CARBOHYDRATES IN TEA PLANTS.
I. THE CARBOHYDRATES OF TEA SHOOT TIPS

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Introduction

The carbohydrates of tea plants have received only little attention in the past except in relation to starch levels in roots (ch. Pethiyagoda, 1964). This is in contrast to the situation with respect to most other agriculturally important plants where the central role of these substances in the metabolism of the plant and the economic importance of the carbohydrates themselves has frequently promoted intensive investigations. The dominant role played by the polyphenolic compounds in tea (Roberts, 1958) has probably been responsible for this state of affairs. However, we must not forget that substances other than polyphenols occur in tea plants which may also be important in tea production. Indeed, when one considers how little is known about the chemical basis of quality in tea after over thirty years of studying the polyphenols it becomes apparent that we should pay more attention to other chemical constituents of the tea plant.

The few investigations of carbohydrates in tea which have been made are primarily qualitative studies designed to identify the sugars (soluble carbohydrates) found in tea plants. Among these investigations are those of Bhatia & Chanda (1959, 1960) on fresh tea flush and of Cartwright & Roberts (1954) on made tea. The Indian Tea Board (1[illegible] 1959) has made rather extensive quantitative analyses of Indian teas in which they measured the soluble carbohydrate content of a large number of Indian teas. The results of these investigations will be discussed below with the discussion of our results.

In this paper we report the results of our initial investigations of the carbohydrates in tea shoot tips (flush) and the changes which the carbohydrates undergo during the manufacture of tea. We then discuss the relationship of the carbohydrates to other chemical constituents of the tea plant and the possible importance of the carbohydrates in the production of tea.

The Carbohydrates in Fresh Tea Shoot Tips (Flush)

Flush was plucked from blocks of tea plants (clones TRI 740 and TRI 777) in the field and brought to the laboratory to be analysed. Samples of fresh flush were air dried in an oven at 180°F within 2 hours of the time of plucking. The carbohydrates were extracted from the dried flush and they were then determined by Somigyi's method (Somogyi, 1945). Individual sugars were identified by paper chromatography (Cartwright & Roberts, 1954). A typical chromatogram of an extract of fresh flush is shown in Figure 1A.

The results of our analyses are summarized in Table 1. These results show that the soluble carbohydrates (sugars) present in tea shoot tips in appreciable amounts consist primarily of glucose, fructose, and sucrose with traces of raffinose and an unidentified sugar. Bhatia and Chanda (1959, 1960) have reported the presence of these sugars and of additional sugars in fresh tea flush but the latter must be present at very low levels which were not detectable by our methods.

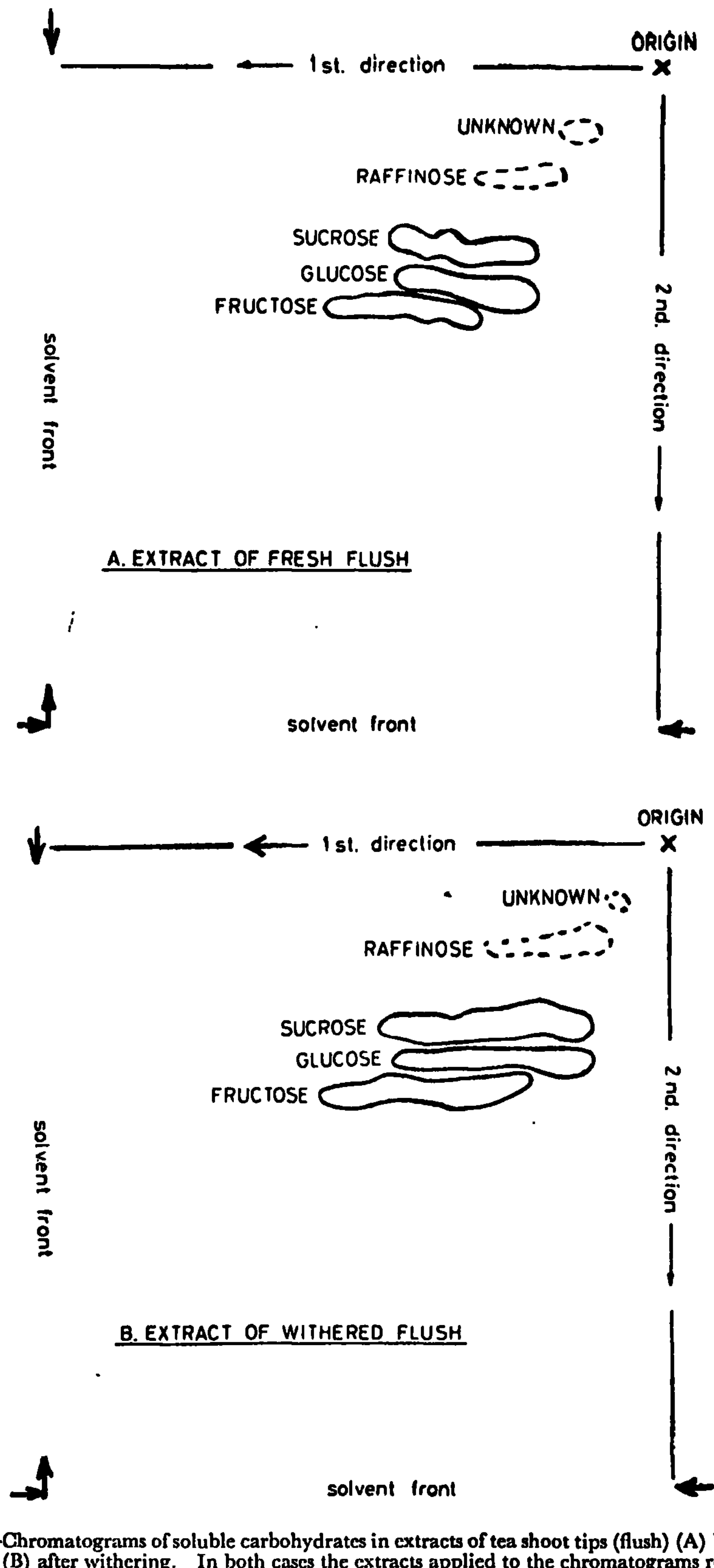

Figure 1.—Chromatograms of soluble carbohydrates in extracts of tea shoot tips (flush) (A) before and (B) after withering. In both cases the extracts applied to the chromatograms represented 1.39 g of fresh flush. The following changes occuring during withering can be seen by comparing (A) with (B) : The unknown sugar decreases ; raffinose and sucrose increases ; and fructose and glucose remain only little changed (see also Figure 2). The chromatograms were developed in the 1st direction with phenol : acetic acid: water (80 : 2 :18) and in the 2nd direction with butanol : acetic acid : water (4 : 1 : 2.2).

TABLE 1.—*The Carbohydrates found in Tea Shoot Tips*

Description	Level in shoot tips (% dry weight)	Biochemical role in the tea plant and in tea manufacture
Soluble Carbohydrates (Sugars)		
Glucose, Fructose	0.3–0.8	Consumed in respiration to provide energy for life processes. Central compounds in biogenesis of many other chemical constituents of the plant.
Sucrose	0.9–2.3	
Raffinose	Trace	
Unknown	Trace	
Total	1.3–3.1	
Insoluble Carbohydrates (Polysaccharides)		
Pectin	3.2–6.4	A cell wall component. Probably important in the formation of the glossy coating on made tea.
Unknown	1.0–3.0	A reserve source of sugars.
Crude fibre	9.6–11.6	Primarily cell wall components. Very inert metabolically. Contributes to stalk in made tea.

The insoluble carbohydrates (polysaccharides) were divided into 3 major fractions; namely, pectin, an unknown constituent and crude fibre. The unknown polysaccharide is of interest because it appears to fill the role that starch fills in the majority of plants (or even in tea roots); namely, a storage form of carbohydrate. Pectin is a structural component of cells which is important in holding individual cells together; especially in young tissues such as shoot tips (ch. Ramaswamy, 1959). The crude fibre is primarily composed of cellulose and is the inert structural material of the cells.

Changes in the Carbohydrates during the Manufacture of Tea

Sub-samples of the flush plucked for analysis of fresh flush were manufactured into black tea by the micro-manufacturing method. These teas were then analysed by the same methods used for the analysis of fresh flush.

It was found that marked changes in the levels of the various carbohydrate fractions took place during tea manufacture. Our results are shown in Table 2. Noteworthy is the increase in soluble carbohydrates during tea manufacture. This increase appears to come primarily from the insoluble carbohydrate fractions as shown by the decrease in the level of the latter which is usually found. But, as will be brought out below, other cell constituents may also contribute to this increase in soluble carbohydrates.

In another experiment, the soluble carbohydrates were determined at regular intervals during tea manufacture beginning within minutes of the time of plucking. These results are shown in Figure 2. They show that there is, in fact, a large rapid

TABLE 2—*Changes in the Level of certain Carbohydrate fractions during the Manufacture of Black Tea.*

(All figures as % Dry Weight)

Date of plucking	Clone	Sample	Soluble Carbohydrates: Reducing	Soluble Carbohydrates: Non-reducing	Soluble Carbohydrates: Total	Insoluble Carbohydrates: Unknown	Insoluble Carbohydrates: Pectin
3-3-1964	TRI 740	Fresh Flush*	0.39 ↓	1.71 ↑	2.09 ↓	1.06 ↑	5.17 ↑
		Made Tea	0.81 ↓	1.38 ↑	2.20 ↓	0.93 ↑	4.59 ↑
	TRI 777	Fresh Flush*	0.39 ↓	0.96 ↑	1.35 ↓	2.54 ↑	6.00 ↓
		Made Tea	1.09 ↓	0.61 ↑	1.70 ↓	1.22 ↑	7.20 ↓
13-3-1964	TRI 740	Fresh Flush*	0.83 ↓	2.26 ↓	3.08 ↓	nd	nd
		Made Tea	1.18 ↓	2.31 ↓	3.49 ↓	nd	nd
	TRI 777	Fresh Flush*	0.77 ↓	1.57 ↓	2.35 ↓	3.05 ↑	5.00 ↑
		Made Tea	2.33 ↓	3.38 ↓	5.72 ↓	1.46 ↑	3.83 ↑
2-4-1964	TRI 740	Fresh Flush*	0.50 ↓	2.30 ↓	2.80 ↓	nd	nd
		Made Tea	1.10 ↓	2.65 ↓	3.75 ↓	nd	nd
	TRI 777	Fresh Flush*	0.27 ↓	1.53 ↓	1.80 ↓	nd	nd
		Made Tea	1.25 ↓	2.25 ↓	3.50 ↓	nd	nd
23-7-1964	TRI 740	Fresh Flush*	0.70 ↓	2.20	2.90 ↓	1.00 ↓	5.33 ↓
		Made Tea	1.16 ↓	2.20	3.36 ↓	1.16 ↓	5.80 ↓
	TRI 777	Fresh Flush*	0.67 ↓	2.21 ↑	2.88 ↓	1.31 ↑	5.80 ↓
		Made Tea	1.50 ↓	2.10 ↑	3.60 ↓	0.75 ↑	7.56 ↓

(↑ = decrease during manufacture ; ↓ = increase during manufacture ; nd = not determined)

*Flush taken at time of spreading to wither ; about 2 hours after plucking.

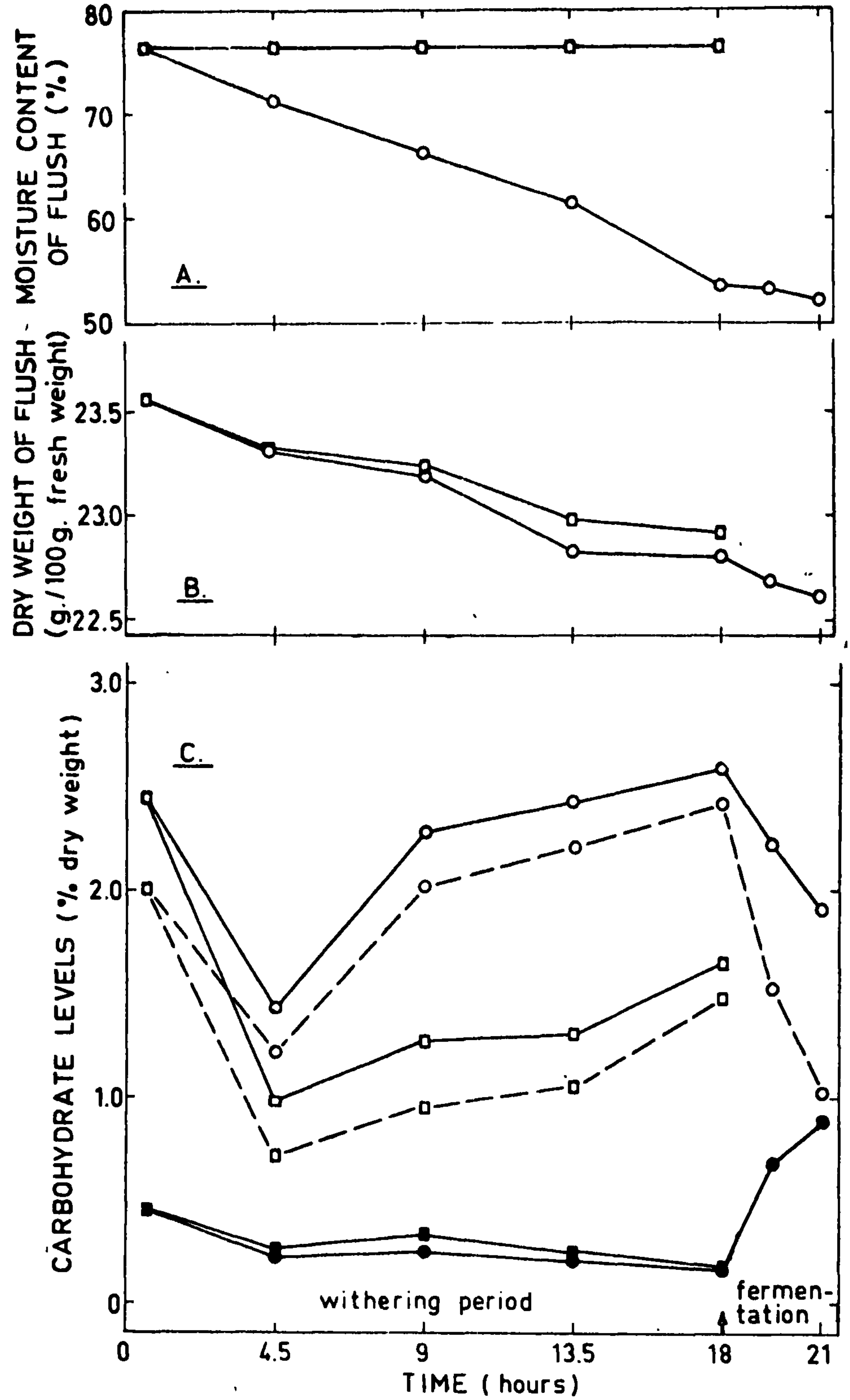

Figure 2.—Changes in carbohydrates occuring during the manufacture of tea. *A*. Record of withering ;O—O, withering flush : □—□, non-withering flush (stored in polythene bags). *B*. Dry weight changes during withering ; O—O, withering flush; □—□, non-withering flush. *C*. Changes in carbohydrate levels ;O—O, total soluble carbohydrates in withering flush; O- - -O, non-reducing sugars in withering flush; ●—●, reducing sugars in withering flush; □—□, total soluble carbohydrates in non-withering flush ; □- - -□, non-reducing sugars in non-withering flush; ■—■, reducing sugars in non-withering flush. Note: Fermentation was started 18 hours after plucking by mincing the flush.

decrease in soluble carbohydrates during the first few hours following plucking which is followed by a steady increase in these substances during the withering period. Finally, the level of soluble carbohydrates decreases from the time the flush is rolled until it is fired. The final level is actually lower than the level at the time of plucking but higher than the level 4½ hours after plucking which corresponds roughly to the time at which plucked flush is normally spread to wither. Therefore, the increase in soluble carbohydrates shown in Table 2 (also compare Figure 1A with Figure IB) and which has been reported previously (Carpenter, 1931; Sanderson, 1964b) must be interpreted as the increase which normally takes place during the withering period but it must be recognized that biochemical changes are taking place beginning immediately the flush is plucked which may affect the final results obtained.

It is noteworthy that the changes in carbohydrate levels which take place in plucked flush which is stored so as to prevent withering (in polythene bags) are different from those taking place in flush which is allowed to wither (see Figure 2). This is in contrast to several other changes that take place in flush after plucking which are the same in withering and in non-withering flush (Sanderson, 1964b). These results suggest that the chemical wither which takes place during storage of flush after plucking is dependent to some extent on the method of storage. Additional research is required before we can adequately understand the importance of these findings.

The levels of carbohydrates in made tea found in this investigation (Table 2) agree well with those reported for Indian tea (Indian Tea Board, 1958, 1959). Our qualitative studies on made tea have shown that the same sugars are present here as in fresh tea flush (Table 1). Cartwright & Roberts (1954) have also reported these sugars and, in addition, three other sugars which must be present at very low concentrations since they were not detected in our work.

The Importance of Carbohydrates in Tea Production

As mentioned in the introduction, carbohydrates are known to play a central role in plant metabolism. The transformations which carbohydrates are known to undergo in tea plants are shown diagramatically in Figure 3. The information in Figure 3 may be summarized as follows: Carbon dioxide (CO_2) is fixed by the green parts of the plant during daylight hours through the process called photosynthesis. The first products of photosynthesis are the sugars and closely related compounds. The sugars can then be metabolized into such varied compounds as polyphenols, organic acids, and polysaccharides. In most cases metabolic changes in plants are capable of proceeding in the forward as well as the reverse directions and this is shown by the double arrows in Figure 3. The conversion of sugars to polyphenols appears to be an important exception in that the polyphenols do not appear to be metabolizable by intact cells. However, the data available to date on this subject is not conclusive.

The two major functions of carbohydrates are also shown in Figure 3. First, carbohydrates serve as a source of energy for the plant. This energy, derived from the sunlight, was captured in photosynthesis and it is released through respiration. Finally, the carbohydrates serve as the starting materials for the biogenesis of many other cell constituents.

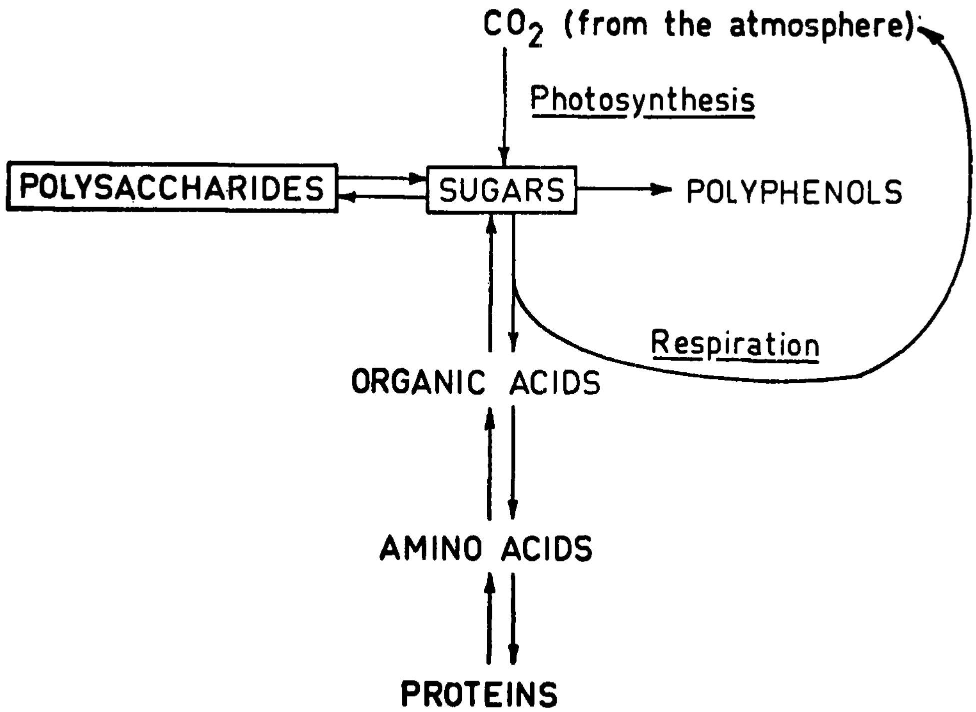

Figure 3.—Diagram showing relationships between several groups of chemical compounds important in the metabolism of plants with special reference to tea plants. Arrows indicate direction of enzymatic changes which can occur between groups of compounds; double arrows indicate that the change can occur in either direction. The groups of compounds which are classed as carbohydrates are enclosed in rectangles.

A large seasonal variation in carbohydrate levels in tea shoot tips is evident from the data shown in Tables 1 and 2. This observation is in keeping with the seasonal variations found with respect to several other chemical constituents of tea flush which have been described previously (Sanderson, 1964a; Sanderson & Kanapathipillai, 1964).

It is often forgotten that tea manufacture is in fact a biological process which is more or less controlled by mechanical means. This can be seen from the data reported in this paper. For instance, the level of the chemical quantities measured changes throughout the course of tea manufacture (ch. Table 2 and Figure 2) and it can be shown that the changes are affected by time, temperature, and the starting material (Sanderson, 1964b). The fact that respiration is proceeding during tea manufacture can be deduced from the decrease in dry weight shown in Figure 2 (the loss in dry weight in this experiment was 3.9%). The energy from this respiration supports the life processes in the plucked flush and it is the source of the heat (a by-product of respiration) which is noticeable in plucking baskets and in heaps of flush in factories.

Knowledge of the fate of the carbohydrates which are metabolized during tea manufacture is only partially known. It is certain that some of these are respired during this process and in that way they are lost completely. However, it is likely that this is not the complete story. It may well be that these substances either contribute directly or indirectly (after being metabolized to other substances) to the quality of the tea produced. Additional research, which is now under way, is required before the importance of the carbohydrates in tea production can be described with any certainty.

Summary

1. The major soluble carbohydrates in tea shoot tips have been found to be glucose, fructose, and sucrose.
2. The major insoluble carbohydrates in tea shoot tips have been found to be pectin, crude fibre (cellulose, etc.), and a carbohydrate which is not starch but which is somewhat similar to it.
3. The level of carbohydrates has been found to vary markedly with the season.
4. The level of carbohydrates undergoes marked changes during tea manufacture.
5. The role of the carbohydrates in tea production has been discussed.

Acknowledgements

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