HEAT AND AIR-FLOW CHARACTERISTICS IN DRYING CROPS

— *by* —

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The importance and the need of drying a crop to a safe level of moisture content so that it can be stored on the farm for a period sometimes extending over a number of months has become accentuated by the general adoption of mechanized harvesting methods, as the crops are now removed from the field at a much higher moisture content than they were with the earlier hand harvesting methods. Various methods of drying are used on the farm, depending upon the size of the crop, initial moisture content and the drying facilities available, the general trend being towards bulk drying and storage as this method offers the maximum possibility of saving in handling and labour costs.

Published literature indicate that earlier investigations on various aspects of crop drying has tended to be concentrated on grain crops like wheat and barley, with comparatively little attention being paid to tropical or specialised crops, as exemplified by cassava (*Manihot esculenta* Crantz), sweet potato (*Ipomoea batatas*), ground nuts (*Arachis hypogea L.*) cherry coffee (*Coffea canephora*) or haricot beans (*Phaseolus vulgaris*). A programme of work has been initiated at the Faculty of Agriculture of the Makerere University College for studying the drying characteristics of a large number of tropical crops including root crops, and the results of experiments carried out to study the heat-and air-flow characteristics of the five crops mentioned above are described in the present article. Similar studies with maize, sorghum, parchment coffee and a type of pulse are being carried out at present.

Experimental results obtained with thin layer (of single grain) drying can be applied to deep bed drying on the assumption that the latter can be regarded as a series of thin beds, and that the analytical methods used to predict moisture changes in a thin bed can also be applicable to thick beds (1-2). This approach has not generally succeeded, however, as without electronic aid the number of calculations required to reach a satisfactory answer would be prohibitive of effort (3). In the present work, therefore, a bed depth of 18 in. has been used for all the investigations.

In order to facilitate experimental work during periods when naturally moist grain or crop is not easily available, investigators have to sometimes fall back upon using artificially rewetted material. Experiments carried out by Dietrich (4) with a single-layer test sample of wheat indicated that in drying from about 28 to 18% m.c. (d.b.), the average drying rate for the artificially rewetted sample was about 50% greater than for naturally moist wheat, while Bailey (5) carried out his investigations on the assumption that the drying rate is equal for both the samples. Vegetative products do not always respond to moisture in a similar manner on both absorption and desorption cycles; Ghosh (6) found that dry sisal fibre at 12% m.c. did not regain its original internal moisture level (approximately 44%) even after 24 hours of soaking in water. In the present investigation, all the five crops were in their naturally moist state at the time of drying.

DESCRIPTION OF APPARATUS

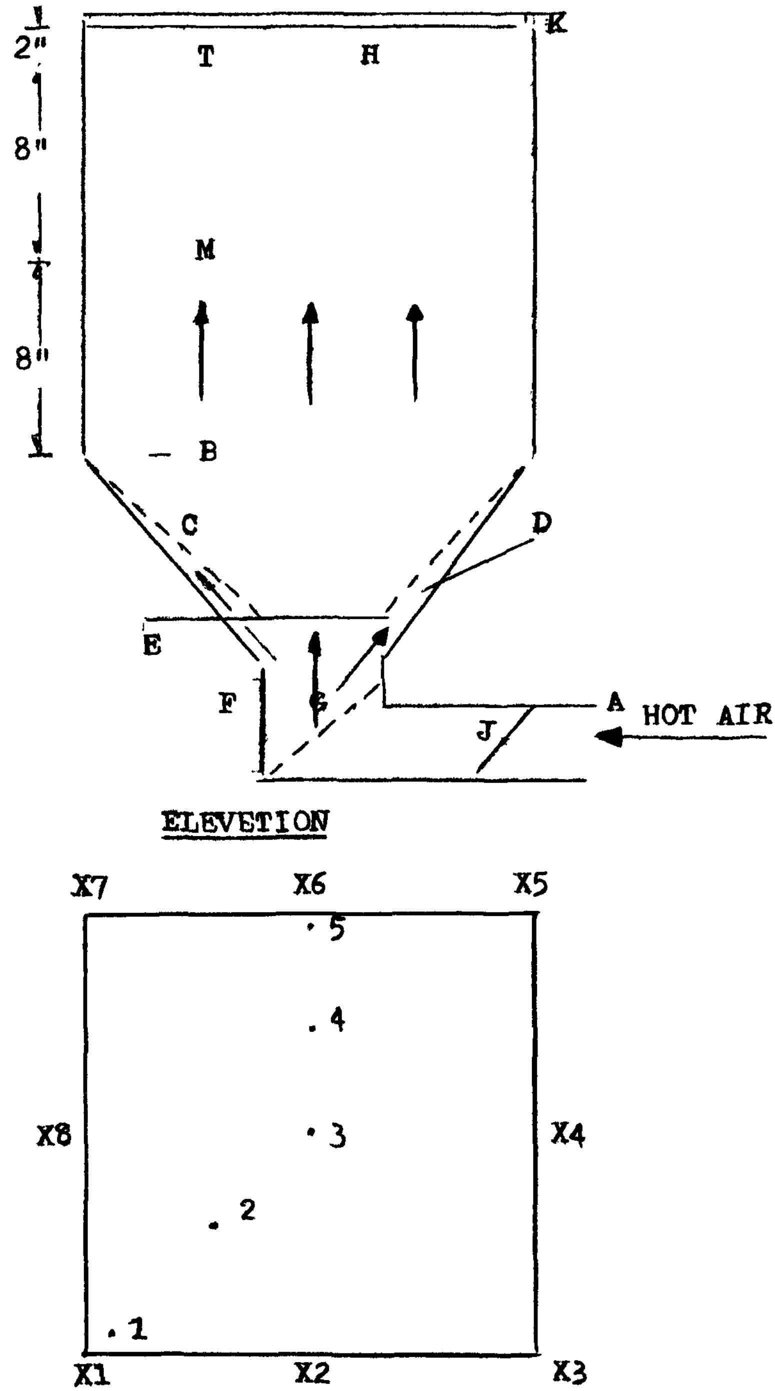
The apparatus (Fig. 1, elevation) used for the experimental work basically consist of a hopper (7) 18 in 3 with a conical bottom section for air inlet through a pipe A and a butterfly J. Inside the conical section of the hopper is located another smaller section C made of perforated metal, so that hot air can flow upwards through the mass of the material being dried. The direction of flow of air through the hopper is shown by arrows in Fig. 1. The space created by the vertical gap between the two conical sections constitute the plenum chamber, and a thermometer D inserted into the chamber gives the temperature of the inlet air at any time. A sliding gate E working on a horizontal plane is provided with a blank section for diverting the air upwards through the sides of the hopper only, a perforated section to enable the air to rise throughout the cross sectional area of the hopper and a slot for discharging the material through another sliding gate F working on a vertical plane and a removable baffle G which can be placed in position only by fully opening the gate F. A loosely fitting hard board lid H sits on the top of the material being dried and is also provided with clips K for additional support. The exhaust air escapes through the space between the lid H and the sides of the hopper. The four vertical walls of the hopper are well lagged with insulating material from outside to prevent heat losses.

A nest of 15 thermocouples, inserted through the hardboard top, in three layers of 5 each were used to measure the temperature of the drying material at intervals of 10 min without disturbing the drying process. The position of the 3 layers at the top, middle and bottom (T,M,B) of the hopper is shown in Fig. 1 (elevation) and the disposition of the 5 thermocouples in each layer in Fig. 1 (top-view) as 1, 2, 3, and 5. The sensing element of each thermocouple was enclosed in a pyrex glass tube to prevent direct contact with the drying material.

The hot air to the hopper was supplied through the inlet tube A (Fig. 1) by a thermostatically controlled laboratory drier (8) for the lower inlet air velocity used and by another electrical heater-blower unit (9) for the two higher inlet air velocities. The thermocouples were connected through contact switches to a highly sensitive spot-galvanometer calibrated to give a scale deflection of approx. 9 in for a temperature range between 0 to 100°C. The other end of sensing elements were kept immersed in ice maintained in a thermosflask. The velocity of the air entering the hopper and at exhaust (XI to X8 in Fig. 1, top-view) was measured by a velometer.

EXPERIMENTAL SCOPE

Woodforde and Lawton (10) have recently studied the temperature changes that take place during drying at the top, middle and bottom layers of a 6 in. deep bed of wheat and barley, while Boyce (3) has emphasised the importance of measuring the changes in air or grain temperature in the bed during drying. In the present experiment, cassava and sweet potatoes were each dried at three levels of moisture content using two different air velocities and nuts in shell were dried



TOP VIEW showing position of thermocouples for each layer (1-5) and points of exhaust air measurement (X1-X8).

Fig. 1. Hopper

at three different air velocities each at a different level of moisture content, while cherry coffee was dried at two levels of moisture content at a constant air velocity. Haricot beans at four levels of moisture content were dried at three different air velocities. In each of the 15 experiments reported in this paper, the temperature changes were measured during drying at the top, middle and bottom layer of an 18 in. deep bed, and the airflow measured both at the inlet (bottom) and the outlet (top). All the moisture determinations were carried out by drying a sample of approximately 10 g. in an air oven for 24 h. at 103°C (Kabanyolo University Farm. Kampala), at an elevation: 3950 ft and the values have been reported on a wet basis. Although some of the material used for the experimental work could be considered as 'dry' for safe storage before drying commenced, these were included in the test programme to study if there was any noticeable change in their heat-flow characteristics as the material dried. The maximum drying air temperature used was also kept somewhat higher (80°C) than the generally recommended values to ascertain the maximum rise in grain temperature that could be expected during deep bed drying. Even higher drying temperatures of 104°C have been recommended for drying grain to be used for feeding purposes on the farm (11), and tests carried out with wheat dried at 82°C and 104°C failed to reveal any damage (other than to germination) or discontinuity in the texture of the endosperm (10). It was beyond the scope of this experiment to study the effect of drying temperature on the subsequent germination of the grains.

PROCEDURE

The material to be tested was well mixed and a small random sample collected for initial moisture determination before filling the hopper level with the top, without making any attempt to pack the material. The hopper lid was placed in position so that the bottom of the lid rested on the material to be dried, the thermocouples were inserted in place and the electrical connections checked with the free end of the thermocouples being kept immersed in ice. The drier of the heater-blower unit was started and set to produce hot air at a predetermined temperature and velocity. The ambient air temperature along with the initial temperature of the 15 thermocouples in position were noted and the hot air conected to the air-inlet tube A of the hopper to commence drying.

Galvanometer reading were taken at 10 min intervals for all the 15 thermocouples in turn and the temperature of the inlet-air read from the thermometer D. In practice, the 16 readings took approximately 1½ to 2 min to read, and each time the same sequence of operation was followed to ensure that a set of readings for a particular thermocouple was very nearly at 10 min intervals. The velocity of the exhaust air was read during the run at the positions X1 to X8 by the velometer. Observations were continued till the temperature of the drying material through-out the dept became equal to the inlet air or for a minimum arbitrary period of 6 hrs. At the end of the run, a random sample of the dried material from the top and the bottom layers were collected for moisture determination before discharging the material from the hopper through sliding gates E and F and the baffle G.

While ground nuts in shell, cherry coffee or haricot beans could be dried in their natural state, cassava and sweet potato tubers had to be cut and reduced in size to facilitate drying. The tubers were first soaked in water for a short time to remove soil and dirt, and then shaped by hand chopping into cubes approximately ¾ in. in size.

RESULTS AND DISCUSSION

(1) *Temperature rise through material.*

With both cassava and sweet potato, the freshly cut material being at a high initial moisture (approx. 60% w.b.), the temperature rise at the top layer is very little even after 6h of drying; with the lower inlet air velocity it is confined to the bottom layers only (Figs. 2a, 3a) while for the higher velocity the middle layers are also affected (Figs. 2b, 3b). At the lower initial moisture of around 35% the temperature rises in both the material throughout the bed and the top, middle and bottom layers are well defined (Figs. 2c, 3c). The difference in temperature between the 5 thermocouple positions for each layer is also noticeable, particularly at the higher initial moisture. Woodforde and Lawton (10) measured the grain temperature during drying at 4 positions for each level, but reported only one curve for each layer. Cassava at 58.21% initial moisture was cut and left in a heap in the afternoon and drying commenced the following morning, when an increase in temperature of up to 8°C from the ambient was noticed in the material.

With groundnuts, the difference in temperature between the top and the bottom layer is approximately 18°C even after 7 h of drying at the lower inlet air velocity and the higher initial moisture (Fig. 4a), while comparison of Figs. 4b and 4c indicates that by increasing the inlet air velocity the increase in temperature throughout the bed is very rapid and it is relatively unaffected by the initial moisture content. The difference in the temperature between the 5 thermocouple positions for each layer is also noticeable, particularly for the lower inlet air velocity (Fig. 4a).

With cherry coffee at initial moistures of 39.48 and 33.96% the rise in temperature at the top layer is very little even after 7 h of drying, and there is a considerable variation between the temperatures recorded by the 5 thermocouples at either the bottom or the middle layers. Cherry coffee at 39.48% initial m.c. was loaded in the hopper at about 4.00 p.m. in the afternoon and the drying commenced at 9.00 a.m. the following morning, when an increase in temperature of up to 13°C from the ambient was noticed inside the hopper.

Two experiments with haricot beans at an initial moisture of 18.15 and 11.69% and an inlet air velocity of 2085 ft. min $^{-1}$ 1 show that the rise in temperature at the top layer is very little in both (Figs. 6a 6b) compared to the bottom layer, with a difference of approximately 34°C after a drying period of 7.5 and 6.5 h respectively. After a slight initial rise in temperature the top layer in both the cases remain more or less constant for the first 4.5 h.of drying, indicating that all the heat available for drying was being utilized at the bottom and middle layers. With higher inlet air velocities (Figs. 6c 6d) the increase in temperature throughout the bed is more rapid.

(2) *Exhaust air velocity*

The exhaust air velocities recorded for cassava, sweet potatoes, ground nuts and cherry coffee (Table 1) show that it is proportional and approximately 10% of the inlet air velocity, although there are some differences between the readings obtained from the eight positions. With haricot beans the exhaust air velocities are somewhat lower, probably due to closer packing together of the material.

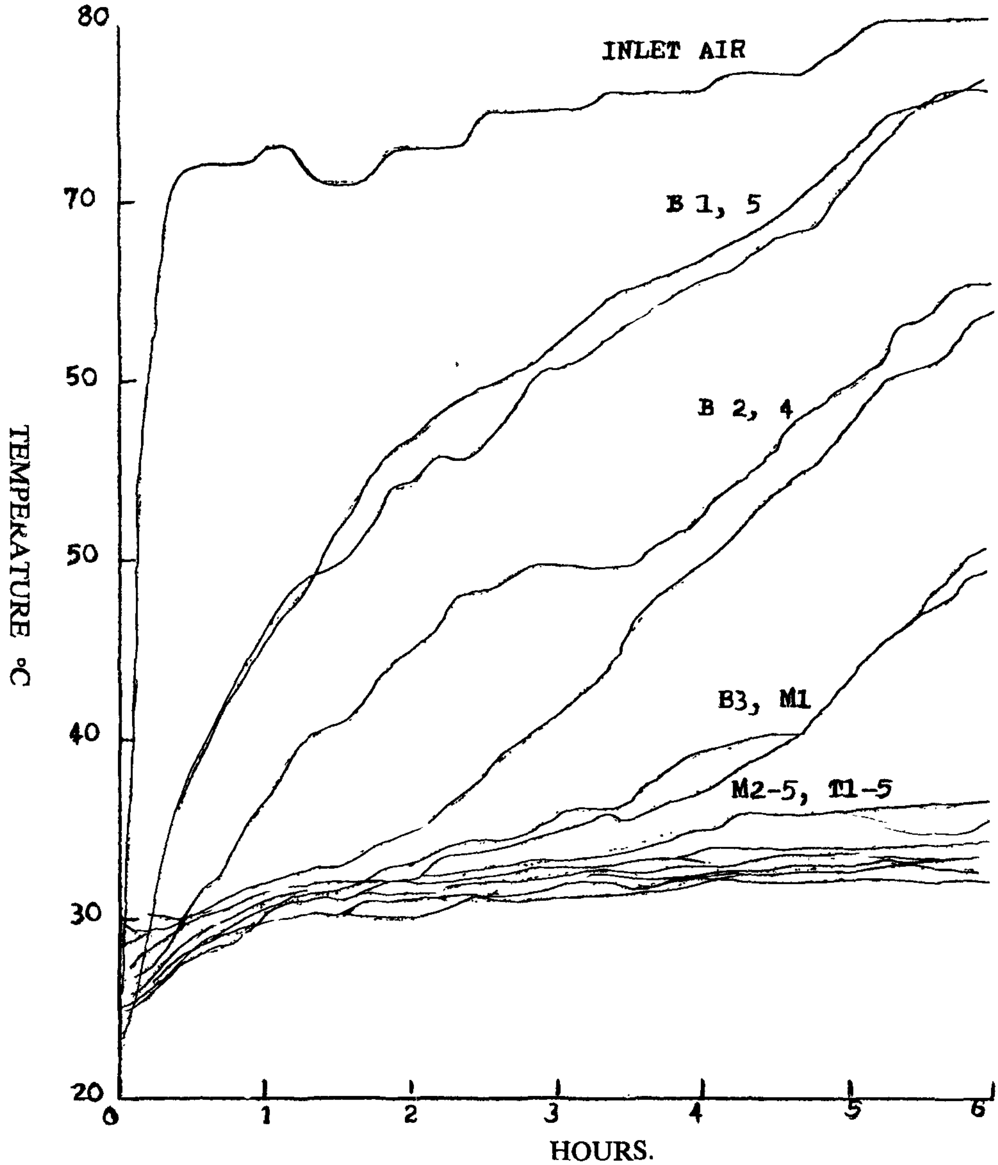


Fig. 2a. Drying time—temperature, Cassava Initial moisture 58.21%, Inlet air 3500 ft. min —1

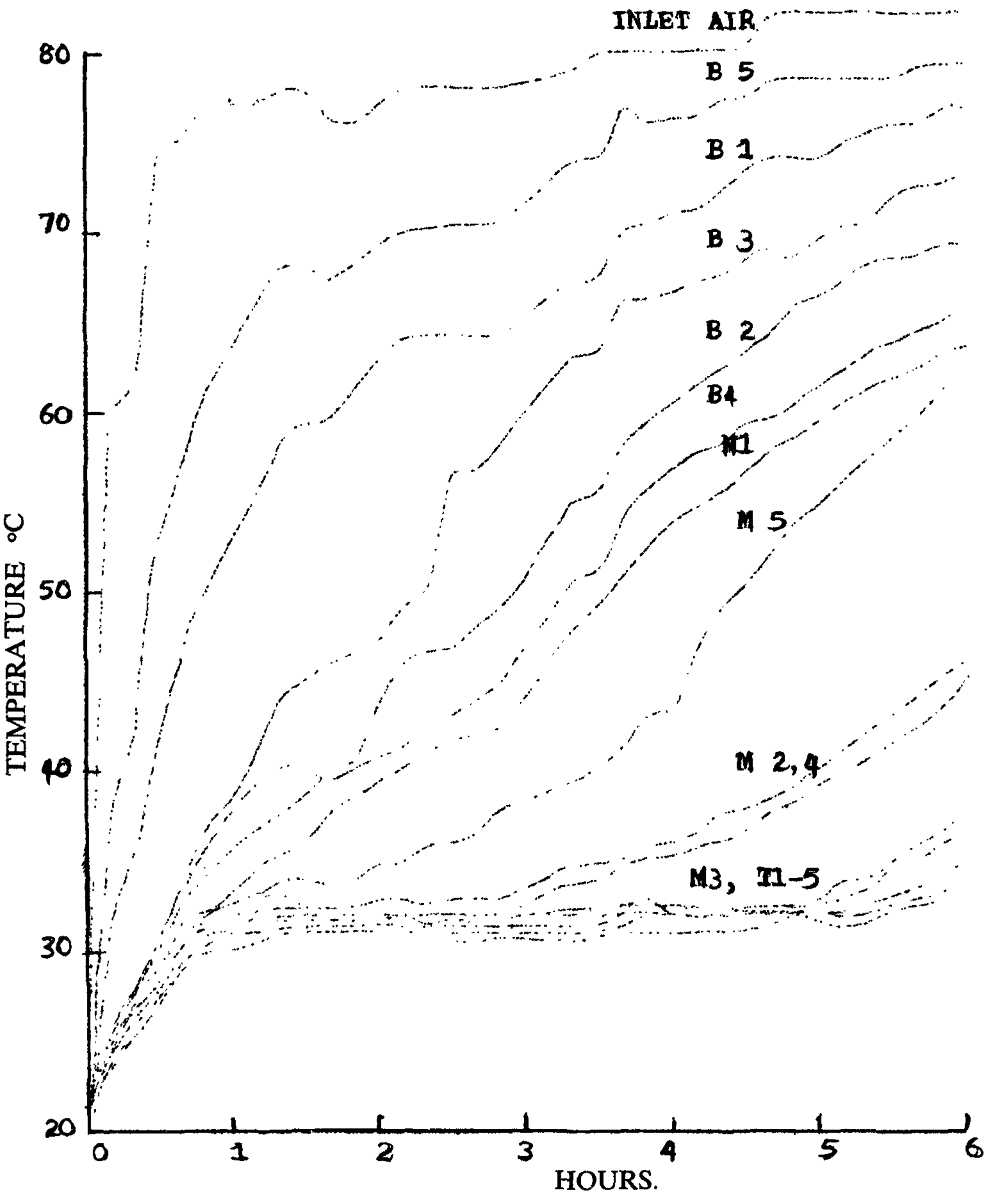


Fig. 2b. Drying time—temperature, Cassava. Initial moisture 59.98%, Inlet air 5410 ft. min $^{-1}$

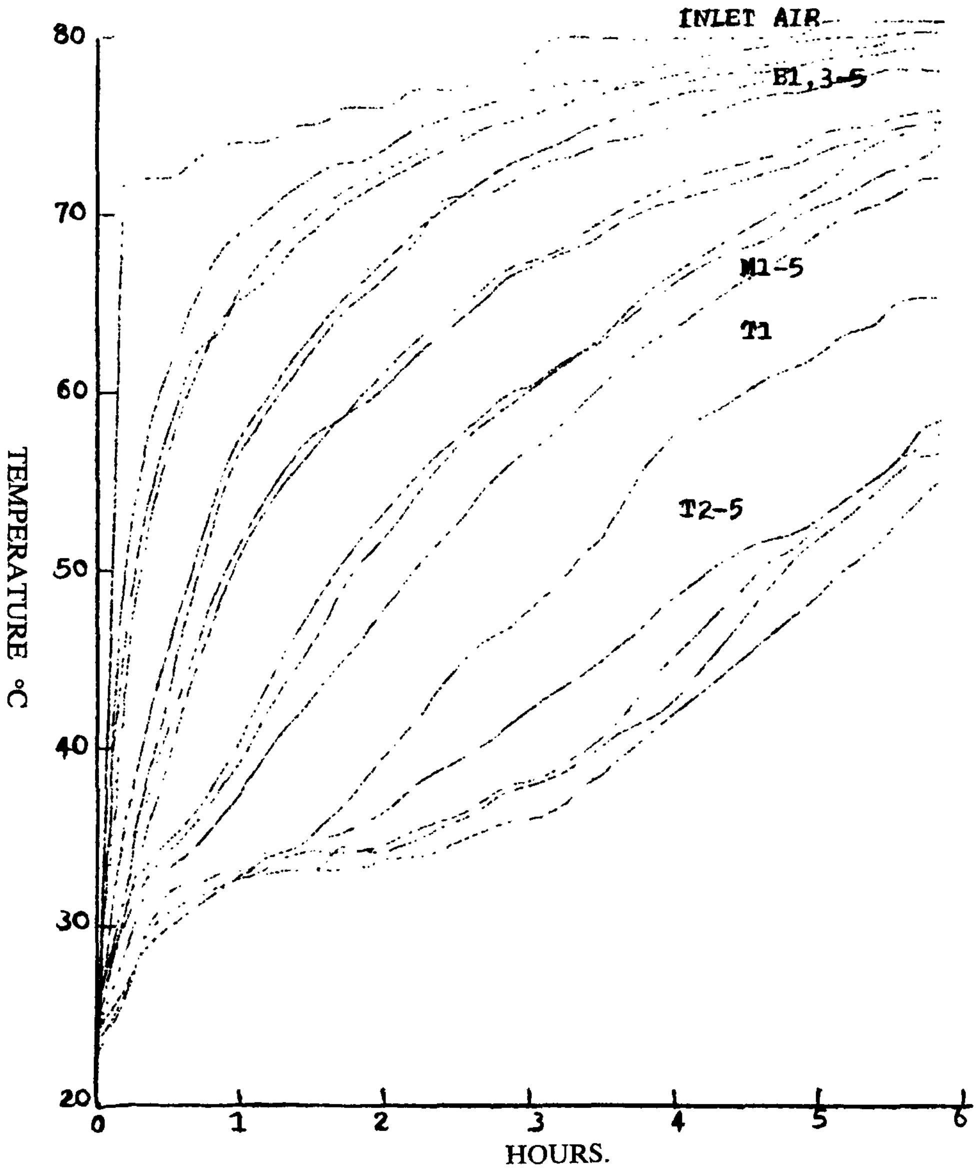


Fig. 2c. Drying time—temperature, Cassava. Initial moisture 34.22% Inlet air 5430 ft. min —1

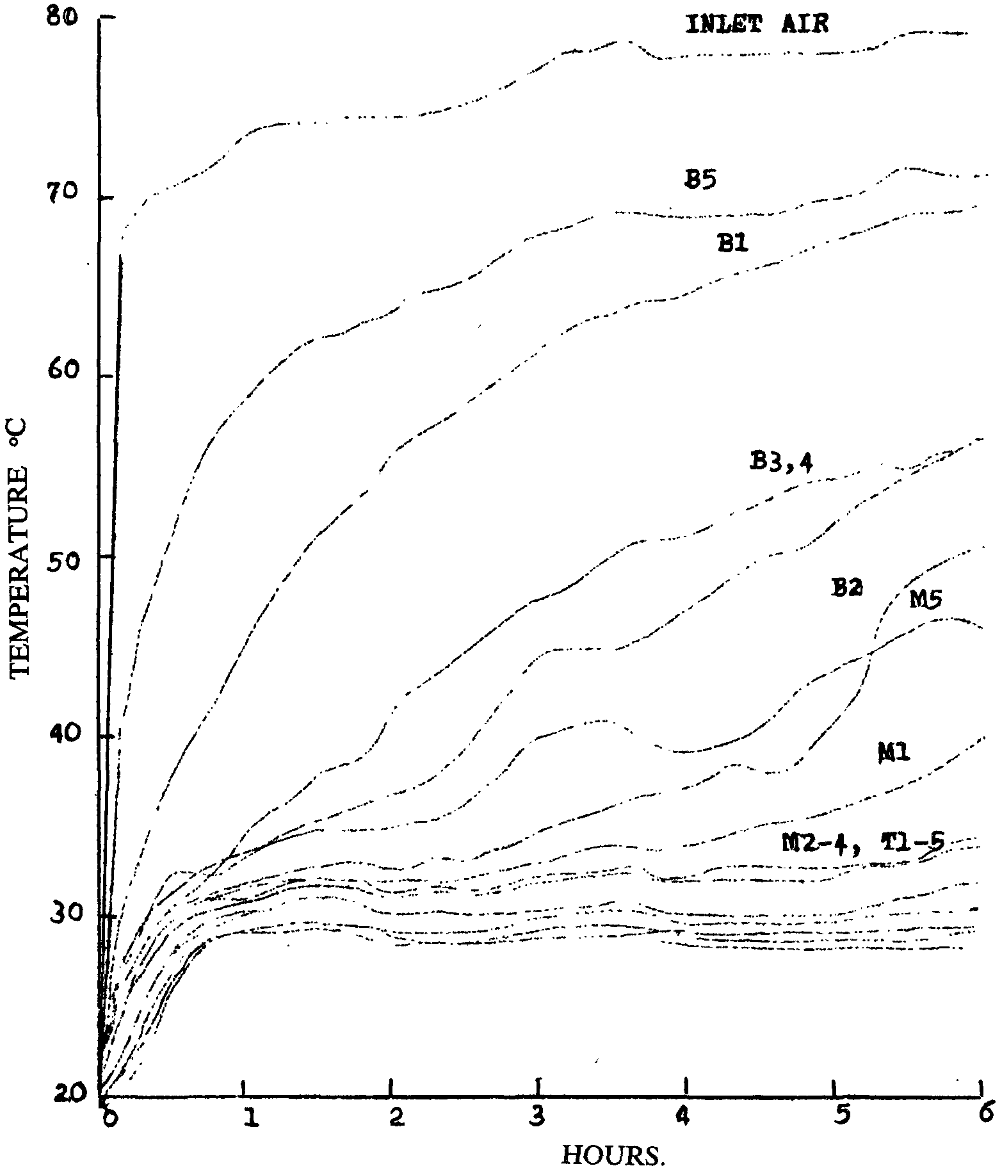


Fig. 3a. Drying time—temperature, Sweet potatoes. Initial moisture 60.61%, Inlet air 3509 ft. min $^{-1}$

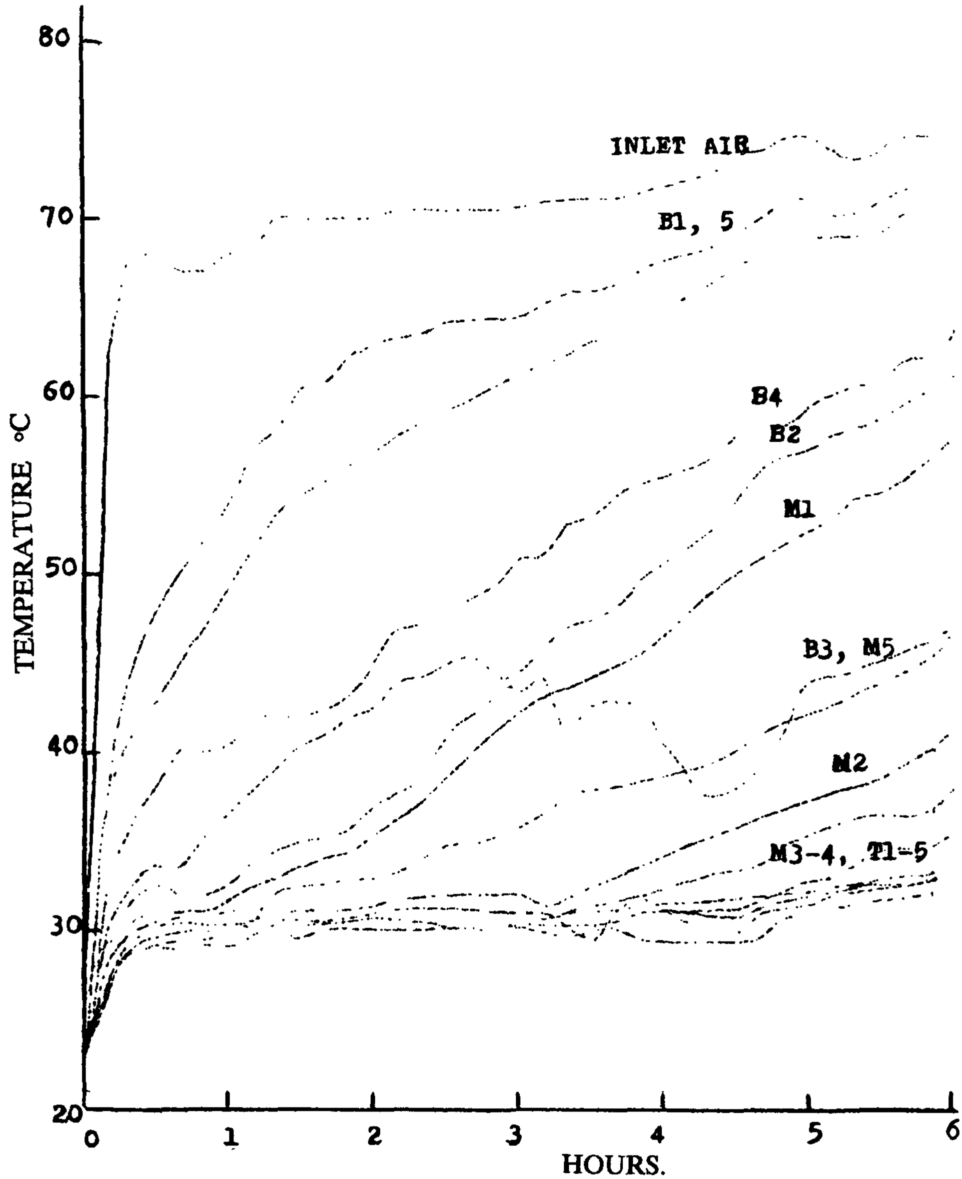


Fig. 3b. Drying time—temperature, Sweet potatoes. Initial moisture 60.11%, Inlet air 5481 ft. min —1

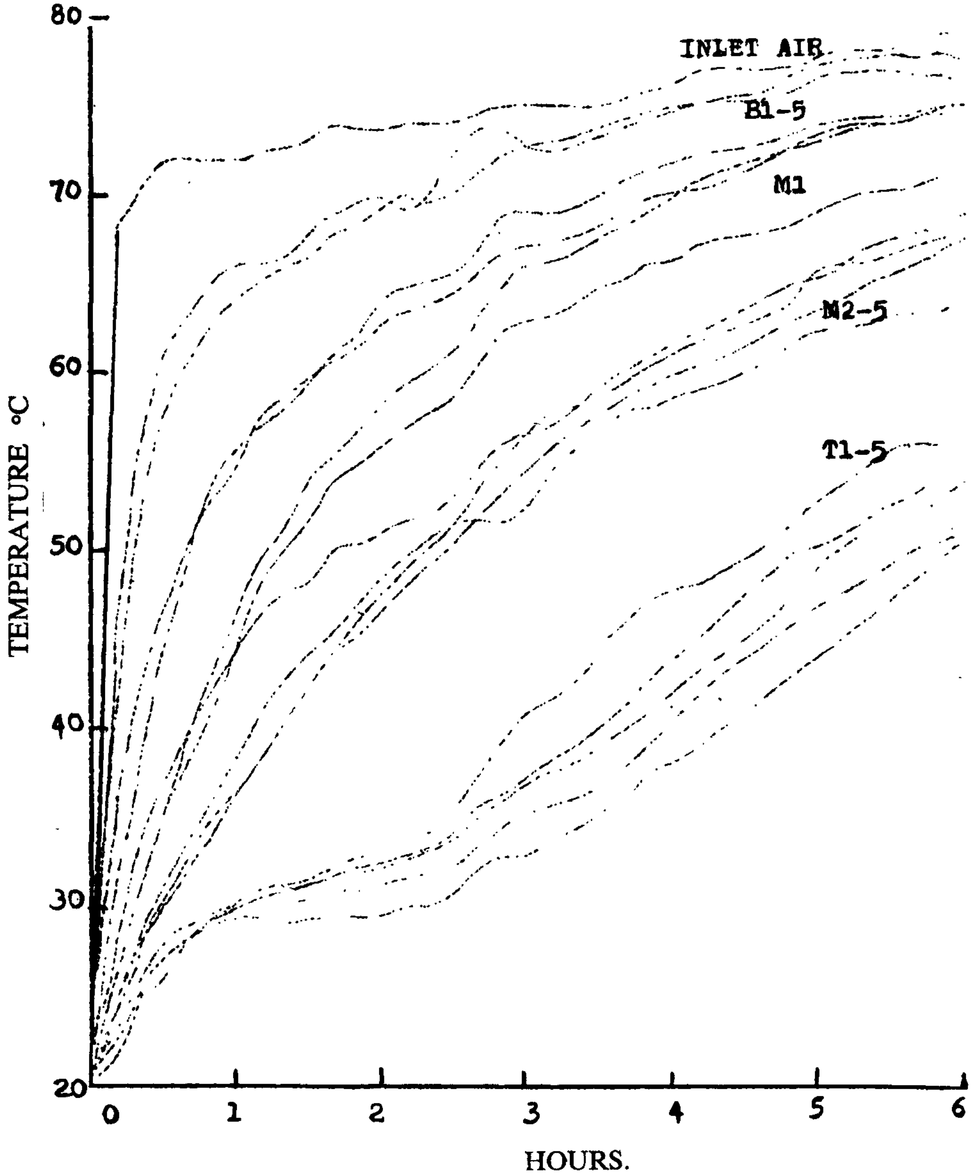


Fig. 3c. Drying time—temperature, Sweet potatoes. Initial moisture 35.91%, Inlet air 5665 ft. min $^{-1}$

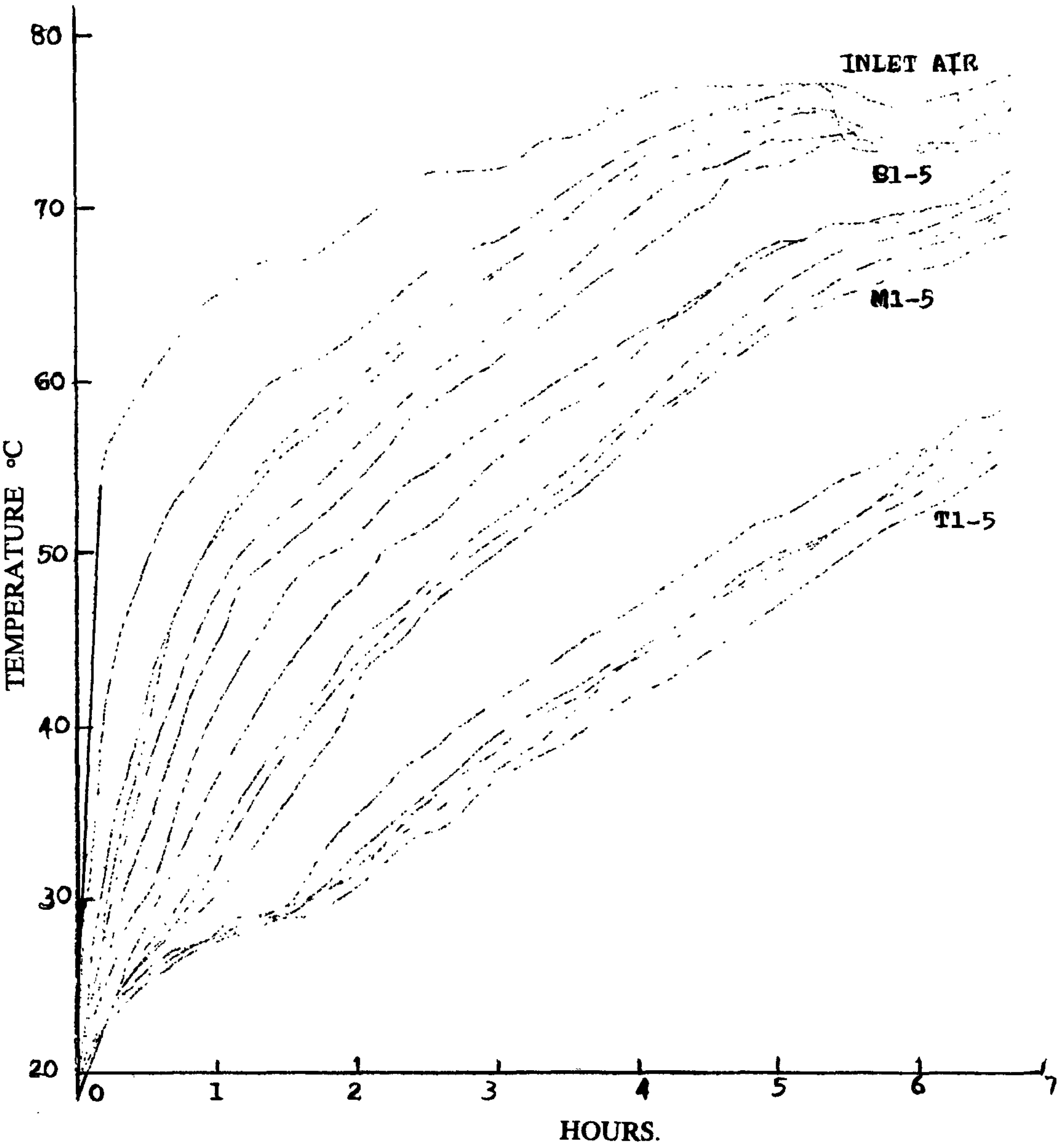


Fig. 4a. Drying time—temperature, Groundnuts in shell. Initial moisture 14.38%, Inlet air 2019 ft. min $^{-1}$

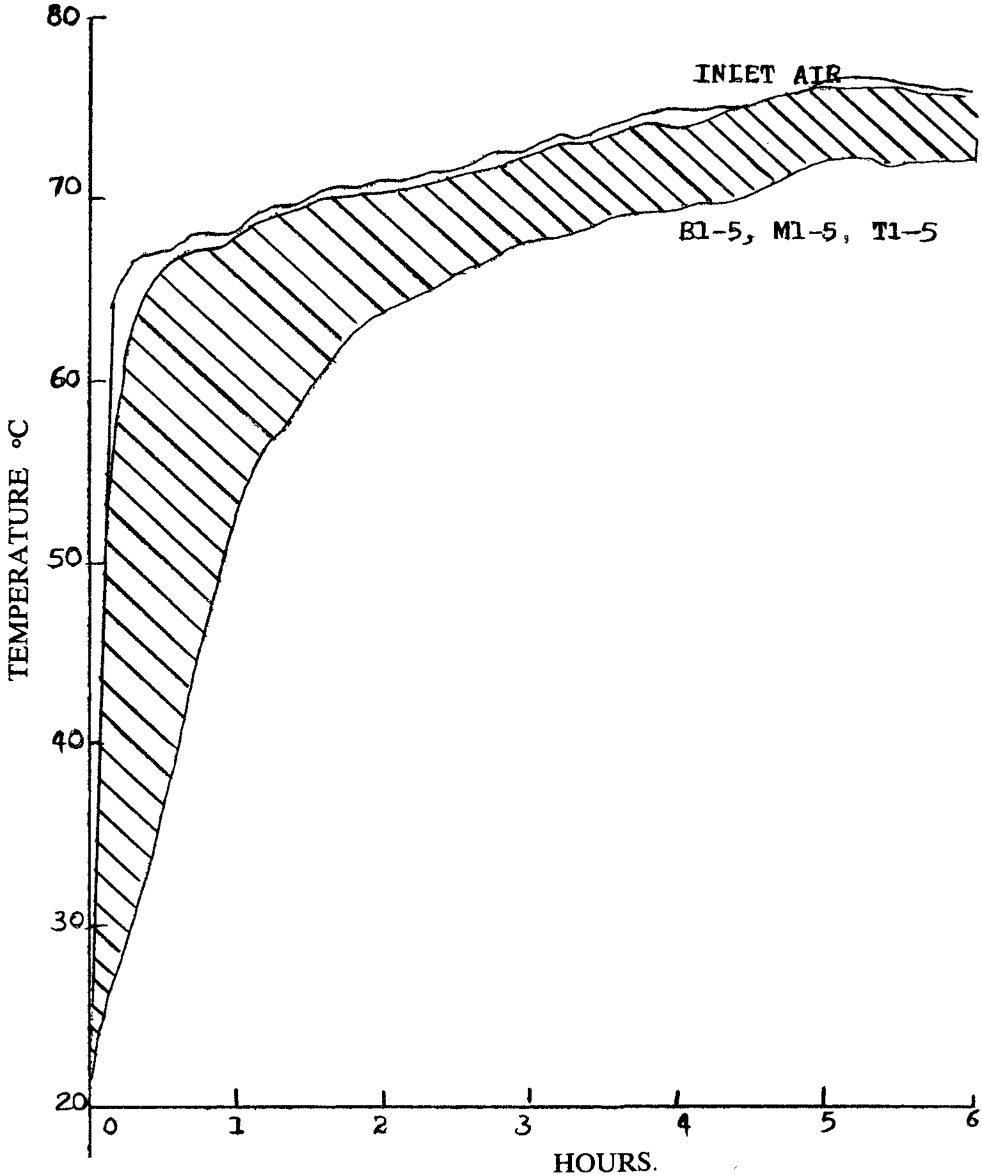


Fig. 4b. Drying time—temperature, Groundnut in shell. Initial moisture 10.14%, Inlet air 5390 ft. min $^{-1}$

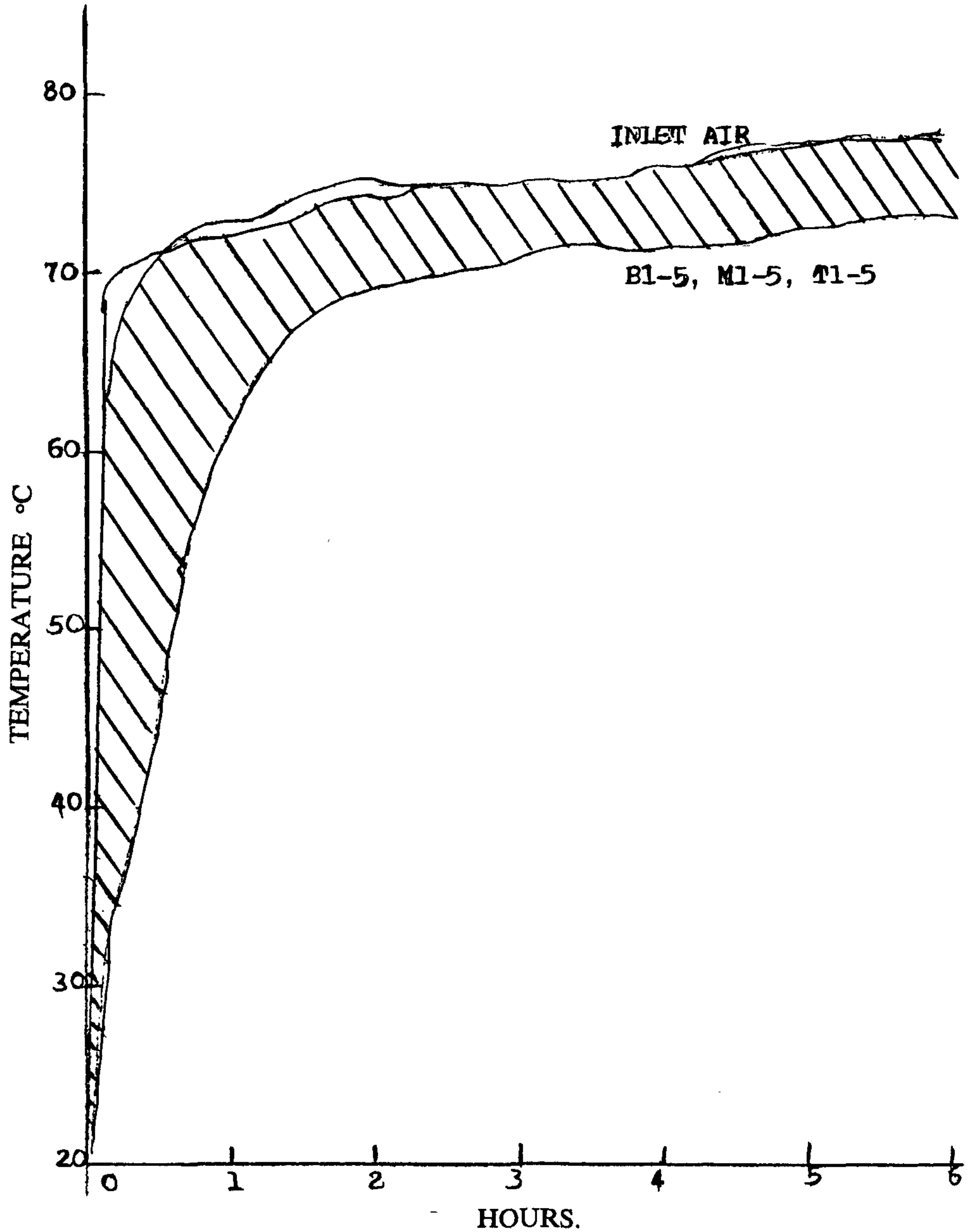


Fig. 4c. Drying time—temperature, Groundnut in shell Initial moisture 3.99%, Inlet-air 3604 ft. min —1

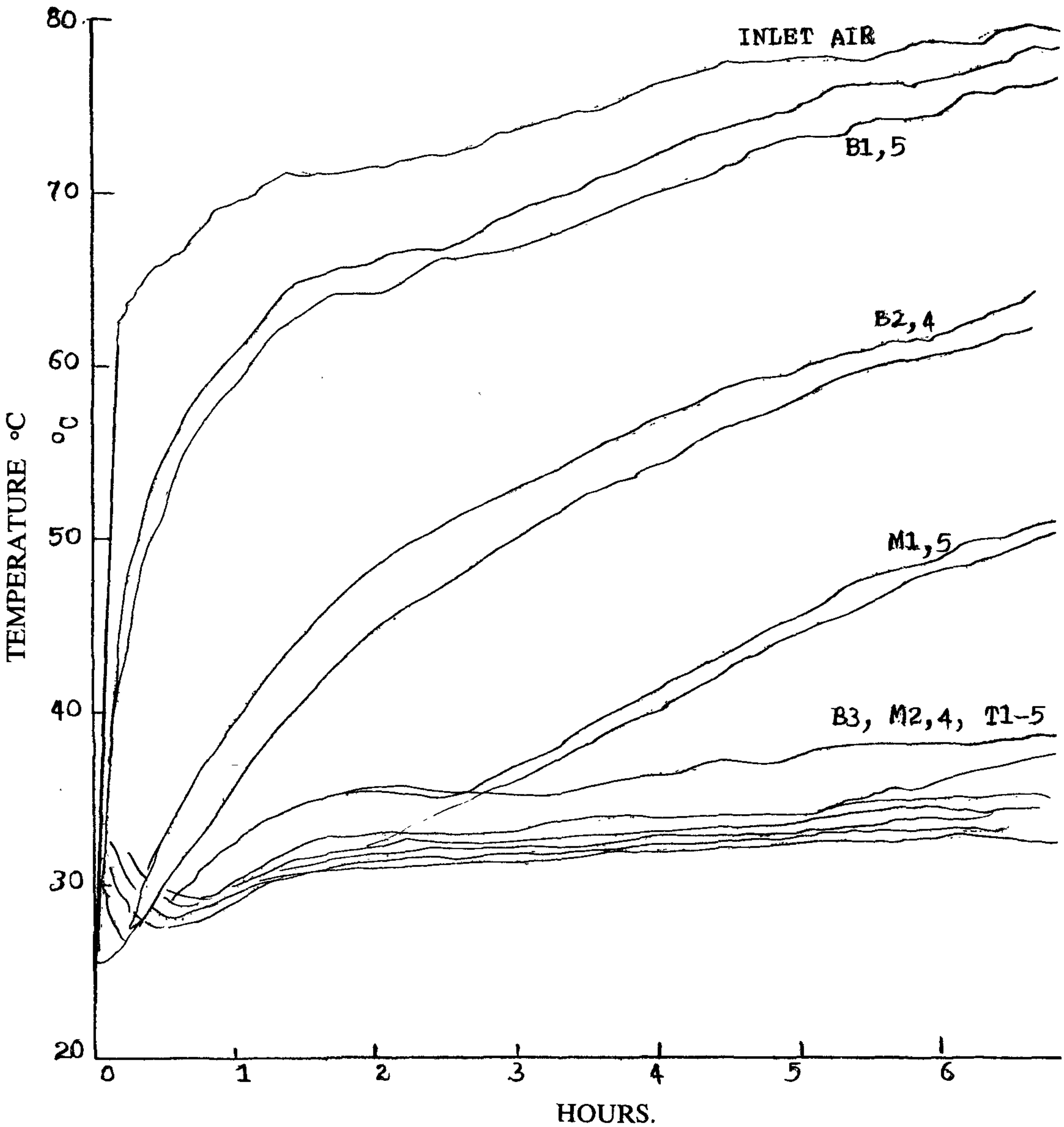


Fig. 5a. Drying time—temperature, Cherry coffee. Initial moisture 39.48%, Inlet air 1970 ft. min —1

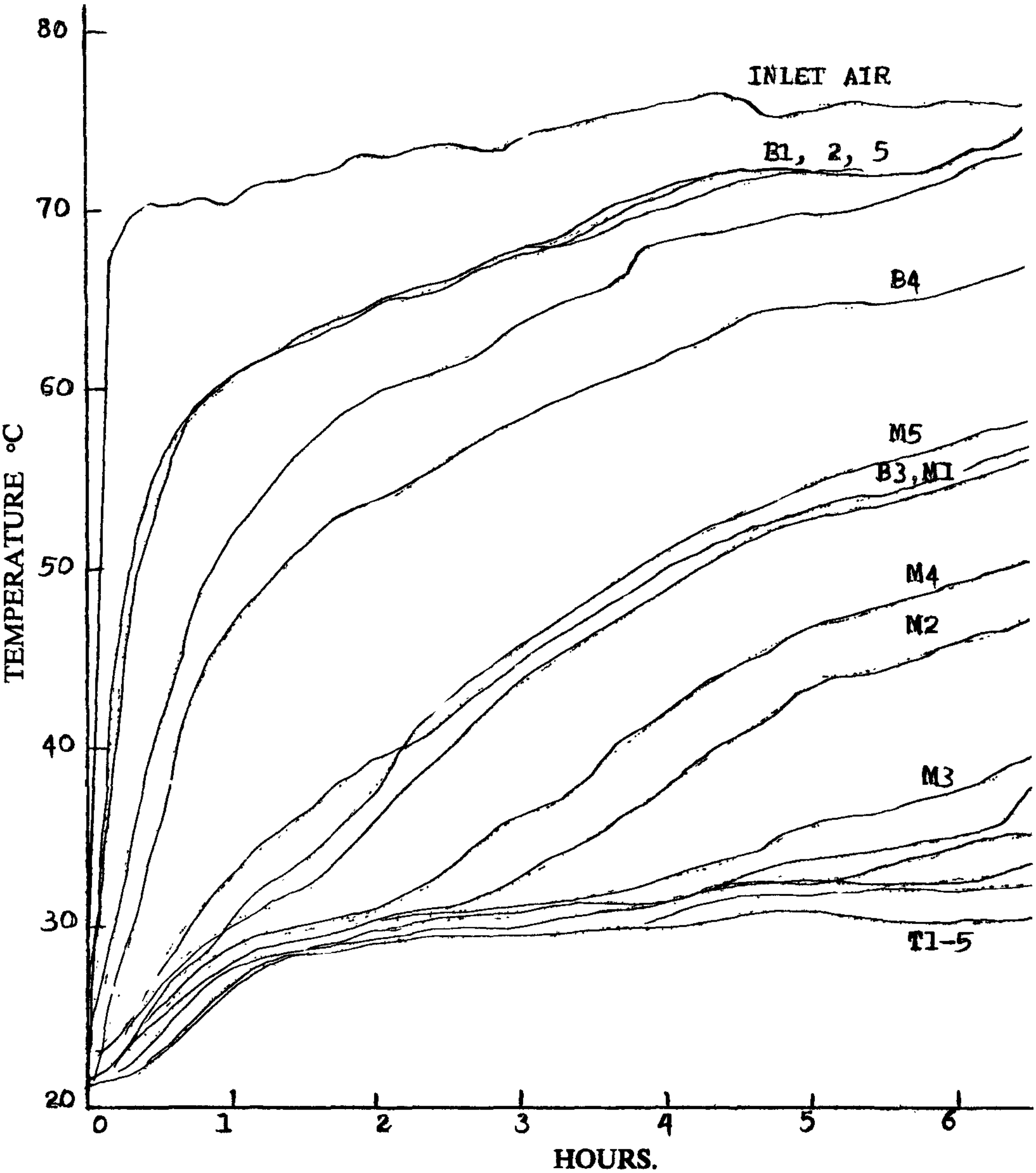


Fig. 5b. Drying time—temperature, Cherry coffee. Initial moisture 33.96%, Inlet air 1970 ft. min $^{-1}$

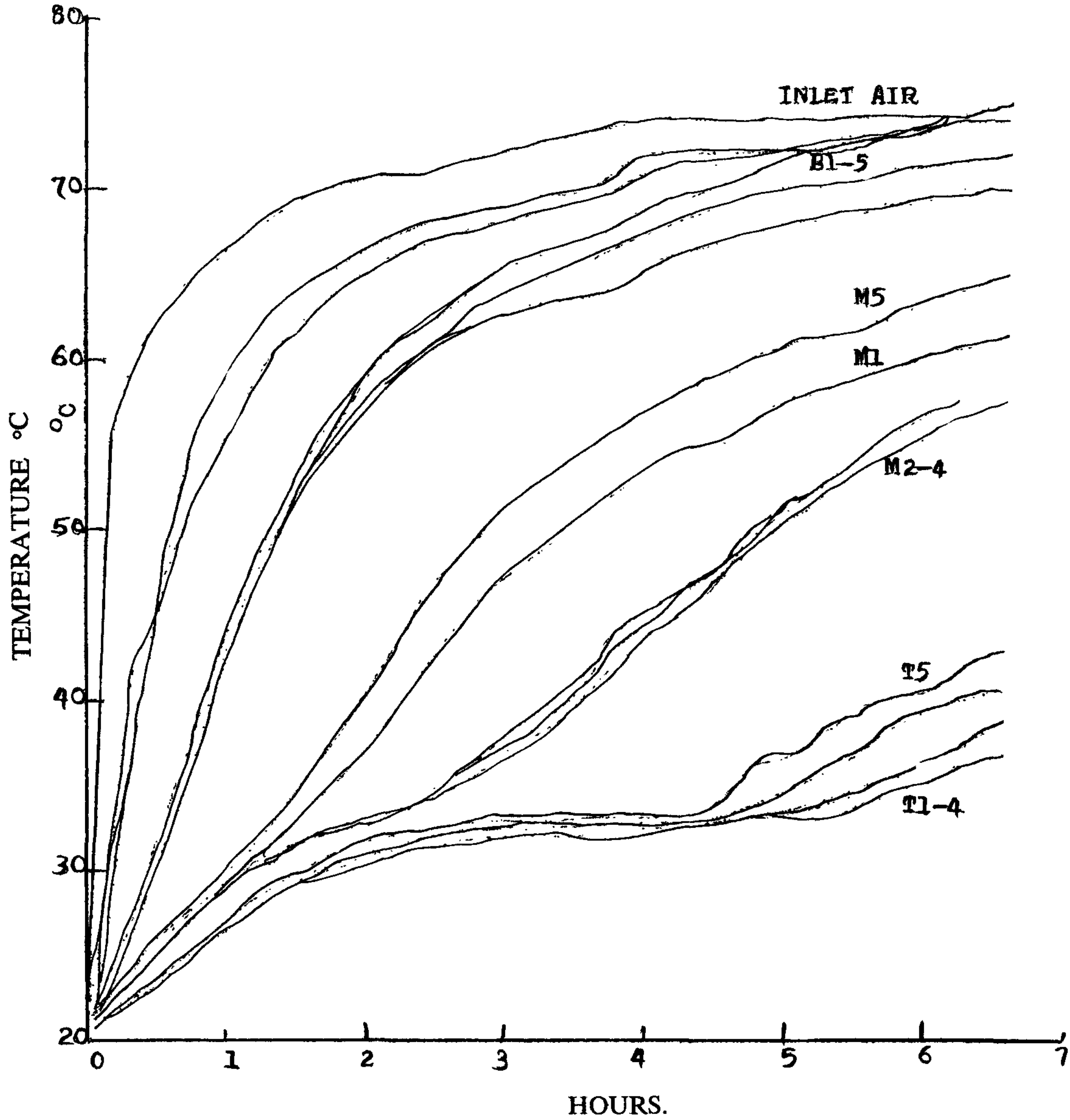


Fig. 6a. Drying time—temperature, Haricot beans. Initial moisture 18.15%, Inlet air 2085 ft. min —1

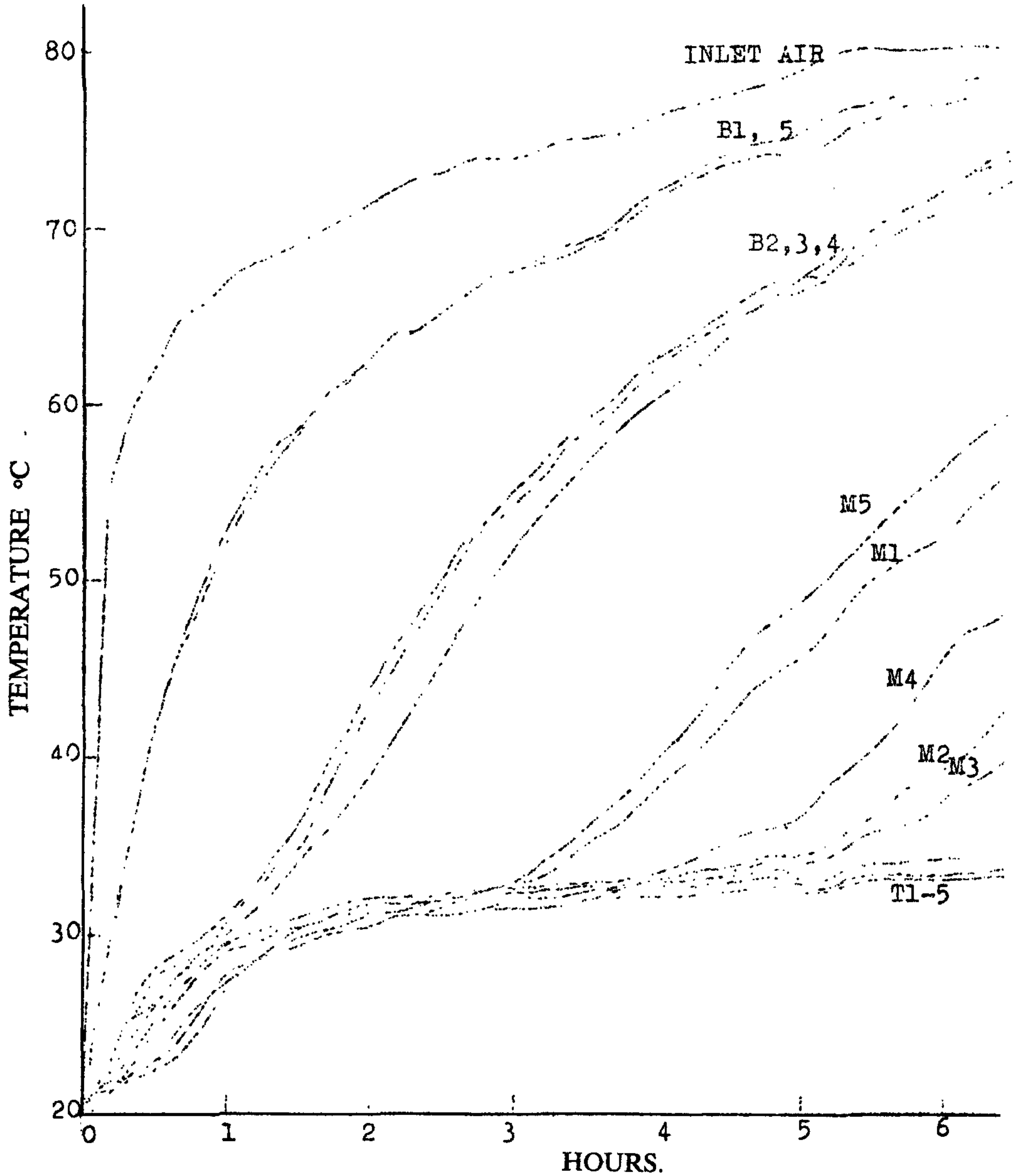


Fig. 6b. Drying time—temperature, Haricot beans. Initial moisture 11.69%, Inlet air 2085 ft. min —1

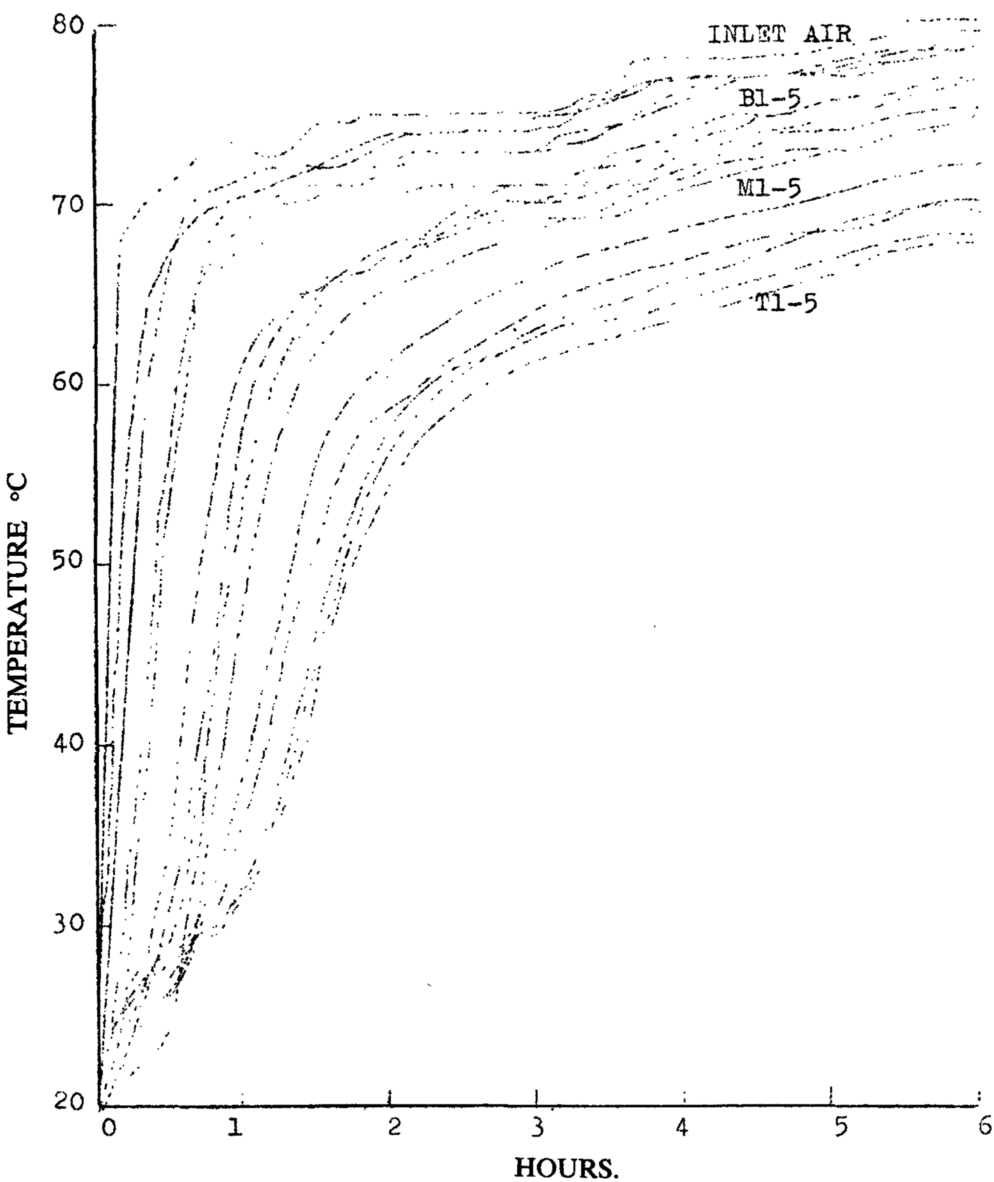


Fig. 6c. Drying time—temperature, Haricot beans. Initial moisture 7.68%, Inlet air 3518 ft. min —1

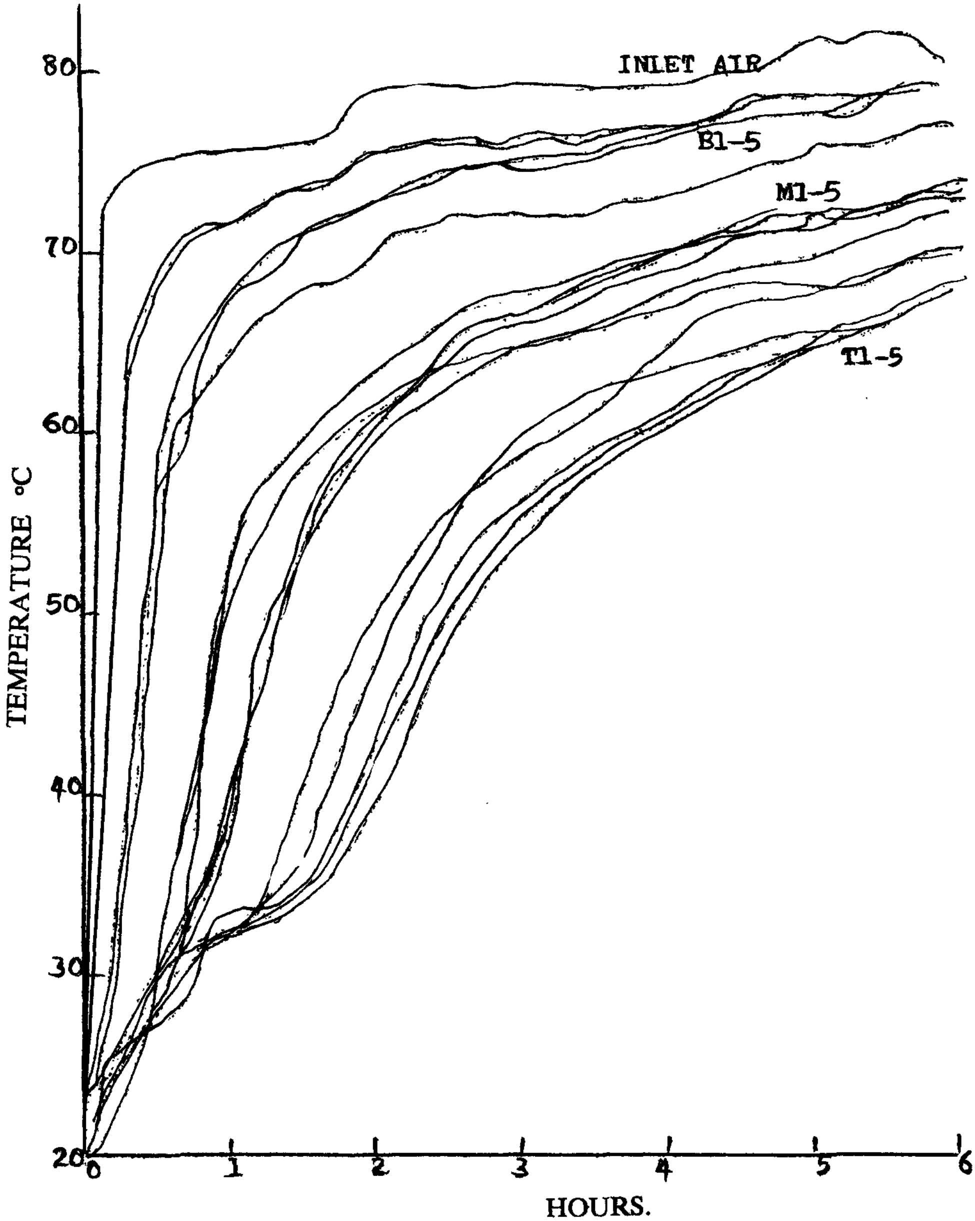


Fig. 6d. Drying time—temperature, Haricot beans. Initial moisture 14.61%, Inlet air 5680 ft. min —1

Table 1. Exhaust air velocity

Initial Moisture % (w.b.)	Inlet-air velocity ft. min^{-1})	Average exhaust air velocity (ft. min^{-1}) at points shown in Fig. 1 (top-view)							
		X1	X2	X3	X4	X5	X6	X7	X8
Cassava									
58.21	3500	250	370	433	320	310	306	340	380
59.98	5410	218	520	540	510	464	560	520	500
34.22	5430	396	580	560	488	424	420	580	474
Sweet potato									
60.61	3509	286	365	335	268	370	356	354	322
60.11	5481	306	552	552	344	505	529	594	481
35.91	5665	376	560	431	444	507	573	578	525
Ground nut									
14.38[1]	2019	125	180	242	193	168	160	254	214
3.99[1]	3604	150[2]	330	380	347	370	348	360	331
10.14[1]	5390	464	573	600	504	540	444	520	504
Cherry coffee									
33.96	1970	116	198	132	173	139	175	145	154
39.48	1970	Reading unobtainable [3]							
Haricot beans									
18.15	2085	84	172	200	145	82	143	129	100
11.69	2085	80	128	171	140	125	154	180	147
7.68	3518	250	322	348	291	240	234	302	291
14.61	5680	451	527	516	414	406	340	404	446

1. Moisture content of whole nut in shell. (See Table 3).

2. Reading suspect.

3. At the higher moisture content the exhaust air contained too much moisture for velometer readings to be obtained.

(3) *Moisture content*

The post-drying moisture content of cassava, sweet potatoes, cherry coffee and haricot beans (Table II) clearly indicate that drying at the top layers is slower than that at the bottom, as expected from a study of the temperature rise through the material during drying. At the lower inlet velocity ground nuts show a similar trend, while for the higher velocities the drying rate is more or less constant throughout the bed.

With haricot beans, at an initial moisture content of 18.15%, condensation takes place at the top layer after 7.5 h. of drying, as evidenced by a slight increase in the final moisture content. Similar trends were also noticed by Woodforde and Lawton (10), working with wheat in 6 in. deep bed.

Table II also gives the total drop in the level of some of the material inside the hopper at the end of the drying period. As the thermocouples at the top layer were located at a depth of 2 in. in certain cases they could only measure the temperature of the exhaust air as the level of the drying material dropped beyond this value.

Figs 4b and 4c clearly indicate that the rather low initial moisture of 3.99% for groundnuts in shell, compared to that of 10.14% does not materially alter the drying characteristics of the crop.

Table II. Moisture content of dried material

Drying time (hour)	Drop in level after drying (inch)	Percent moisture content (w.b.) Initial	After drying: Hopper top	After drying: Hopper bottom
	Cassava			
6.0	4.0	58.21	56.54	16.81
6.0	5.3	59.98	53.74	18.96
6.0	5.0	34.22	24.66	6.37
	Sweet potato			
6.0	4.8	60.61	57.76	25.53
6.0	7.0	60.11	52.99	20.56
6.0	6.0	35.91	31.14	3.77
	Cherry coffee			
7.0	1.5	39.48	37.22	30.46
6.5	1.5	33.96	30.78	23.77
	Haricot beans			
7.5	0	18.15	18.18	12.08
6.5	0	11.69	10.83	5.84
6.0	0	7.68	6.42	4.92
6.0	0	14.61	8.48	6.27

The moisture content of the groundnut is difficult to express in one figure as there is a considerable difference between the values of nuts in shell, nuts only, shell only and nuts in shell with the shell split open (Table III.). The unsplit shell surrounding the nut tends to mask the true content of the nut. At the end of the 7 h drying period, the level of material in the hopper had dropped by 2in.

Table III. Moisture content of various portions of groundnut

Inlet-air velocity 2019 ft. min^{-1}, drying time 7 h

Portion of ground-nut	Percent moisture content (w.b.)		
	Initial	After drying	
		Hopper top	Hopper bottom
Nuts in shell	14.38	8.74	7.21
Nuts only	15.63	7.69	6.54
Shell only	13.84	9.58	9.77
Nuts and shell, split open	11.85	10.70	6.53
Inlet-air volocity 3604 ft. min^{-1}, drying time 6 h			
Nuts in shell	3.99	1.79	1.96
Nuts only	3.73	1.38	1.29
Shell only	6.01	2.11	1.48
Nuts and shell, split open	4.01	3.11	1.33
Inlet-air velocity 5390 ft. min^{-1}, drying time 6 h			
Nuts in shell	10.14	2.68	2.69
Nuts only	6.80	2.41	2.47
Shell only	14.00	2.90	2.32
Nuts and Shell, split open	9.52	2.50	2.10

CONCLUSIONS

The heat—and air-flow characteristics during drying of the five materials, reported in this paper, indicate that the drying rate and temperature rise at the top layers is considerably lower than that at the bottom. In order to ensure even drying in a deep bed, therefore, it is necessary to turn or invert the material well during drying. Higher inlet-air velocities for a given drying temperature increases the drying rate to an appreciable degree. The drying characteristics of the two root crops, cassava and sweet potatoes, are found to be very similar to each other, while they differ somewhat from other crops like ground nuts, cherry coffee or haricot beans. The drop in level of the material during drying appears to be related to the initial moisture content.

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