DETERMINATION OF THERMAL CONDUCTIVITY OF SWEET POTATO USING LINE HEAT SOURCE TECHNIQUE

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ABSTRACT

The experiment was to investigate the possibility of using line heat source technique to determine thermal conductivity. Sample of sweet potato were used both peeled and unpeeled under ambient condition with a temperature range of 9-55^{0}C. The sweet potato has a diameter of 0.025-0.04m and moisture content of 68.5-76.47% wb. Result gave that thermal conductivity is with linear increase as the moisture content increases. Result indicated the thermal conductivity of sweet potato range from 0.5573 to 1.0491W/m^{0}C for peeled sample and 0.3243 to 0.8917W/m^{o}C for unpeeled sample. From the data obtained, linear regression for estimated thermal conductivity of sweet potato, as a function of moisture content and diameter of sample were built when compared with experimental data, the model showed a correlation confirmation between 0.681215 to 0.8046W/m^{o}C for peeled and 0.4525671 to 0.717000W/m^{o}C for unpeeled with the experimental data.

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NOTATIONS

A	Cross sectional area, m^2
C	Specific heat capacity, J/kg K
D	Diameter of material, m
h	unit surface conductance
I	Current, A
K	Thermal Conductivity, W/mK
L	Length of Sample
M	Mass, kg
mwb	Moisture content (wet basis) %
Q_k, q,	Quantity of heat J
R	Resistance, Ω
t_1	Observed initial temperature, °C
t_2	Observed final temperature, °C
v	Voltage, V
V_o	Volume, m^3
θ	Time, minutes
ρ	Density kg/m^3
Δ	Change
α	Thermal diffusivity of the material, m^2/s
Π	3.142
∇	Gradient

CHAPTER ONE

1.0 INTRODUCTION

Historically, the food industry and its associated technology has been developed on a relatively qualitative and empirical level. It is only in recent years that management and engineers have come to recognize that advancement in knowledge would require a more fundamental and quantitative understanding of the underlying mechanisms of their process. The food industry is also under continuing pressure to provide food that is more natural and less processed and also to provide food with even higher level of safety. There is also the issue of reducing energy usage and effluent production to meet both environmental and economic goals (John, 1992). Hence, the engineering of food processes is now undergoing a transition towards a more technical approach. The speed of product innovation in the fast moving consumer-goods business to which the majority of the food business belongs, is accelerating. The half-life of product development times has decreased from 10years in 1970 to what will be an estimated 2 to 3 years in the year 2000- (Lewis and Seetharamu, 1995). The speed of the product / process development cycle is therefore of paramount importance (Bruin, 1992).

Today, consumers are adventurous in their purchases of heat-treated food, and the trend is for the manufacturer to develop convenient products of high added value. This trend has been brought about by significant changes in society such as the increasing proportion of women going out to work and the greater social demand for leisure time activities. These factors have brought about a general trend towards less formal meal times, with the replacement of traditionally prepared meals by foods, that are easily stored and quick and convenient to prepare. These evolving social patterns have in some measure been made possible by the corresponding improvements in heat treatment of food and distribution technology (Summers, 1984).

To active considerable savings and to optimize the thermal processing of solid foods, it is essential to have a more fundamental understanding of the factor influencing heat and mass transfer in porous bodies.

Luikov's couple partial differential equations for heat and mass transfer can be used to describe the multiphase distribution in porous media, for both the freezing and drying processes.

The formulation of heat flow equations through solid materials (by conduction) is based on the principles of the conservation of heat and mass transfer and irreversible thermodynamics (Lewis and Seetharamu, 1995). A detailed description and derivation of the equations involved has been presented by Kreith and Bohn (1986). Due to the complexity of these equations, both analytical and experimental techniques have been used to prefer solution to these equations. The need for the accurate determination of thermophysical data for moist food materials under various conditions is an immediate necessity in solving these differential equations as well as for a better prediction of food processing (Narayana and Murthy, 1981).

In the present research work, effort was geared towards the determination of the thermal conductivity value of sweet potato (peeled and unpeeled) experimentally using the line heat source technique.

OBJECTIVE

The research work is aimed at

a. Investigating the applicability of line heat source technique to the determination of the thermal conductivity of sweet potato.

b. Determining the thermal conductivity values for sweet potato.

c. Studying the effect of moisture content of sweet potato on thermal conductivity.

d. Determining the relationship between thermal conductivity and moisture content.

CHAPTER TWO

2.0 LITERATURE REVIEW.

Many of the Agricultural products of plants or animals origin are subjected to various type of thermal processing before they are placed at the access of the consumer (Mohsenin, 1978). The thermal processing may include heating, cooling, drying, freezing or a combination of or two more thermal processes ie freeze-drying. In the processes mentioned above, the Thermal properties of the product-specific heat, diffusivity and thermal conductivity are of paramount concern. Finding the data needed in the design and analysis of numerous equipment, storage structures, aeration and cooling processes during the storage and food manufacturing practices involving sweet potato, and for developing predictive models are of paramount concern to designers. The thermal properties of a wide variety of agricultural materials including oil-bearing seeds are available in literature (Rahmain, 1995) nevertheless they are not documented for the sweet potato.

2.1 THERMAL PROPERTIES OF BIOENGINEERING MATERIALS

2.1.1 HEAT TRANSFER TERMINOLOGIES

Specific Heat Capacity:- This is the amount of heat required to change the temperature of a unit mass of material by 1^0C. Mathematically, it is expressed as

$$C = \frac{Q_k}{M\Delta T} \quad (2.1)$$

Or

$$C = \frac{Q_k}{\rho V \Delta T} \quad (2.2)$$

Where

C	=	Specific heat capacity, J / kgK
M	=	Mass, kg
ΔT	=	Temperature change, K
V	=	Volume, m^3
ρ	=	Density material, kg / m^3
Q_k	=	heat input into the material, J

b. **Thermal Conductivity**

The thermal conductivity of a material indicates the amount of heat that will flow per unit across a unit area when the temperature gradient is unity (Bohn and Kreith, 1985).

In Mathematical notation, it is expressed as

$$K = \frac{Q_k / A}{dT / dx} \quad (2.3)$$

Where

K	=	the thermal conductivity of the material, W/mK
Q_k	=	Heat flow through the materials, J

A = Cross sectional area, m^2

dT/dx = Temperature gradient.

c. **Thermal Diffusivity**

The rate at which heat is diffused in a material is termed thermal diffusivity. In mathematical notation, it is expressed as

$$\alpha = \frac{k}{C\rho} \quad (2.4)$$

Where

α = Thermal diffusivity of the material, m^2/s

K = Thermal conductivity of the material, W/mK.

C = Specific heat of the material J/kgK.

ρ = Density of the material kg/m^3

Onuachu (1992) reported Ijabo (1984) to have worked on the determination of thermal conductivity of corn using the line heat sources technique. Onuachu also followed the same method used by Ijabo in determining the thermal conductivity value of plantain. The technique utilizes a constant heat source on an infinite solid along a line with infinitesimal diameter. In using this technique, the heat source was embedded in the sample (plantain). The line-source is energized and the temperature rise at a given distance from the source was measure after a short heating time. Temperature was then plotted against time on a semi logarithm graph paper. The result was a straight line point where located on the graph from which data were obtained to calculate the thermal conductivity of the plantain.

Turhan and Gunasekaran (1999) have also determined the thermal properties of frizzy and starch – coated cotton. In their experimental investigation, the duo used the conductivity probe method in determining the thermal conductivity of the cottonseed. In this method, a probe constructed of stainless steel needle tubing was attached to a miniature type E thermocouple female connector. Bare constantan wire (ϕ 0.076mm) with enamel insulation was utilized as the heater wire. Thermocouple wires with plastic spaghetti tubing were used to insulate the thermocouple junction. The heater wire and thermocouple wires were insulated from each other and the stainless steel tubing. Bulk thermal conductivity of the cottonseeds was determined by inserting the probe into the axial center of the cup packaged with the sample. Temperature and time data were collated and a graph of temperature against the natural logarithm of time was plotted. The thermal conductivity of the cottonseeds was then determined from the calculated slope of the graph using appropriate relation. Chandrasekar and Visivanathan (1999) also used the same technique used by Turhan and Sundaram in determining the physical and thermal properties of coffee.

In all the results reported used by all the researchers, the thermal conductivity value was adversely affected by one or a combination of the following factors– moisture content, density and temperature.

2.1.2 FACTORS AFFECTING THERMAL CONDUCTIVITY OF BIOENGINEERING MATERIAL

A number of factors which the thermal conductivity values of Agricultural materials or Bio-Engineering material depends have been highlighted (Onuachu, 1992) these include chemical composition, physical structure, the state of the substance, temperature, density, moisture content and genetic factors.

The state of the material explains the reason for lower conductivity of non-homogeneous (porous) materials. – Solids with air pockets that cause heat to be transmitted by free convection.

a. **Effect of Temperature**

The effects of temperature on thermal conductivity and specific heat have been noticed. Nevertheless, thermal properties of a limited number of biological materials follow a metallic pattern (Mohsenin, 1980). Under experimental conditions, the temperature effect could be considered by taking the mean property between available values at the extremes of the expected temperature range. In other cases, distinct curves were obtained for temperature ranges. Earlier studies carried out by Mohsenin (1980) indicated that for temperature of – 40°C to – 7°C, typical specific heat curves for fruits and vegetable vary from 0.04 to 3.4J/kgK.

Chakrbati and Johnson (1972) added temperature in their logarithm prediction equation for specific heat of tobacco. Jasensky and Bilansky (1973) gave a curvilinear variation of thermal conductivity with temperature for soya-beans. In the present research work, measurement shall be within room temperature.

b. **Effect of Moisture Content**

Onuachu (1992) reported works carried out in this area with regard to porous materials (agricultural material). He noted that the effect of moisture content on thermal conductivity, K values can be seen in two ways. The first is the boostering effect, moisture has on K at given moisture contents due to Dufour effect. This coupling effect is brought about by moisture migration (mass transfer) which occurs when temperature difference exist in permeable moist medium Transmission by this mechanism which is in addition to the heat transfer by condition is largely in the form of latent heat under such a condition. The effect of moisture migration could result in a exaggerated value of K of the material under test. Investigations on this effect by Moote (1953) are confirmed by Mohsenin (1980). However, the explanation by Moote (1953) is different from others. In her investigation, she found out that the absorbed molecules of water may not have the same degree of freedom of movement as liquid molecules and therefore it cannot be assumed that absorbed water exhibit these properties if it were liquid water. Moote rather explained moisture migration during heating to be due to diffusion within the particles by inter-changing of moisture between the particles and air surrounding them. The heat of absorption requires the hot particles to give up moisture. The heat of absorption, which is acquired when another particles (cool one) absorpted this moisture resulted in a heat transfer from the central axis (heated wire) towards the outside of the cylinder. This transfer of heat caused an increase in the rate of heat flow making thermal conductivity before equilibrium, to be greater than when equilibrium had been reached.

The use of technique that require long period of time for attaining heat transfer condition specified by the theory in the determination of K could be stunned when the boostering effect. in the particle is to be avoided. The steady state conditions are typical of theoretical specification. This error is known to be less serious at low moisture content (Mohsenin, 1980).

Another way of viewing the effect of moisture contents on the thermal properties is in terms of patterns of variation for deliberately changed values of moisture contents. In general, K and specific heat of porous materials have linear relationship with moisture contents. For instance, a review of Mohsenin (1980) indicated this linear regression of K on moisture content for oats and red delicious apples. Sweat (1974), however, pointed out that K. has low linear correlation with moisture content for apples because of the large amount of air spaces in it. Kazarian and Hall (1965) indicated that bulk thermal conductivity and specific heat for oats and wheat have linear relationship with moisture content.

Miller (1963) in his own contribution reported that conductivity-moisture content relationship for Sorghum is slightly sigmoid in the moisture content region of 5-2% (wb). Similarly, Chakrabati and Johnson (1972) gave K to have logarithmic relationship with moisture content while that of specific heat is curvilinear for tobacco. There are also point values of K for some liquid food materials (Mohsenin, 1980) as indicated in Table 2.1.

c. **Density and Particle Size Effects.**

The effect of bulk density on thermal conductivity of unconsolidated food like yam flour, rough and milled rice and gari, as reported by Makinde (1977) indicated that K increase with increasing bulk density.

Jasansky and Bilanski (1973) worked on the effect of bulk density and particle size on thermal properties of whole, crushed and powdered Soya beans. They concluded that K increases with increase in dimension of the particles, which agreed with Bilanski and Fisher's work with ground and whole rapseed (Bilanski and Fisher, (1976). Turhan and Gunasekaran (1999).

Table 2.1: Thermal Conductivity K Values of Food Materials.

S/N	MATERIAL	K(W/mk)	MOISTURE CONTENT(M.C.%)	TEMPERATURE % MEASUREMENT (^{O}C)
1	Olive oil [a]	0.17	-	20
2	Whole milk [a]	0.56	-	20
3	Freeze – dried foods	0.01-0.04	-	20
4	Frozen beef [b]	1.30	-	-10
5	Pork (Lean) [b]	0.48	-	3.8
6	Frozen cod	1.66	-	-10
7	Green beans	0.80	-	-12.1
8	Cauliflower	0.80	-	-6.6

9	Egg	0.96	-	-8
10	Starch coated cotton seeds	0.1318-0521	2 – 50	20 – 50
11	Fuzzy cotton seed	0.0859-0.442	2 – 50	20 – 50

Source: From Earle (1983), Lewis (1987), Woodams and Nowrey (1968) and Fellows (1990) also confirmed this trend in their work with fuzzy and starch coated cotton seeds.

a. Assuming convention comments are absent

b. Heat flow parallel to Fibres

d. **Other Factors**

There are variations of K with genetic factors deduced from the differences of K and other thermal properties values obtained for various cultivars and varieties of the same crop. The different values or regression lines obtained for yams (Odigboh, 1978), corn kernels and wheat (Kazarian and Hall, 1965) confirmed this assertion. Similarly, derivations of regression equations for K and specific heat on moisture content for most agricultural materials from Andersons and Sibel's equations are suggestive that chemical composition of the test material might be a contributing factor.

2.2 METHODS OF DETERMINING THERMAL CONDUCTIVITY OF AGRICULTURAL MATERIALS

Mohsenin (1980) as reviewed by Onuachu (1992) stated that there are about ten different techniques of determining thermal conductivity of agricultural and biomaterials. These can generally be divided into two classes. Steady state technique (- where heat flow position to another does not vary with time) and Non-steady state (transient) technique (- where heat flow from one position to another is time) dependent.

2.2.1 STEADY STATE TECHNIQUE

a. **Steady State Radial Heat Flow Method**

The steady state radial heat flow technique is used for determining conductivity value of loose, unconsolidated, powder or granular materials. Details of this method have been discussed in Mohsenin (1980).

2.2.2 NON-STEADY STATE (TRANSIENT) TECHNIQUES

Non-steady state or transient methods used for thermal conductivity measurements either uses a line heat source or one or more plane source of heat. In both cases, the usual technique is to apply a constant heat flux to the specimen which must have been in or on thermal equilibrium initially, then the temperature rise at the same point in the sample resulting from the applied flux is measured. The transient method has the advantage of reducing the moisture-temperature coupling effect (- Dufour effect).

a. **Fitch Method**

Fitch method is one of the most common transient methods applied to the measurement of thermal conductivity of poor conductors. Essentially, it requires sandwiching a regular cross-section of the test sample between the heat source and sink. Details of this technique are discussed in mohsenin (1980).

Onuachu (1992) reported Babarinsa (1976) to have used this technique to determine thermal conductivity of some Nigerian food materials like yam, cassava, plantain and gari. He also noted that Odigboh (1977) compared Babarinsa's results with those obtained by Ezeima (1976) using thermal conductivity probe. In general, the values obtained by the two techniques are within range of agricultural materials (Mohsenin 1980). The conditions in the two experimental setup are not the same hence the slight difference in their values.

b. **Thermal Conductivity Probe Method**

This method utilizes a constant heat source to an infinite sample body at a uniform initial temperature along a line of infinitesimal diameter compared to the sample body (Turhan and Gunasekaran, 1999).

When measuring the thermal conductivity of a material, the probe is either buried in the external medium whose thermal conductivity is being measurement – in the case of granular materials or inserted in a long hole, in the case of social materials.

Turhan and Gunasekaran (1999); Chandrasekar and Viswanathan (1999) as earlier reviewed used this technique in determing thermal conductivity value of fuzzy and starch – coated cotton seeds as well as that of coffee respectively.

c. **Line Heat Source Technique**

This technique utilizes a constant heat source on an infinite solid along a line with infinitesimal diameter, such as a thin resistance wire. In using this technique, subject to the sample diameter, it would be necessary to identify time and current values that allow for minimum heat loss to the surrounding (Onuachu, 1992). A maximum of 10minutes is that recorded for most materials (Kazanian and Hall, 1965). This technique forms the basis of the present study.

d. **Other Techniques**

Other methods also used to determine thermal conductivity value include the plane heat source, statistical modeling (Mohsenin, 1980); frequency response (Otten, 1974) and packed Bed analysis (Lukov et al; 1968).

2.3 THEORETICAL ANALYSIS

2.3.1 MODES OF HEAT TRANSFER

Kreith and Bohn (1986) noted that, there are generally three distinct modes of heat transmission: conduction, radiation and convection. Radiation is concerned with the transfer of heat by electromagnetic waves. Convection is the transfer of heat by groups of molecules that moves as a result of differences in density or as a result of energy transfer due to molecular motion, that is, the conductive mode.

Conduction on the other hand is the movement of heat by direct transfer of molecular energy within solids (i.e. through metal containers or solid foods. Since this forms the basis of the present research, it will be discussed further in detail.

2.3.2 GOVERNING SYSTEM EQUATION

The governing system of equations which describe the variation of temperature with respect to time through a solid material (sweet potato) have been derived for rectangular, cylindrical and spherical coordinate systems respectively.

The cylindrical coordinate system has been chosen for the research work because of the shape of sweet potato. To derive the basis differential equation of heat conduction in the cylindrical coordinates, we shall consider an element of the body under investigation as shown in figure 2.1

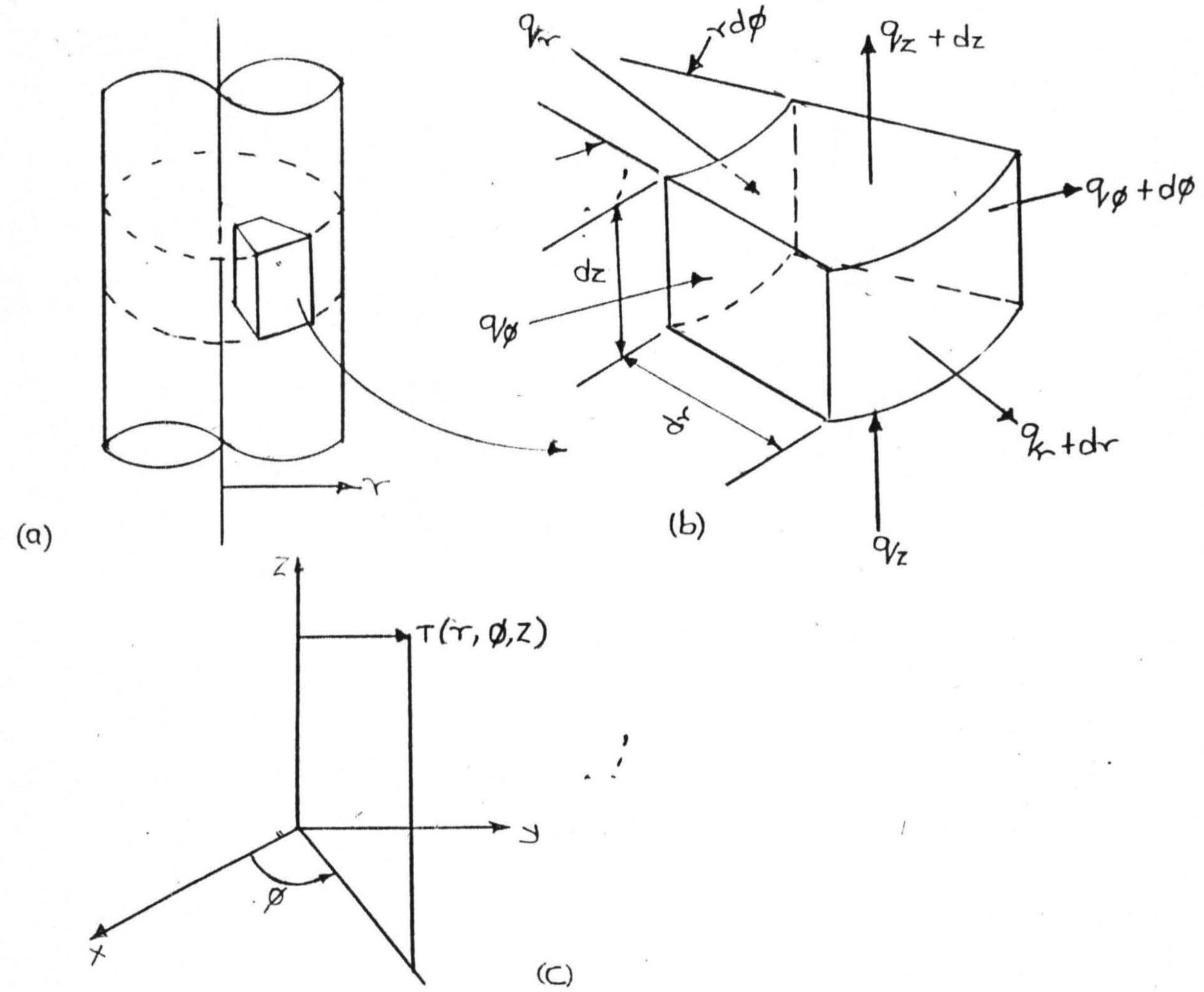


Fig. 2.1 differential control volume dr. rdϕ. dz. For conduction analysis in cylindrical coordinate (r, ϕ, z) (Frank and David, 1990).

For the element control volume, it is assumed that the temperature and head distribution in the material is a function of the coordinates (r, ϕ, z) and time, t. or

$$T = T(r, \phi, z, t) \tag{2.5}$$

$$q = q(r, \phi, z, t) \tag{2.6}$$

And the material properties conductivity, K, density, ρ, and specific heat, C are all constant.

Carslaw and Jaeger (2000), Kreith and Bohn (1985) gave the energy balance relation for a control volume as

Rate of heat	rate of heat	rate of heat	rate of heat
Conduction into +	generation =	conduction out +	storage inside (2.7)
Control volume	inside control	of control volume	control volume
	Volume		

The heat flow through the body is given by Fourier's law.

$$q = -K\nabla T \tag{2.8}$$

when the del operator, ∇ of equation 2.8 is expressed in cylindrical coordinates, the general form of the heat flues vector, and hence Fourier's law is

$$q = -K\left(i\frac{\partial T}{dr} + j\frac{1}{r}\frac{\partial T}{r\phi} + \frac{k\partial T}{\partial z}\right. \tag{2.9}$$

where

$$q_r = -\frac{k\partial T}{\partial r}, q\phi = -\frac{k\partial T}{r\partial\phi}, q_z = -\frac{k\partial T}{\partial z} \tag{2.10}$$

are heat flux components in the radial, circumferential and axial directions, respectively,

Applying the energy balance equation 2.7 to the control volume in figure 2.1, the following more general form of the heat equation is obtained.

$$\frac{1}{r}\frac{\partial}{\partial r}(kr\frac{\partial T}{r^2}) + \frac{1}{r^2}\frac{\partial}{\partial\phi}(k\frac{\partial T}{\partial\phi}) + \frac{\partial}{\partial z}(k\frac{\partial T}{\partial z}) + q = pc\frac{\partial T}{\partial t} \tag{2.11}$$

If the heat flow in cylindrical shape is only in the radial direction,

$$T = T(r, t) \tag{2.12}$$

The conduction equation reduces to

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + \frac{q}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \tag{2.13}$$

where $\frac{k}{\rho c}$ is referred to as the thermal diffusivity of the material.

2.3.3 ASSUMPTIONS

In all heat transfer problems, simplifying assumption are normally made in order to reduce the complex equation generated into solvable ones.

The following assumption shall be made, for the ease of analysis in the present research.

i. Heat flow only in the radial direction.

ii. The thermal conductivity of the material (sweet potato) is constant within room temperature.

iii. The sweet potato does not generate its own heat internally.

iv. The mode of heat transfer through the sweet potato is assumed to be that of conduction.

v. There is symmetry with respect to geometric axis.

2.3.4 METHOD OF SOLUTION

A number of solution schemes - numerical, analytical and experimental technique have been proposed for solving differential equation such as the transient heat conduction equation 2.11.

The experimental technique has been adopted for the research work to enable the determination of the time and temperature relationship for obtaining the value of thermal conductivity, K of the material (sweet potato).

Applying the simplifying assumption, equation 2.13 can be further reduced to

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) = \frac{I}{\alpha}\frac{\partial T}{\partial t} \qquad (2.14)$$

The solution to equation 2.14 interms of the characteristics of the fast material has been quoted by Kazarian and Hall (1965) as

$$T = \frac{q}{2\Pi k} \ln (rx) \qquad (2.15)$$

where q = constant strength line heat source

x = % αt

The function in (rx) is given by

$$\ln (rx) = A - \ln (rx) + \left(\frac{rx}{2}\right)^2 + \ldots\ldots\ldots\ldots \qquad (2.16)$$

Where A is a constant.

For small value of r, the terms in the second and higher powers of r are negligible.

Then $\ln (rx) = A - \ln (rx)$

And equation (2.15) becomes

$$T = \frac{q}{2\Pi k} (A - \ln (rx) \qquad (2.17)$$

In order to make r sufficiently small it would be assured that the thermocouple hot junction is sufficiently close to the line heat source heater wire. This could be achieved by using a layer of plastic cellotape to cover the hot junction before passing the heater wire.

The temperature rise between time ϕ_1 and ϕ_2 is given by substituting for X in equation 2.17. i.e.

$$T_1 = \frac{q}{2\pi k}[A - \ln (r/2)\, \phi_1]$$

$$= \frac{q}{2\pi k}[A - \ln (r/2) + \ln \phi_1]$$

Treating t_2 in a similar way and simplifying, we have

$$T_2 - T_1 = \frac{q}{4\pi k}[\ln \phi_2 - \ln \phi_1]$$

$$= \frac{q}{4\pi k} \ln \phi_2/\phi_1 \qquad (2.18)$$

Where T_1 and T_2 are temperature at time ϕ_1 and ϕ_2, respectively.

The thermal conductivity is then obtained from measured quantities of q, ϕ_1, ϕ_2 T_1 and T_2.

2.4 CORRECTION FOR BASIC ASSUMPTIONS

2.4.1 TIME CORRECTION FOR LINE HEAT SOURCE DIAMETER

Mohsenin (1980) reported that, any line heat source have a finite radius. He also indicated a time correction factor ϕ_o, which was subtracted from each observed time. The time correction factor depends to a great extent on the particular test and also takes into account the effect of contact resistance, position of the temperature sensor, the specific heat of both the probe and the sample. Determination of the time correction factor involves the plot on a graph paper with arithmetic scales, temperature rise above ambient against time. Then the instantaneous slope (dt/dx) can be taken at different time from this plot. The plot of ($-dt/d\phi$) values against time on an arithmetic scales is then carried out. The intercept on the time axis is the values of ϕ_o. This modified equation 2.18 to

$$K = \frac{q}{4\pi} \frac{\ln[(\phi_2 - \phi_0)/(\phi_1 - \phi_0)]}{T_2 - T_1} \qquad (2.19)$$

Practically, if the slope of the plot of temperature rise against time. $\ln[(\phi_2 - \phi_0)/(\phi_1 - \phi_0)]$ is denoted S, then equation 2.19 can be re-written as

$$K = \frac{qs}{4\pi} \qquad (2.20)$$

The method described above is shown in figure 2.2

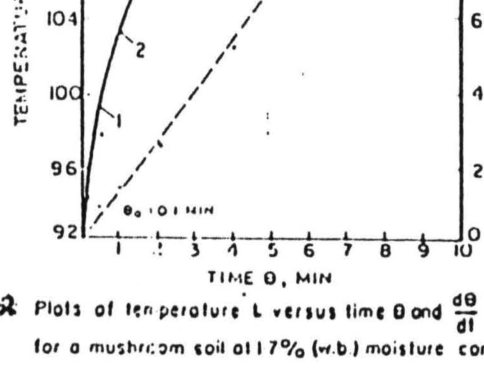


Fig 2.2 Plots of temperature t versus time θ and $\frac{d\theta}{dt}$ versus time for a mushroom soil at 17% (w.b.) moisture content (Mohsenin, 1980).

Onuachu (1992) reported Underwood and Mc Taggart (1960) as the originator of a much simpler and approximate method. In this method, a plot of temperature rise verses time is done directly on semi-logarithm graph paper. A line of best fit is drawn through the points whose slope indicates the steady state. Thus equation 2.18 could be conveniently used. Any two points A (ϕ_1, t_1) and B (ϕ_2 t_2) could be selected for determining the value of the thermal conductivity, K of the test material.

Figure 2.3 illustrates this technique.

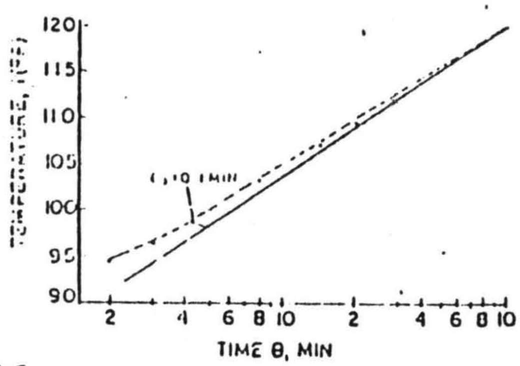


Fig 3-5 Data of figure plotted as temperature versus log of time showing the correction time θ, (Mohsenin,1980).

2.4.2 CORRECTION FOR AXIAL FLOW IN THE HEAT SOURCE

A recommended length to diameter ratio of between 25 to 100 for the heater wire in other that conditions or radial heat flow with negligible axial flow be valid as reported by Onuachu (1992) shall be used. The Nichrobes resistance heater wire used has a length (86mm) to diameter (1.41mm) ratio of about 60.99 which is in conformity with that recommended shall be used for the purpose of this experimental work.

2.4.3 CORRECTION FOR FINITE SAMPLE SIZE

The line heat source assumes the utilization of a constant heat source on an infinite solid along a line with infinitesimal diameter. But in practice the length of the potato, which is to be used for the experimental work, is finite.

In order to minimize error resulting from this assumption, the measurement of time would be shortened so that there will be no significant temperature increase at the boundary. This could be achieved by having a temperature measuring devices (thermocouple) at the sample boundary to monitor the boundary temperature.

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 EXPERIMENTAL DESIGN.

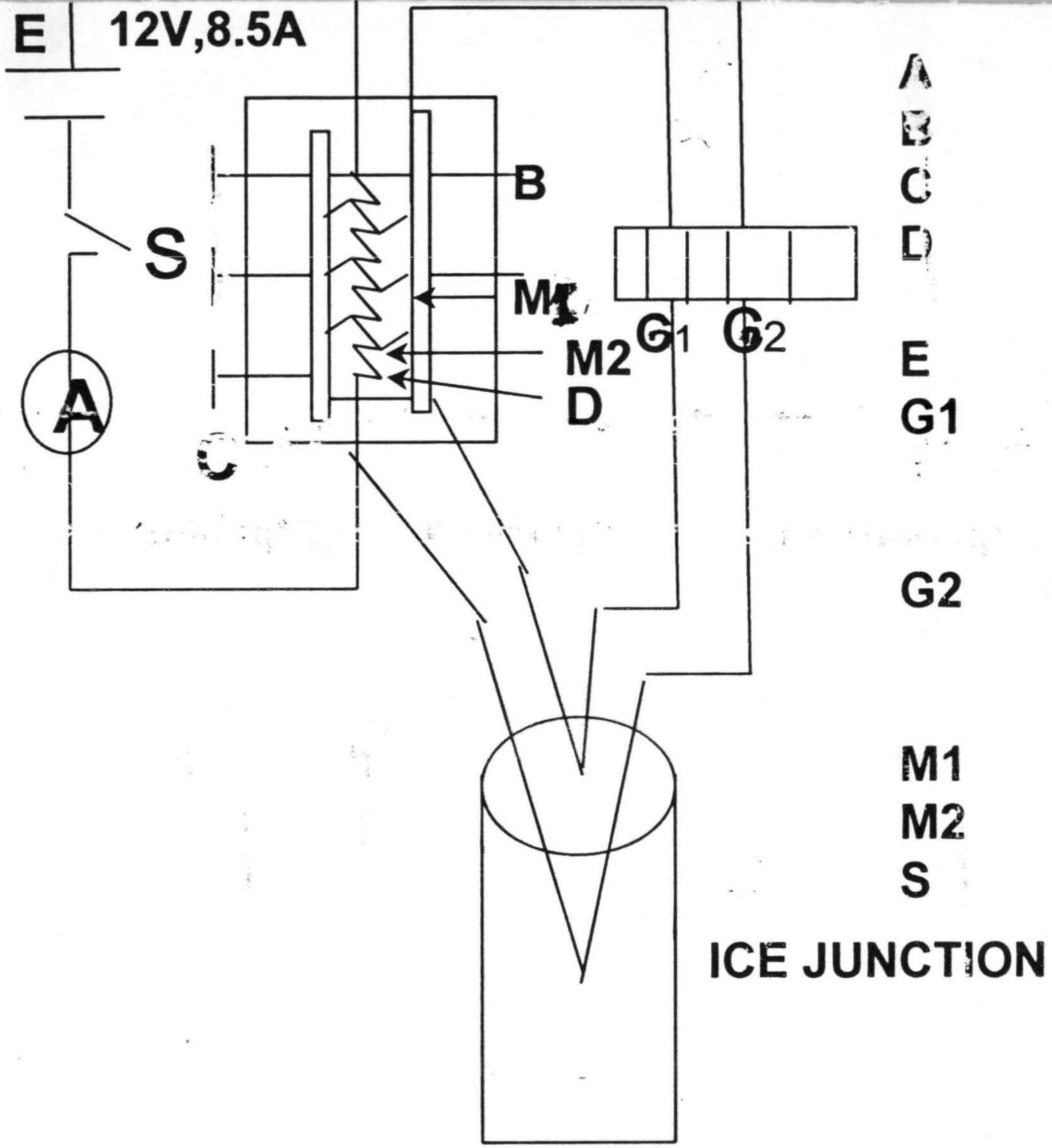
The experiment was designed as a 2 – way classification with more than one observation per experimental unit. The potato condition, peeled and unpeeled formed the level of one factor while the moisture content formed the second factor.

3.2 EXPERIMENTAL SETUP

The setup used for the determination of the thermal conductivity of the sweet potato is shown in figure 3.1. it consist of a wooden box built from wood, and it measures 425mm x 285mm x 220mm. At the center of the box, two wooden battens driven by three sets of M14 screws (145mm). The screws help tighten the battens against the sweet potato during experimentation.

Two holes, ϕ15mm were drilled through the sides of the box to allow for the passage of the heating wires (86mm) with resistivity $100X10^{-8}\,\Omega$ m and length 86mm, the thermocouple wire and connecting copper leads.

The heating element was connected to a 12V, 8.5A AC/DC converters source. The flow of current through the circuit was controlled using a variable resistor (25KΩ). Two thermocouples, constructed from gauges 24 copper and constantan (16900mm) wires was used to monitor the changes in e.m.f. With respect to time at the center and surface of the material during the experiment.



KEY

A	DC ammeter
B	Wooden box
C	Adjustable screwing bolt
D	Gauge 24 Nichrome résistance wire
E	12- Vantomobile battery
G1	A readout system potentiometer Gauge digital meter (external reading)
G2	A readout system potentiometer Gauge digital meter(internal reading)
M1	External Thermocouple
M2	Internal Thermocouple
S	Switch

Fig. 3.1: Schematic Diagram of the Experimental Set up.

3.3 STANDARDIZATION OF SETUP

Plantain been a porous material and with known thermal conductivity values, have been selected as a reference material in order to list the precision and accuracy of the experimental setup.

In the trial - run of the experiment using plantain, an unripe plantain with diameter ϕ35mm and length 70mm was used. The plantain was cut into two halves using a sharp knife and the heater wire, the hot junction of the copper constantan thermocouple well insulated with a transparent sellotape were embedded into the central portion of the plantain and the two halves joined together. One junction of the second thermocouple was clamped to the surface of the joined plantain halves and the other cooled junction placed in the beaker containing melting ice. The second thermocouple was used to measure any temperature change on the surface of the plantain during the course of the experiment. The whole setup was allowed for two minutes to equilibrate before the box was closed and the power source switched on. The e.m.f reading were taken at half a minute interval for five minutes to ensure that there is no appreciable temperature rise at the boundary between the surface of the potato and the wooden batten.

3.4 EXPERIMENTAL PROCEDURE

Several sample of the material (sweet potato, peeled and unpeeled) were prepared and cut into two halves lengthwise with a sharp knife. The central portion was located and sliced into a V - groove to accommodate the heating element and thermocouple hot junction.

In carrying out the experiment the millivolts reading of both thermocouple and hence the temperature was computed and noted and then the power switched on. The temperature readings as given by the digital voltmeter in millivolts were taken down at half a minute interval beginning with one minute to six minutes

After taking the millivolts readings from the digital voltmeter, the sweet potato was unscrewed out of the box. Samples were taken, initial moisture content determination using the standard procedures (1.e. oven drying the samples at 103 $\pm$ 2^{0}c for 24 hours).

CHAPTER FOUR

4.O RESULTS, ANALYSIS OF RESULT AND DISCUSSION.

4.1 RESULTS:

Table 4.1 through 4.9 depicts results obtained for both the peeled and unpeeled conditions. Conversion of e.m.f reading in millivolt to temperature in degrees, have been carried out using the relation source: (Holman and Gajda (1985)).

$T(^{o}C) = 2.16+23.2V$

Where

V = reading of the e.m.f obtained during the test in millivolt(mV).

Table 4.1: Temperature Rise with Time in Material(Plantain) Converted from Digital Meter Readings.

S/N	TIME(min)	METER READINGS(mV)	T°C = 2.16 +23.2V	T°C Rise
1	0	0.7	18.4	0
2	1	0.9	23.04	4.64
3	1.5	1.0	25.36	6.96
4	2.0	1.1	27.68	9.28
5	2.5	1.2	30.00	11.6
6	3.0	1.2	30.00	11.6
7	3.5	1.3	32.32	13.92
8	4.0	1.3	32.32	13.92
9	4.5	1.3	32.32	13.92
10	5.0	1.4	34.64	16.24
11	5.5	1.4	34.64	16.24
12	6.0	1.4	34.64	16.24

Table 4.2: Characteristics Size and Weight of Sample use (Unpeeled). Sweet Potato.

S/N	Weight (g)	Length (mm)	Diameter∅ (mm)	Initial sampleweight For moisture Contents test(g)	Final sample weight For moisture Contents test(g)	Moisture contents(wb) %
Sample 1	82.6	70.0	31.0	6.6	1.9	71.20
2	71.7	70.0	30.0	12.7	4.0	68.50
3	70.2	70.0	30.0	10.2	2.4	76.47
4	73.0	70.0	32.0	16.6	4.6	72.29
5	75.9	66.0	34.0	14.0	3.6	74.29
6	102.0	71.0	37.0	16.5	4.9	70.30
7	82.8	67.0	32.0	16.1	4.5	72.05
8	57.2	66.0	31.0	12.2	3.2	73.77
9	79.3	64.0	32.0	15.7	4.3	72.61
10	100.6	67.0	40.0	19.0	5.3	72.11

Table 4.3 Characteristics Size And Weight Of Sample Used (Peeled). Sweet Potato

S/N	Weight (g)	Length (mm)	diameter∅ (mm)	Initial sample weight for moisture content (g)	Final sample weight for moisture content (g	Moisture contents (wb) (%)
Sample 1	79.8	70.0	32.0	17.1	4.1	76.02
2	74.2	72.0	30.0	18.5	6.0	67.57
3	102.8	71.0	37.0	16.6	4.2	74.79
4	116.2	74.0	39.0	18.1	5.8	67.96
5	74.8	72.0	30.0	18.2	5.0	72.53
6	60.0	71.0	25.0	13.7	3.9	71.53
7	50.4	75.0	29.0	16.0	5.0	68.75
8	63.0	66.0	30.0	18.2	4.7	74.18
9	60.0	70.0	30.0	14.9	4.5	69.80
10	58.4	72.0	30.0	18.4	5.6	69.57

Table 4.4 E.M.F Readings (mV) Obtained For Ten Samples (Unpeeled Condition) Sweet Potato

S/N	Time (min)	1(mV)	2(mV)	3(mV)	4(mV)	5(mV)	6(mV)	7(mV)	8(mV)	9(mV)	10(mV)
1	0	1.4	1.3	1.2	1.4	1.4	1.2	1.1	1.2	1.2	1.2
2	1.0	2.4	2.0	2.1	2.2	2.2	2.0	1.8	1.5	1.6	1.7
3	1.5	2.8	2.4	2.4	2.3	2.4	2.4	2.0	1.7	1.7	1.9
4	2.0	3.0	2.6	2.6	2.5	2.6	2.7	2.2	1.8	1.8	2.0
5	2.5	3.2	2.8	2.7	2.6	2.8	2.8	2.3	1.9	1.9	2.2
6	3.0	3.3	2.9	2.9	2.7	2.9	3.0	2.4	1.9	1.9	2.2
7	3.5	3.4	3.1	3.0	2.8	3.0	3.1	2.5	2.0	2.0	2.3
8	4.0	3.5	3.2	3.0	2.9	3.0	3.2	2.6	2.1	2.1	2.3
9	4.5	3.6	3.3	3.1	2.9	3.0	3.2	2.7	2.1	2.1	2.4
10	5.0	3.6	3.3	3.1	3.0	3.1	3.1	2.9	2.1	2.1	2.4
11	5.5	3.6	3.4	3.1	3.0	3.1	3.1	2.9	2.2	2.2	2.5
12	6.0	3.7	3.5	3.2	3.1	3.1	3.1	3.0	2.2	2.2	2.5

Table 4.5: E.M.F Reading (mV) Obtained For Ten Samples Peeled Conditions Sweet Potato

S/N	Time (min)	1(mV)	2(mV)	3(mV)	4(mV)	5(mV)	6(mV)	7(mV)	8(mV)	9(mV)	10(mV)
1	0	1.1	1.3	1.3	1.3	1.3	1.4	1.2	1.3	1.3	1.3
2	1.0	1.5	1.8	1.7	1.9	1.6	2.0	1.4	1.9	1.6	1.6
3	1.5	1.7	2.0	1.9	2.1	1.7	2.2	1.5	2.1	1.8	1.8
4	2.0	1.8	2.1	2.0	2.3	1.8	2.4	1.6	2.2	1.9	1.9
5	2.5	1.9	2.3	2.3	2.4	1.9	2.6	1.7	2.3	1.9	2.0
6	3.0	2.1	2.4	2.3	2.5	2.0	2.7	1.8	2.4	2.0	2.1
7	3.5	2.1	2.5	2.4	2.5	2.0	2.8	1.8	2.5	2.0	2.2
8	4.0	2.2	2.6	2.4	2.6	2.1	2.8	1.9	2.5	2.1	2.2
9	4.5	2.3	2.6	2.4	2.6	2.1	2.9	1.9	2.6	2.1	2.3
10	5.0	2.4	2.7	2.4	2.7	2.2	2.9	2.0	2.6	2.1	2.3
11	5.5	2.4	2.2	2.3	2.8	2.2	3.0	2.0	2.6	2.2	2.3
12	6.0	2.5	2.7	2.4	2.8	2.2	3.0	2.1	2.7	2.2	2.4

Table 4.6: E.M.F Meter (mV) Converted to Temperature (°C) with Relation $T = 2.16 + 23.2V$ for Unpeeled Sweet Potato.

Time (min)	1	2	3	4	5	6	7	8	9	10
0	34.64	32.32	30.00	34.64	34.64	30.00	27.68	30.00	30.00	30.00
1.0	57.84	48.56	50.88	50.88	53.20	48.56	43.92	36.96	39.28	41.60
1.5	67.12	47.84	57.84	55.52	57.84	57.84	48.56	41.60	41.60	46.24
2.0	71.76	62.48	62.48	60.16	62.48	64.80	53.20	43.92	43.92	48.56
2.5	76.40	67.12	64.80	62.48	67.12	67.12	55.52	43.92	46.24	53.20
3.0	78.72	69.44	69.44	64.80	69.44	71.76	57.84	41.60	46.24	53.20
3.5	81.04	74.08	71.76	67.12	71.76	74.08	60.16	46.24	48.56	55.52
4.0	83.36	76.40	71.76	69.44	71.76	76.40	62.48	48.56	50.88	55.52
4.5	85.68	78.72	74.08	69.44	71.76	76.40	64.80	50.88	50.88	57.84
5.0	85.68	78.72	74.08	71.76	74.08	74.08	69.44	50.88	50.88	57.84
5.5	85.68	81.04	74.08	71.76	74.08	74.08	69.44	50.88	53.20	60.16
6.0	88.00	83.36	76.40	74.08	74.08	74.08	71.76	53.20	53.20	60.16

Table 4.7: Digital Meter Reading Given as Temperature Rise Above Ambient Unpeeled Sweet Potatoes

Time	SAMPLES										
(min)	1	2	3	4	5	6	7	8	9	10	
0	0	0	0	0	0	0	0	0	0	0	
1.0	23.20	16.24	20.88	16.24	18.56	18.56	16.24	6.96	9.28	11.60	
1.5	32.48	25.52	27.84	20.88	23.20	27.84	20.88	11.60	11.60	16.24	
2.0	37.12	30.16	32.48	25.52	27.84	34.80	25.52	13.92	13.92	18.56	
2.5	41.06	34.80	34.80	27.84	32.48	37.12	27.84	13.92	16.24	23.20	
3.0	44.08	37.12	39.44	30.16	34.80	41.76	30.16	11.60	16.24	23.20	
3.5	46.40	41.76	41.76	32.48	37.12	44.08	32.48	16.24	18.56	25.52	
4.0	48.02	44.08	41.76	34.80	37.12	46.40	34.80	18.56	20.88	25.52	
4.5	51.04	46.40	44.08	34.80	37.12	46.40	37.12	20.88	20.88	27.84	
5.0	51.04	48.40	44.08	37.12	39.44	44.08	41.76	20.88	20.88	27.84	
5.5	51.04	48.72	44.08	37.12	39.44	44.08	41.76	20.88	23.20	30.16	
6.0	53.36	51.04	46.40	39.44	39.44	44.08	44.08	23.20	23.20	30.16	

Table 4.8: E.M.F Readings (mV) Convertd to Temperature (°C) with the Relation $T = 2.16 + 23.2\ V$ for Peeled Sweet Potato.

Time(min)	SAMPLE									
	1	2	3	4	5	6	7	8	9	10
0	27.68	32.33	32.32	32.32	32.32	34.64	30.00	32.32	32.32	32.32
1.0	36.96	43.92	41.60	46.24	39.28	48.56	34.64	46.24	39.28	39.28
1.5	41.60	48.56	46.24	50.88	41.60	53.20	36.96	50.88	43.92	43.92
2.0	43.92	50.88	48.56	55.52	43.92	57.84	39.28	53.20	46.24	46.24
2.5	46.24	55.52	55.52	57.84	46.24	62.48	41.60	55.52	46.24	48.56
3.0	50.88	57.84	55.52	60.16	48.56	64.80	43.92	57.84	48.56	50.88
3.5	50.88	60.16	57.84	60.16	48.56	67.12	43.92	60.16	48.56	53.20
4.0	53.20	62.48	57.84	62.48	56.88	67.12	46.24	60.16	50.88	53.20
4.5	55.52	62.48	57.84	62.48	50.88	69.44	46.24	62.42	50.88	55.52
5.0	57.84	64.80	57.84	64.80	53.20	69.44	48.56	62.48	50.88	55.52
5.5	57.84	64.80	55.52	67.12	53.20	71.76	48.56	62.48	53.20	55.52
6.0	60.16	64.80	57.84	67.12	53.20	71.76	50.88	64.80	53.20	57.84

Table 4.9: Digital Meter Reading Given as Temperature Rise (°C) Above Ambient Peeled Sweet Potato.

Time	SAMPLE										
(min)	1	2	3	4	5	6	7	8	9	10	
0	0	0	0	0	0	0	0	0	0	0	
1	9.28	11.6	9.28	13.92	6.96	13.92	4.64	13.92	6.96	6.96	
1.5	13.92	16.24	13.92	18.56	9.28	18.56	6.96	18.56	11.60	11.60	
2.0	16.24	18.56	16.24	23.20	11.60	23.20	9.28	20.88	13.92	13.92	
2.5	18.56	23.20	23.20	25.52	13.92	27.84	11.60	23.20	13.92	16.24	
3.0	23.20	25.52	23.20	27.84	16.24	30.16	13.92	25.52	16.24	18.56	
3.5	23.20	27.84	25.52	27.84	16.24	32.48	13.92	27.84	16.24	20.88	
4.0	25.52	30.16	25.52	30.16	18.56	32.48	16.24	27.84	18.56	20.88	
4.5	27.84	30.16	25.52	30.16	18.56	34.80	16.24	30.16	18.56	23.20	
5.0	30.16	32.48	25.52	32.48	20.88	34.80	18.56	30.16	18.56	23.20	
5.5	30.16	32.48	23.20	34.80	20.88	37.12	18.56	30.16	20.88	23.20	
6.0	32.48	32.48	25.52	34.80	20.88	37.12	20.88	32.48	20.88	25.52	

4.2 ANALYSIS OF RESULTS

4.2.1 COMPUTATION OF THERMAL CONDUCTIVITY OF THE TEST MATERIAL FROM THE CONVERTED DIGITAL METER READINGS.

The measurement of the physical properties of the sweet potato and other data used include :

Length of sample = 70mm

Diameter of sample = ∅32mm

Current strength = 8.5A

Condition of sample = peeled

Voltage strength = 12V

Table 4.1 represent e.m.f values and their corresponding computed temperature rise during the test run. The temperature rise versus time plot on a semi – log scale for above test material are shown in Appendix.

From the graph on the appendix (S $_1$P) the following information are taken:

Temperature rise at the later minutes, t_2 = 32.5

Temperature rise at the second minute, t_1=16 .5

The heat input 'q' is given by

$$q = I^2 R$$

Now, from ohm's law ,

$$V = IR$$

Reforming $R = V/I$

Therefore,

$$q = IV$$

from equation 2.19

$$K = \frac{q \ln(Q_2/Q_1)}{4\pi (t_2 - t_1)}$$

now Q_2 = 6mins

Q_1 = 2mins

$t_2 = 32.5^0$ C

$t_1 = 16.5^0$C

I = 8.5A

V=12V

Therefore $$K = \frac{8.5 \times 12 \ln(6/2)}{4\pi\ (32.5 - 16.5)} = 0.5573 W/m^0C$$

A similar procedure was followed in calculating the thermal conductivity of the unpeeled sweet potato and standardized material (plantain).

Table 4.10. Depicts results of calculated thermal conductivity values for both peeled and unpeeled sweet potato and that of the standardized material (plantain).

Table 4.1.0: Results of Calculated Thermal Conductivity Values for Peeled and Unpeeled Sweet Potato and Plantain .

	Thermal conductivity values W/m^0C-		
Sample No.	Peeled sweet Potato	Unpeeled Sweet-potato	Test material (Plantain)
1	0.5573	0.4954	1.115
2	0.5945	0.4053	
3	0.6859	0.5245	
4	0.9387	0.6149	
5	1.0491	0.4954	
6	0.5753	0.3243	
7	0.8107	0.5753	
8	0.6605	0.8917	
9	0.9908	0.8917	
10	0.7134	0.8107	

4.2.2 REGESSION ANALYSIS OF THERMAL CONDUCTIVITY DATA OF SWEET POTATO WITH DEPENDENT VARIABLES.

The cumulative effect of the contributions of moisture contents (wet basis) and diameter of the sample on the thermal conductivity value was studied. To this end a linear regression model was developed for predicting thermal conductivity values, knowing sample diameter and moisture content. The model was formulated with moisture content.

(wet basis) and diameter forming the independent variables while the thermal conductivity value is dependent variable.

The result of the regression model lumped together are shown as follows:-

(a) For the unpeeled sweet potato Table 4.11 was used to develop the model.

Table 4.11 variable used for the regression Analysis (unpeeled)

N/S	Diameter (m)	Moisture content (%)	Thermal conductivity K (W/m^{0}C)
1	0.031	71.20	0.4954
2	0.030	68.50	0.4053
3	0.030	76.47	0.5245
4	0.032	72.29	0.6149
5	0.034	74.29	0.4954
6	0.037	70.30	0.3243
7	0.032	72.05	0.5753
8	0.031	73.77	0.8917
9	0.032	72.61	0.8917
10	0.040	72.11	0.8107

The relating linear equation is given as

$K = -2.05096+7.68762D+0.03318M_{wb}$

With a standard deviation of 0.0734 and a mean thermal conductivity value of 0.6029.

Table 4.12: Variables Used for the Regression Analysis (Peeled Sample)

S/N	Diameter of sample (m)	Moisture content (%)wb	Thermal conductivity K (W/m^0C)
	0.032	76.02	0.5573
2	0.030	67.57	0.5945
3	0.037	74.70	0.6859
4	0.039	67.80	0.9387
5	0.030	72.53	0.0491
6	0.025	71.53	0.5753
7	0.029	68.75	0.8107
8	0.030	74.18	0.6605
9	0.030	69.80	0.9908
10	0.030	69.57	0.7134

The relating linear equation is given as

$K = 1.600852494+11.35986825D-0.016826985M_{wb}$

With a standard deviation of 0.069 and a mean thermal conductivity value of 0.7564

Where

D = diameter of sample, m

M = moisture content of sample (wet basis) %

K = Thermal conductivity value, W/m^0C.

4.23 DISCUSSION OF RESULTS

Thermal conductivity values of peeled and unpeeled sweet potato are tabulated in the table 4.10.The result shows that, the thermal conductivity values from 0.5573 to 1.0491 W/m^0c and 0.3243 to $0.8917W/m^0C$ for peeled and unpeeled sweet potato respectively.

A review of Tables 4.11 and 4.12 reveal that moisture content has significant effect on the values of the calculated thermal conductivity although other sources of errors especially unassignable causes may have also accounted for these variations. Linear regression models for estimating the thermal conductivity values for the two conditions (peeled and unpeeled) as function of diameter and moisture content gave a very well correlation between the experimental and predicated data, with the coefficient of determination close to 1.00. Thermal conductivity of the sweet potato increased with increasing moisture content because of the high Thermal conductivity of water. K = 0.6W/mK. The magnitude and trend of the thermal conductivity of the sweet potato samples were in agreement with the literature. Desphande et al, (1996) observed a linear increase bulk thermal conductivity of Soya bean from 0.1157 to 0.1756W/mK at 27^0c in the moisture content range of 8 and 25%(d.b). Shepherd and Bharddiva,(1986) reported that the bulk thermal conductivity of pigeon pea linearly increased from 0.1388 to 0.1862 W/mK in the moisture content range 8-26% (d.b) between 10 and 40^0C.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The thermal conductivity of sweet potato has been determined. It exhibited a trend against diameter of sample (0.025-0.04m) and moisture contents 68.5-76.02%wb) in the temperature range of 9-55^{0}C

The Thermal conductivity value, K was linearly increased with increasing moisture content and diameter. The value of K was determined to be between 0.5573W/m^{0}C and 1.0491W/m^{0}C for peeled and unpeeled sweet potato respectively.

A regression model was also developed to aid in the prediction of K values knowing percentage moisture content (wet basis) and sample diameter. A mean and standard deviation value of 0.6029 and 0.0734 and 0.7562 and 0.069 were observed with the model, for unpeeled and peeled sweet potato respectively.

5.2 RECOMMENDATION

For further work on this project, effort should be geared towards: -

(a) The determination of thermal diffusivity of the sweet potato.

(a) The specific heat capacity of sweet potato.

These properties if determined will provide a complete data base on the thermal properties of the sweet potato which are important in the design of its storage structures aeration and cooling process during the storage and food manufacturing practices involving sweet potato.

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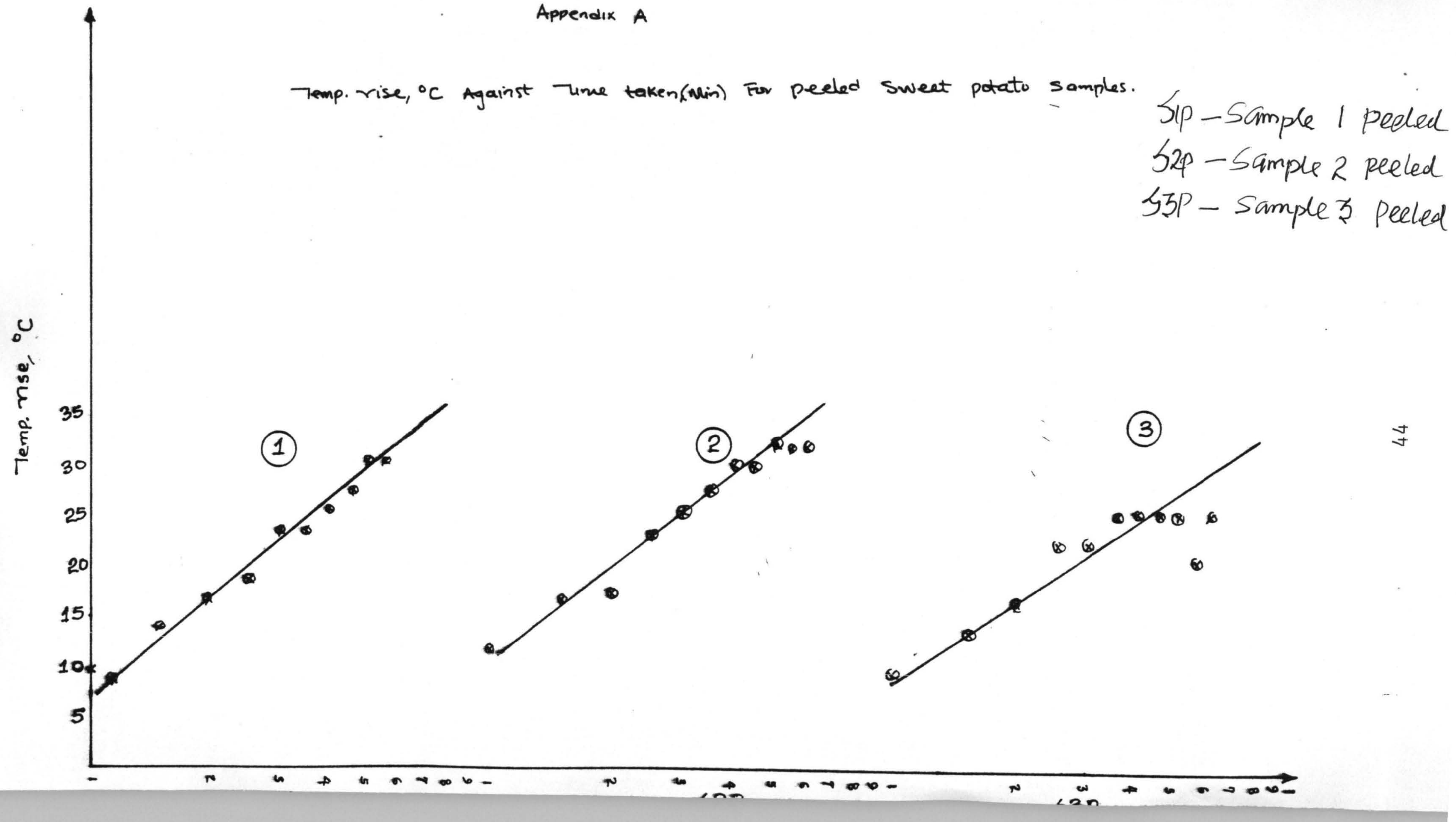
Appendix A

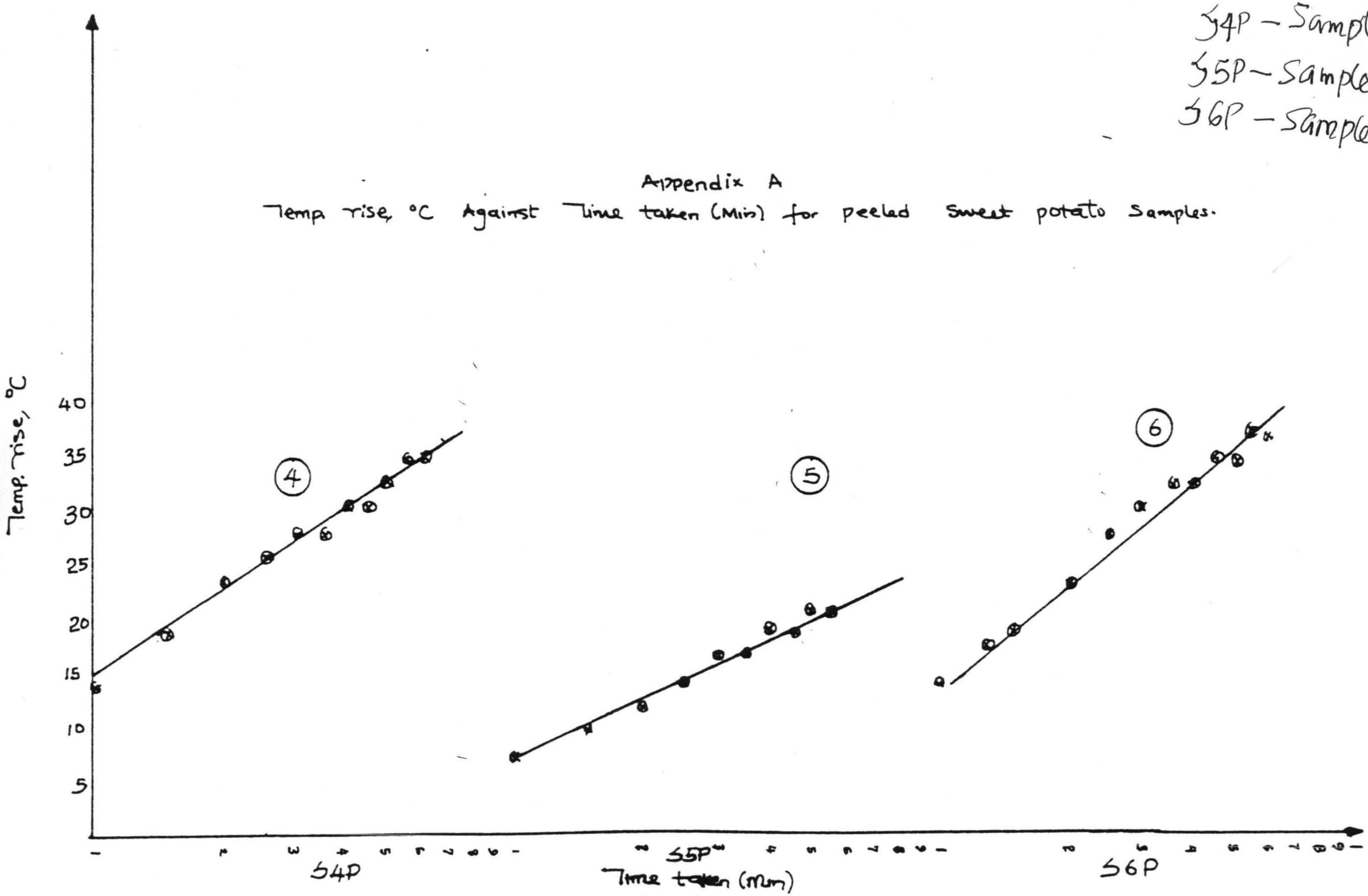
Temp. rise, °C Against Time taken(Min) For peeled sweet potato samples.



S4P – Sample 4 Peeled
S5P – Sample 5 Peeled
S6P – Sample 6 Peeled

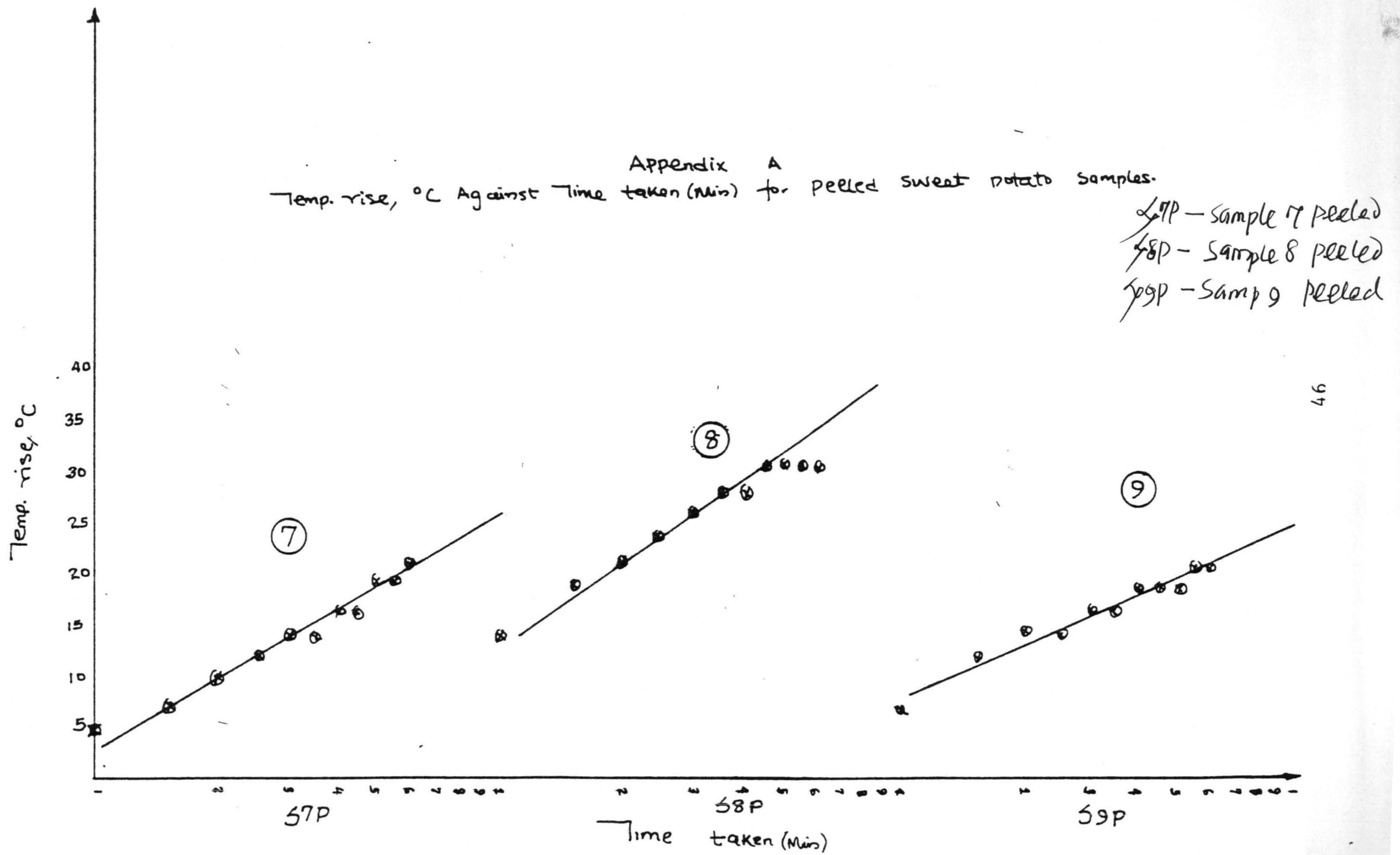
Appendix A

Temp rise, °C Against Time taken (Min) for peeled sweet potato samples.



Appendix A

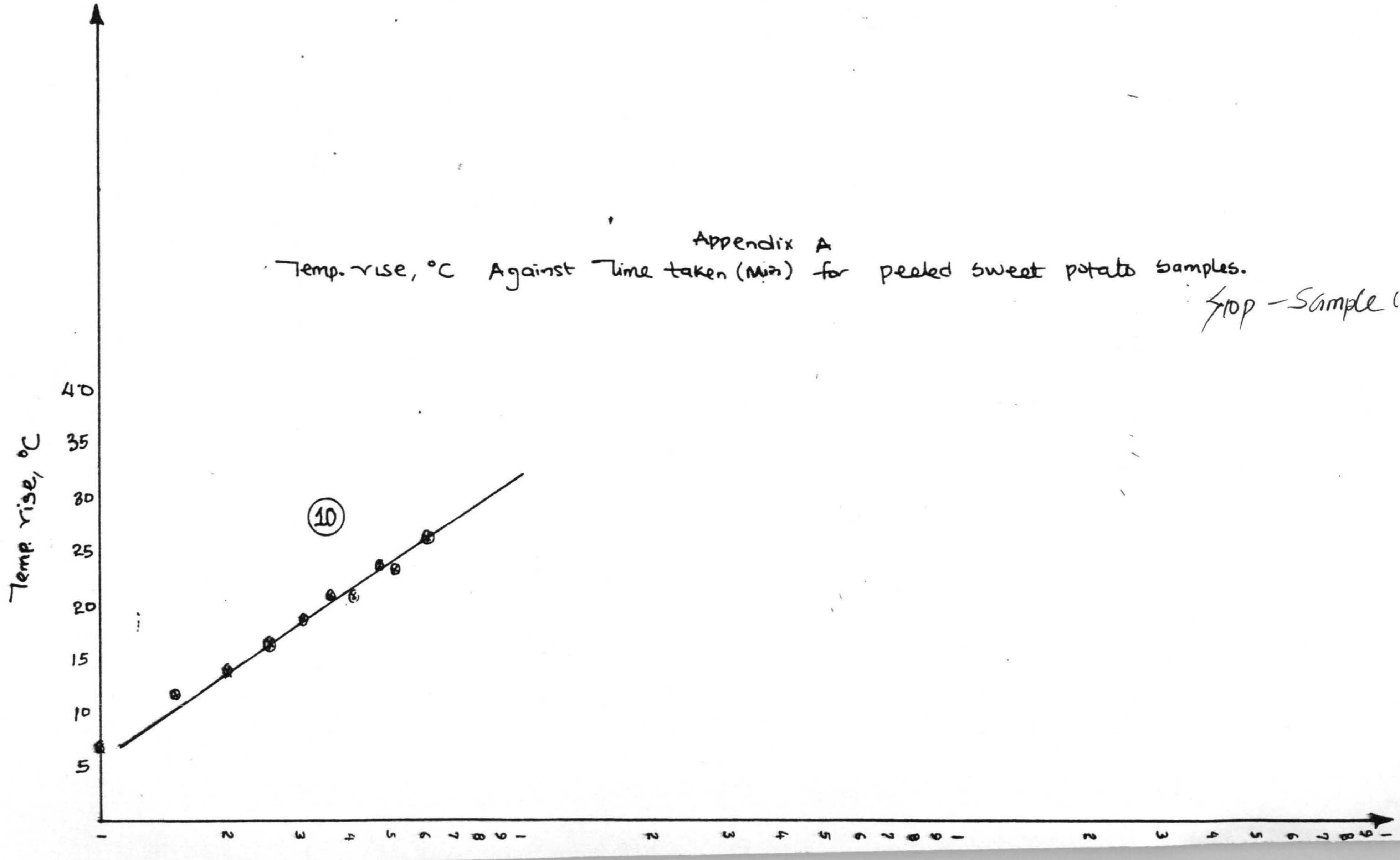
Temp. rise, °C Against Time taken (Min) for peeled sweet potato samples.



Appendix A

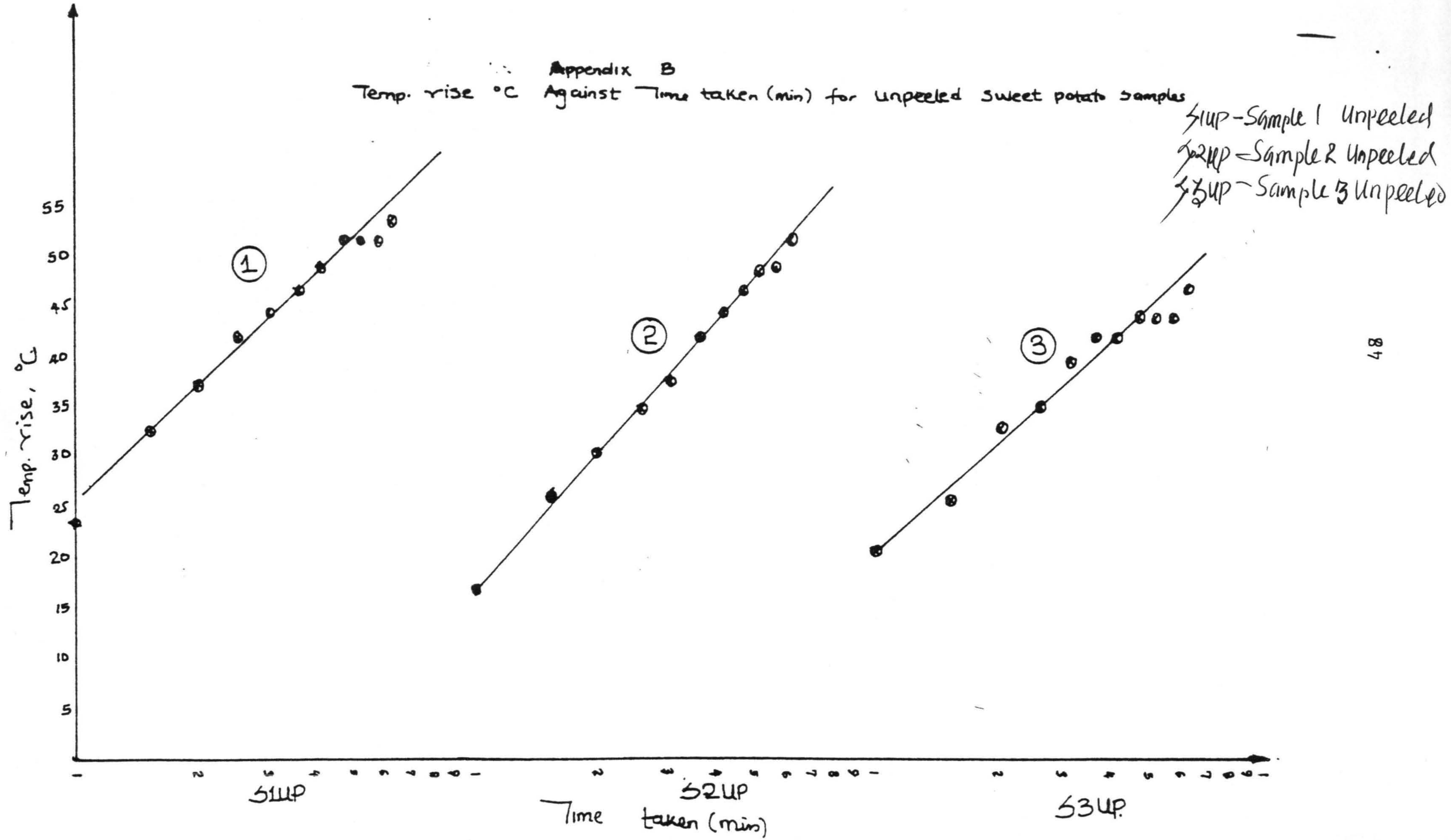
Temp. rise, °C Against Time taken (Min) for peeled sweet potato samples.

S10P – Sample 10 Peeled



Appendix B

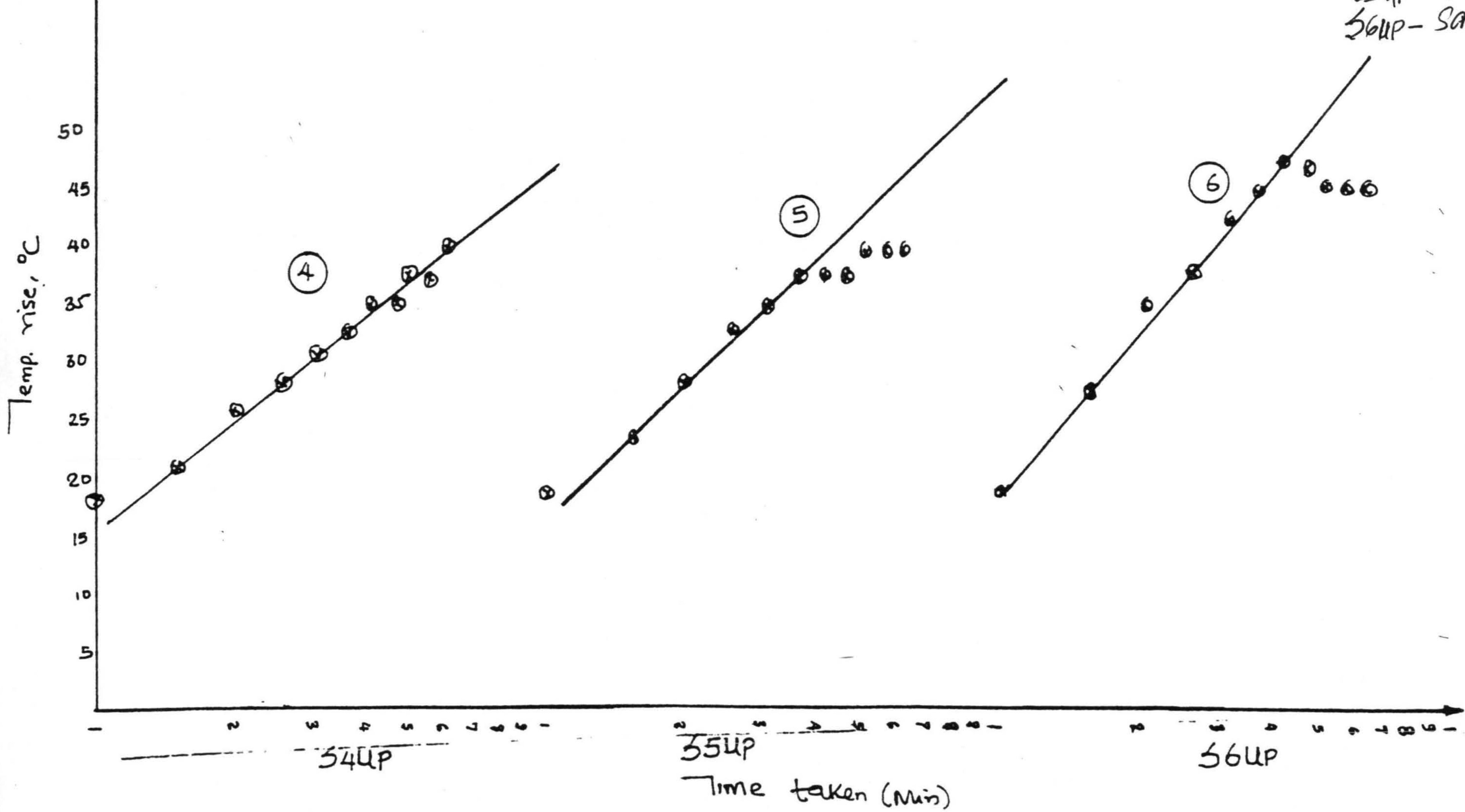
Temp. rise °C Against Time taken (min) for unpeeled sweet potato samples



Appendix B

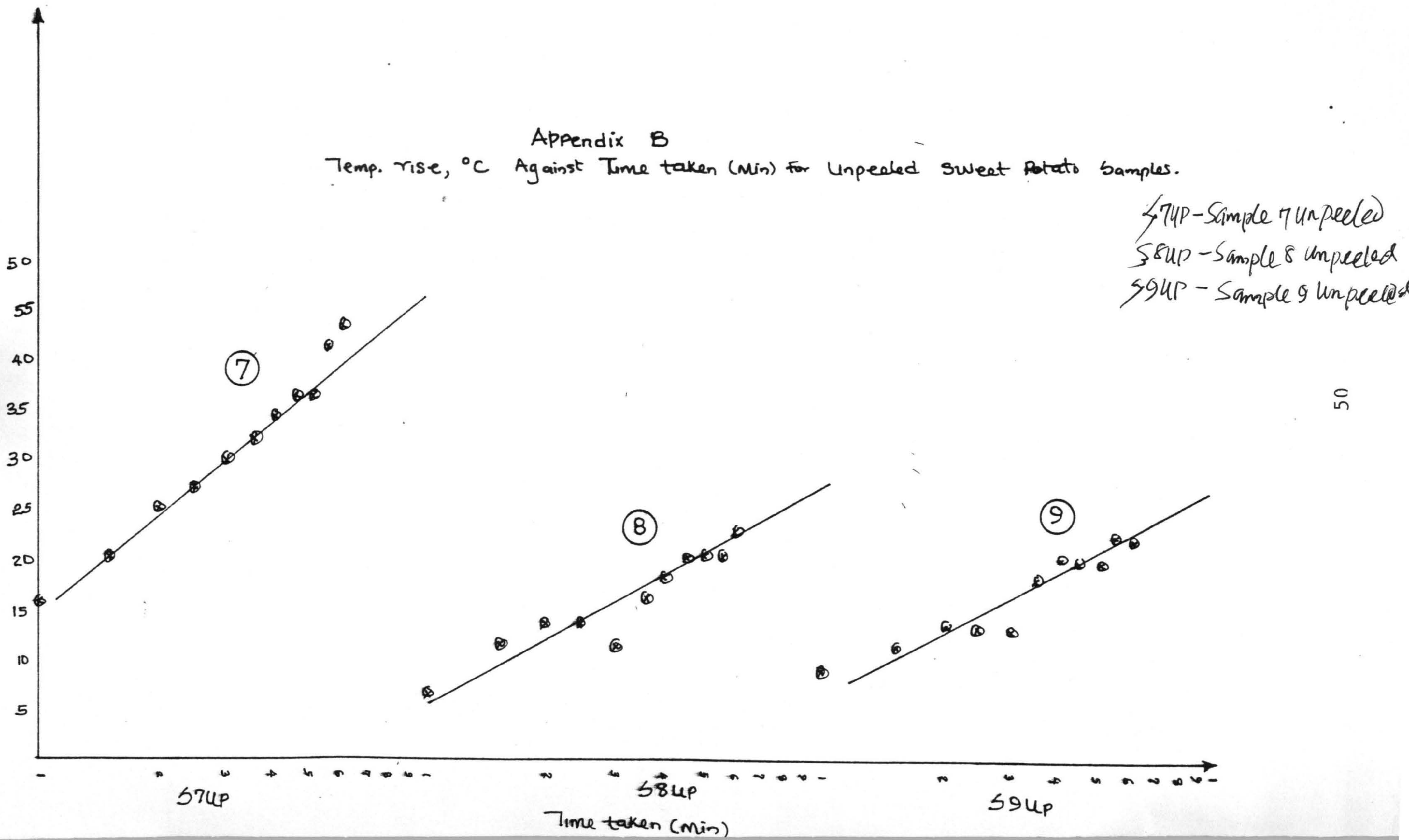
Temp. rise, °C Against Time taken (Min.) for Unpeeled sweet potato Samples.

54UP – Sample 4 Unpeeled
55UP – Sample 5 Unpeeled
56UP – Sample 6 Unpeeled



Appendix B

Temp. rise, °C Against Time taken (Min) for Unpeeled Sweet Potato Samples.

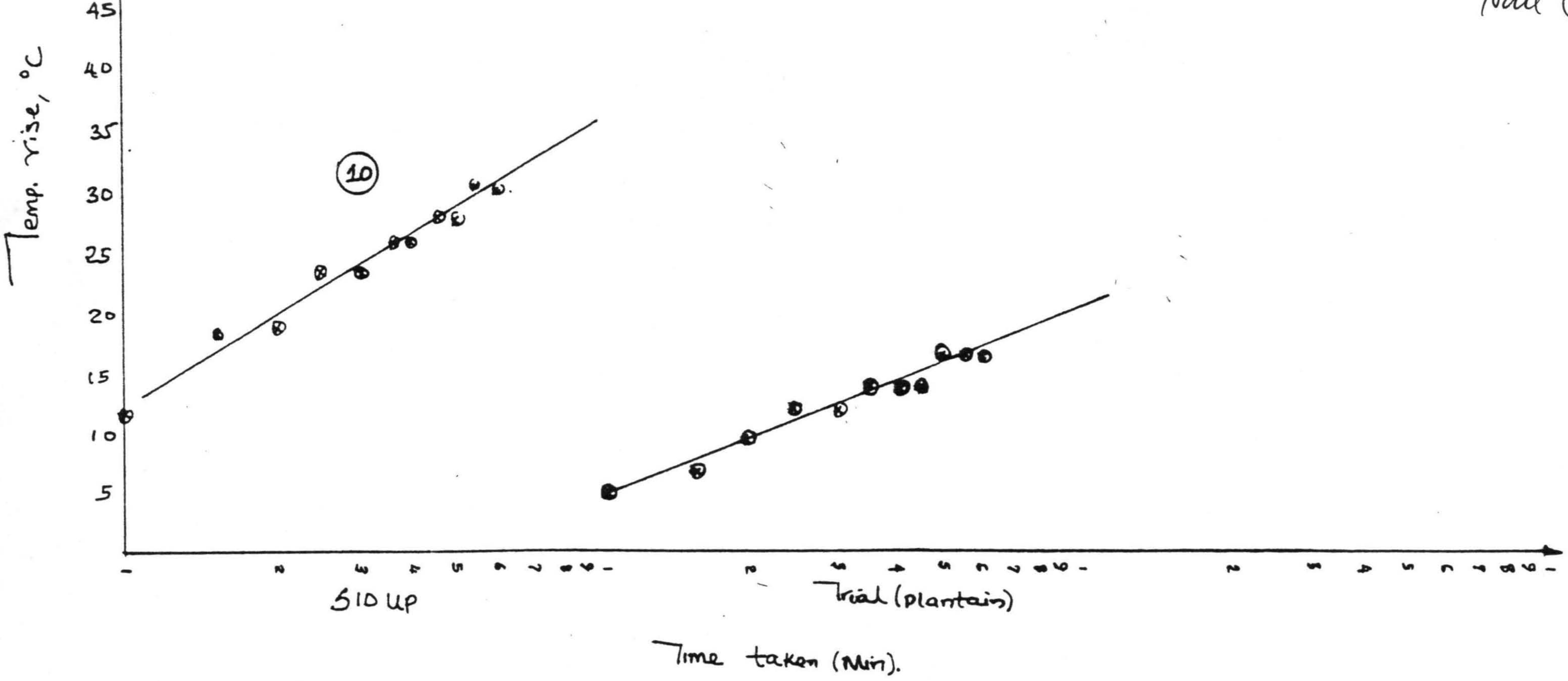


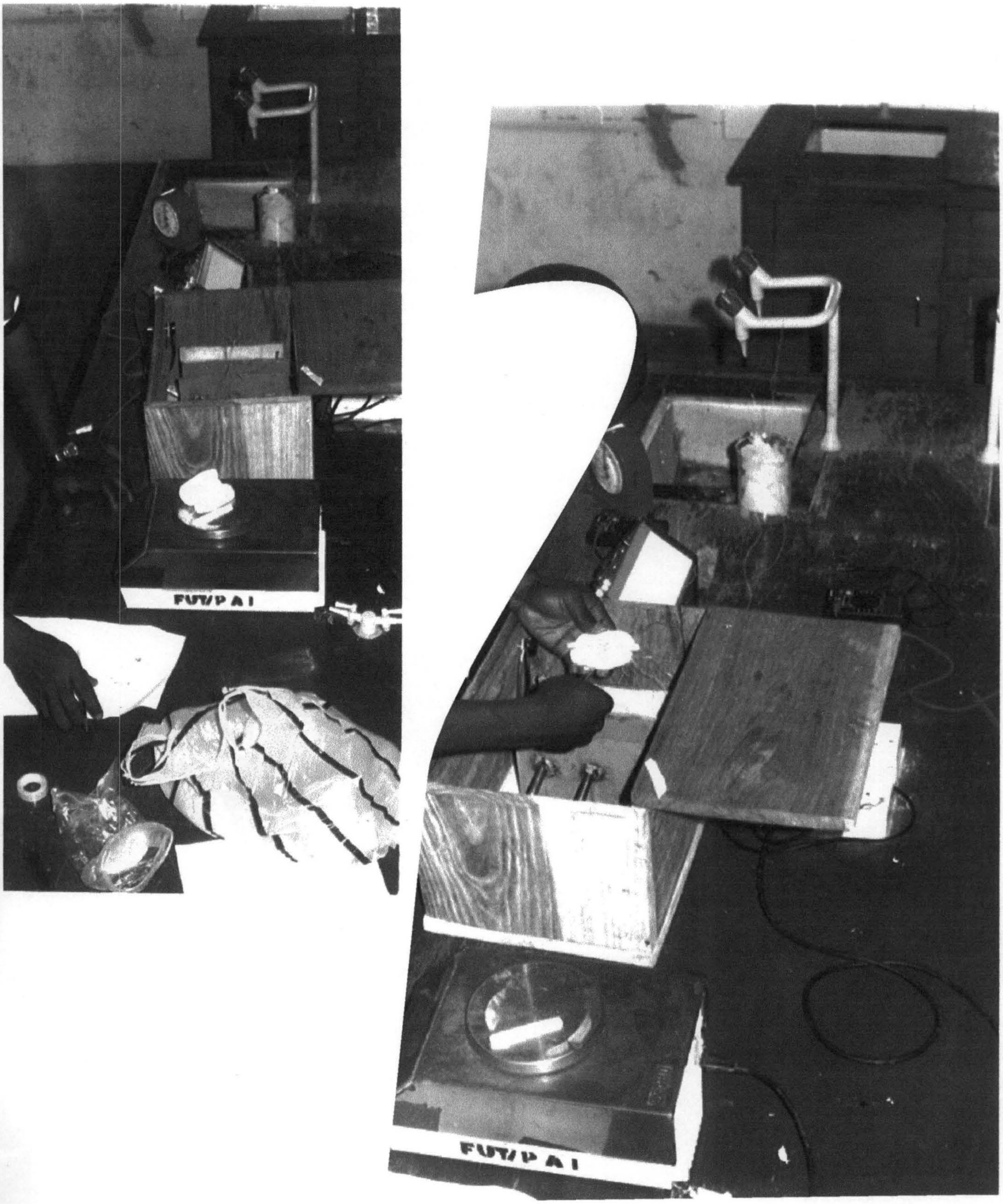
Appendix B

Temp. rise, °C Against Time taken (Min). For sweet potato samples and plantain

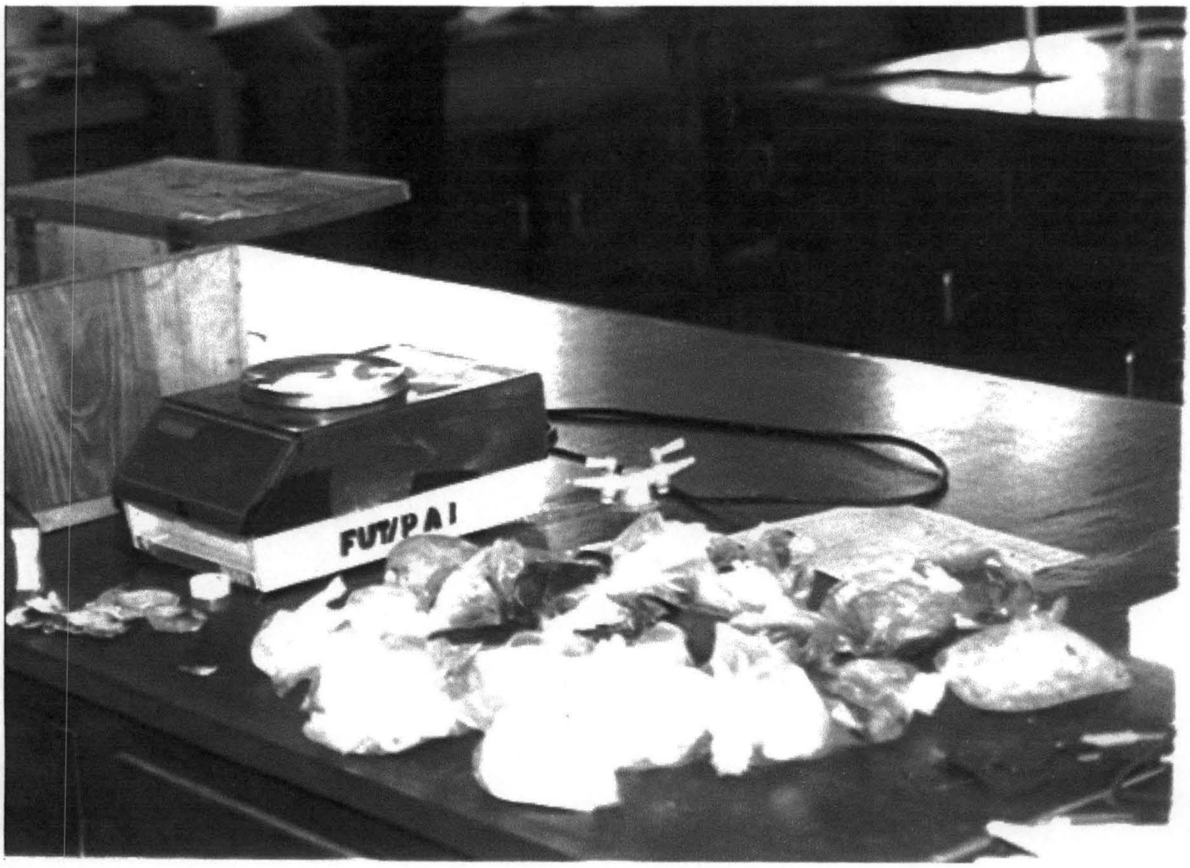
S10UP – Sample 10 Unpeeled

'T' – Trail (Plantain)





Experimental Setup



Experimental Setup