature was 72°. It would thus be noted that though the rollers in question were refrigerated at temperatures of 30° to 35°, a considerable quantity of heat was developed during rolling to raise the temperature of the leaf to 66°F. If this had not been so, very little fermentation would have taken place.

It has been stated (Evans, 1930) that in Indonesia some of the estates situated at high elevations (5,500 ft) find the morning temperatures so low that a good fermentation is not possible unless fermenting rooms are warmed. Successful results were obtained at a temperature of 72°F coupled with a high humidity.

No information is available on the temperatures of the leaf in rolling and it is very likely that, on account of the light rolling in vogue at that time, sufficient heat was not developed in the rollers. To counteract this, higher temperatures were found necessary for the dhools.

Further evidence of the onset of fermentation being delayed by very cool conditions was observed during the cold seasons when leaf rolled in the Institute's small-scale rollers failed to ferment properly in the rolling room, which was at a temperature of about 55°F (Lamb, 1935). By fermenting this leaf at a temperature of about 65°F, fuller fermentation was obtained with better colour and strength but with no loss in quality and flavour. Leaf rolled on a commercial scale, however, failed to show this improvement when fermented at 65°F because of the higher temperatures attained in rolling.

Experimental evidence of the influence of temperature has always indicated the desirability of warmth in rolling and from observations made on a full commercial scale at St Coombs during cold weather it was found that really fine flavoury teas could be produced even at rolling temperatures of 85–90°F (Keegel, 1956a).

Considering all the major points which influence the process of fermentation, which includes rolling, it would appear that we cannot do without some heat, and that a temperature of at least 70°F is necessary and anything above 90°F is not suitable. The effects of temperature in fermentation on the individual characteristics of tea, from the evidence we have to date (Keegel, 1955a), is somewhat as follows, all temperatures given referring to the temperature of the leaf itself.

Quality and flavour: (i) Temperatures over 90°F are harmful. (ii) For equal periods, no matter of what length, the lower the temperature the better.

Colour: (i) High temperatures improve this character considerably. At temperatures above 90°F development of colour is apt to be checked; it is most marked between 70 and 80°, and slow below 70°.

Strength: This character does not appear to be markedly affected by high temperatures.

Infusion: The lower the temperature, the brighter the infusion.

According to early workers (Evans, 1930b), humidity of the air was considered to play an important part in fermentation. A humid atmosphere assisted in the production of the desirable properties in fermenting leaf, whereas a dry atmosphere resulted in the production of dark-brown insoluble compounds. Investigations carried out at St Coombs, however, have not proved conclusively the absolute need for it. It is true that fermentation may be slightly retarded by a lower humidity, but the supposed harmful effects from exposure of fermenting leaf to an atmosphere which is not humid have often been over-estimated.

In a series of experiments where two sets of conditions were compared—a hygrometric difference of 2°F with that of 4°—no difference of commercial importance was found in the characteristics of the teas over the normal range of fermenting periods (Keegel, 1953). In another investigation where the hygrometric difference was much higher, as much as 15°F, the teas were not unfavourably reported on (Evans, 1933).

These paradoxical results could probably be explained by the influence of the actual temperature of the leaf, which is governed by the wet-bulb temperature

of the air, just as in withering. So it would appear that what is of greater importance in fermentation is temperature and not humidity. Why then should we go to the trouble and expense of providing humidifying appliances in rolling rooms? If this is not done, the most suitable conditions would not be available for rolling and fermenting. In humidifying air we also lower the temperature, so that the greatest benefit derived from efficient humidification is not the higher humidity but the lower temperature.

Firing

The temperature of firing is no longer a fad or fancy. It has been proved conclusively (Lamb, 1941) that in a single firing operation, firing above 190°F is injurious to quality and that while firing at 160° produces teas of better quality when fresh, these teas are uncertain in keeping properties even when stored at low moisture contents. Pungency, quality and flavour when present, depreciate with rise of temperature employed in firing. Colour and strength are not affected to any marked extent (Lamb, 1939). The main effect of firing temperature is obviously on quality. In a series of experiments in which comparisons were made between teas fired at 160°, 190° and 210°F, the best all round teas were obtained at 190° (Lamb, 1942).

A second treatment with hot air results in a loss of quality, which is most marked in teas requiring final firing owing to a gain in moisture content (Lamb, 1942). Teas stored in a hot condition also lose quality and acquire a bakey character (Lamb, 1942).

On account of the high temperatures employed in firing and the low humidity of the heated air, variations in the humidity of the atmosphere have no effect on the process but they certainly do control the rate and degree of subsequent absorption of moisture by the made tea.

Storage

Tea conforms to well known physical laws, the amount of water vapour taken up tending to establish an equilibrium with the water vapour of the atmosphere. The attraction tea has for water is so strong that in a humid atmosphere it absorbs moisture rapidly. Tea can also lose moisture at low humidities. In an atmosphere of relative humidity 60–65%, which corresponds to a hygrometric difference of about 10°F, the rise in moisture content of normal tea is very small and slow (Lamb, 1935a).

Many years ago there used to be frequent complaints with regard to deterioration of tea in transit to London and it was found that in a good many cases of such fading-out, the deterioration had been the result of teas having been despatched with too high a moisture content. The unfavourable effect of increase in moisture content as a result of increase in humidity is revealed in the following figures (Norris, 1939).

| | | <i>Average valuation</i> | |
|---|-----|--------------------------|---------|
| Tea fired to 3% moisture and stored at 3% | ... | ... | 83 cts. |
| Moisture raised to 5% | ... | ... | 78 " |
| do. 6% | ... | ... | 75 " |
| do. 7% | ... | ... | 74 " |
| (period of storage—4 weeks) | | | |

At the time this investigation was carried out, market prices for up-country teas were in the region of 75 cts. There appears to be a roughly linear relation between moisture content and decline in price.

Teas do not keep indefinitely—they deteriorate with time, however carefully they may be stored—but the lower their moisture content the longer they can be preserved. The higher the moisture content the faster the deterioration, and if the period of storage is extended the deterioration is so marked that only final firing could arrest it. We do not yet understand fully what changes take place in the tea to bring about such a deterioration. To guard against excessive gains in moisture, it is quite obvious that we must have some control over the humidity of the air in the grading room while work is in progress.

It is perhaps not realised that temperature also influences the properties of a tea during storage. If the moisture content is high, teas will deteriorate more rapidly in a warm climate than in a cold climate (Lamb, 1935a). In some recent investigations teas stored in moisture-proof packages in a domestic refrigerator were found to have better colour, strength and quality than similar samples stored in a room where the ambient temperature was about 70°F. The teas stored at the higher temperature also lost some flavour. The period of storage was 3 months.

The sum total of all this evidence has boiled down to one simple fact, namely that quality is lost by exposure of leaf to excessive temperatures right up to the time it reaches the consumer. There is some quality in leaf at all elevations, which is initially brought out or destroyed by such factors as temperature and humidity. We do not pretend to be able to introduce more quality to leaf in the process of manufacture. We wish we could. But we can help to keep what quality there is in the leaf or at least reduce its loss to a minimum by cooler conditions in all stages of manufacture.

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