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Effects of temperature and time on clarification of sweet sorghum juice

S. Nwanele Aso

To the Graduate Council:

I am submitting herewith a thesis written by S. Nwanele Aso entitled "Effects of temperature and time on clarification of sweet sorghum juice." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering.

L. R. Wilhelm, Major Professor

We have read this thesis and recommend its acceptance:

B. L. Bledsoe, J. L. Collins

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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and recommend its acceptance:

B. L. Bledsoe

J. J. Hallis

Accepted for the Council:

C. W. Minkel

The Graduate School

EFFECTS OF TEMPERATURE AND TIME ON CLARIFICATION OF SWEET SORGHUM JUICE

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

S. Nwanele Aso

August 1983

Dedicated to members of Aso family
past, present, and future.

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ABSTRACT

Raw sweet sorghum juice from three different sources was heated in four different jars. The jars identified as "A" through "D" were heated to 26.7°C, 46.1°C, 65.6°C, and 85°C respectively. Jar A served as the control. At the beginning of the experiment (time = 0 minutes), a juice sample was withdrawn from each jar and stored. The temperatures of jars B, C, and D were then raised and maintained respectively at 46.1°C, 65.6°C, and 85°C. Juice samples were subsequently withdrawn from the top, middle, and bottom portions of each jar at 30-, 60-, and 90-minute intervals.

The acidity (pH), percent total soluble solids (PTSS), percent total solids (PTS), and percent total ash (PTA) content of each withdrawn juice sample were measured. The data obtained were evaluated by statistical procedure to determine if temperature and time had any effect on clarification of sweet sorghum juice. Based on the statistical analysis of this study, the following inferences can be made:

1. Temperature and time do affect the clarification of sweet sorghum juice. Physical observation of the experimental units showed that when a jar of raw sorghum juice was heated, much of the impurities was coagulated. Part of the coagulated material precipitated to the bottom and part rose to the surface thus leaving the middle portion fairly well clarified. The statistical analysis revealed that after this coagulation period (which was about 30 minutes),

the clarification process was no longer temperature dependent.

2. Temperature and time affect color formation in sweet sorghum juice.

3. The acidity (pH) of a heated sweet sorghum juice is the same at all sections of the container. However, percent total soluble solids (PTSS), percent total ash (PTA), and percent total solids (PTS) of heated sweet sorghum juice (and possibly of other heated natural juices) at the top, middle, and bottom sections of the container at a given temperature and time (where tem and t represent temperature (°C) and time (minutes) respectively) can be predicted with the following equations:

At the top section (Location 1)--

Percent total soluble solids (PTSS) =

$$27.698 - 33.47 \times 10^{-2}\ tem + 6.5 \times 10^{-3}\ t - 11.17 \times 10^{-7}\ tem\ t + 2.62 \times 10^{-3}\ tem^2 + 1.8 \times 10^{-4}\ t^2 - 64.35 \times 10^{-7}\ tem^3 - 35.27 \times 10^{-7}\ t^3 + 79.96 \times 10^{-10}\ tem\ t^3$$

Percent total ash (PTA) =

$$0.3602 + 2.9 \times 10^{-3}\ tem + 74.13 \times 10^{-9}\ tem^2 - 21.71 \times 10^{-8}\ tem^2\ t - 48.11 \times 10^{-9}\ tem^3 + 11.06 \times 10^{-10}\ tem^3\ t + 15.6 \times 10^{-13}\ tem^3\ t^2$$

Percent total solids (PTS) =

$$30.556 - 35.59 \times 10^{-2}\ tem - 1.64 \times 10^{-2}\ t + 1.68 \times 10^{-4}\ tem\ t - 75.92 \times 10^{-9}\ tem\ t^2 + 2.69 \times 10^{-3}\ tem^2 - 22.36 \times 10^{-5}\ t^2 - 64.56 \times 10^{-7}\ tem^3 + 24.3 \times 10^{-7}\ t^3$$

At the middle portion of the jars (Location 2)--

Percent total soluble solids (PTSS) =

$29.6426 - 36.42 \times 10^{-2}$ tem $- 10.44 \times 10^{-3}$ t $- 11.2 \times 10^{-7}$ tem t $+ 26.92 \times 10^{-4}$ tem^2 $+ 36.8 \times 10^{-5}$ t^2 $- 64.35 \times 10^{-7}$ tem^3 $- 35.27 \times 10^{-7}$ t^3 $+ 79.96 \times 10^{-10}$ tem t^3

Percent total ash (PTA) =

$0.3602 + 2.91 \times 10^{-3}$ tem $+ 14.83 \times 10^{-8}$ tem^2 $- 21.71 \times 10^{-8}$ tem^2 t $- 48.11 \times 10^{-9}$ tem^3 $+ 1.11 \times 10^{-9}$ tem^3 t $+ 1.56 \times 10^{-12}$ tem^3 t^2

Percent total solids (PTS) =

$30.738 - 36.15 \times 10^{-2}$ tem $- 3.28 \times 10^{-2}$ t $+ 1.69 \times 10^{-4}$ tem t $+ 2.69 \times 10^{-3}$ tem^2 $- 1.8 \times 10^{-4}$ t^2 $- 75.92 \times 10^{-9}$ tem t^2 $- 64.56 \times 10^{-7}$ tem^3 $+ 24.3 \times 10^{-7}$ t^3

At the bottom section of the jars (Location 3)--

Percent total soluble solids (PTSS) =

$31.584 - 30.07 \times 10^{-2}$ tem $- 2.75 \times 10^{-2}$ t $- 1.12 \times 10^{-6}$ tem t $+ 2.77 \times 10^{-3}$ tem^2 $+ 5.52 \times 10^{-4}$ t^2 $- 6.43 \times 10^{-6}$ tem^3 $- 3.53 \times 10^{-6}$ t^3 $+ 79.96 \times 10^{-10}$ tem t^3

Percent total ash (PTA) =

$0.3602 + 2.9 \times 10^{-3}$ tem $+ 2.22 \times 10^{-7}$ tem^2 $- 21.71 \times 10^{-8}$ tem^2 t $- 4.81 \times 10^{-8}$ tem^3 $+ 1.11 \times 10^{-9}$ tem^3 t $+ 1.56 \times 10^{-12}$ tem^3 t^2

Percent total solids (PTS) =

$30.920 - 36.71 \times 10^{-2}$ tem $- 4.93 \times 10^{-2}$ t $+ 16.88 \times 10^{-5}$ tem t $+ 26.94 \times 10^{-4}$ tem^2 $- 13.68 \times 10^{-5}$ t^2 $- 75.92 \times 10^{-9}$ tem t^2 $- 64.57 \times 10^{-7}$ tem^3 $+ 2.43 \times 10^{-6}$ t^3

For all the equations, tem and t represent temperature and time respectively. The 3-dimensional graph and contour maps plotted with these equations are presented in Figures B-1 through D-6 in the Appendix.

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CHAPTER I

INTRODUCTION AND OBJECTIVES

Introduction

Production of sorghum syrup involves evaporation of water from juice which has been expressed from sweet sorghum cane. In addition to water and sugar, the juice contains extraneous substances which can lower the quality of syrup produced by adulterating its color, flavor, and clarity. Therefore, these substances must be removed to produce a high quality syrup.

Some of the extraneous substances in the juice are particulate materials, while others such as proteins, starch, and other natural substances have colloidal properties. Particulate substances can be removed by physical means such as filtration and/or sedimentation processes, but colloidal substances require other means for adequate removal. Traditionally, colloidal substances have been eliminated by heating the filtered raw juice in a kettle or an open pan evaporator. (Figure 1 shows a typical continuous stubbs-type evaporator that is widely used.) The heat precipitates some of the proteins, solubilizes much of the starch, and coagulates some of the mechanically suspended substances. The flocculated material rises to the surface of the juice and is skimmed off by a hand-held device. The skimming process is continued as water evaporates until the desired sugar content for the syrup is reached.

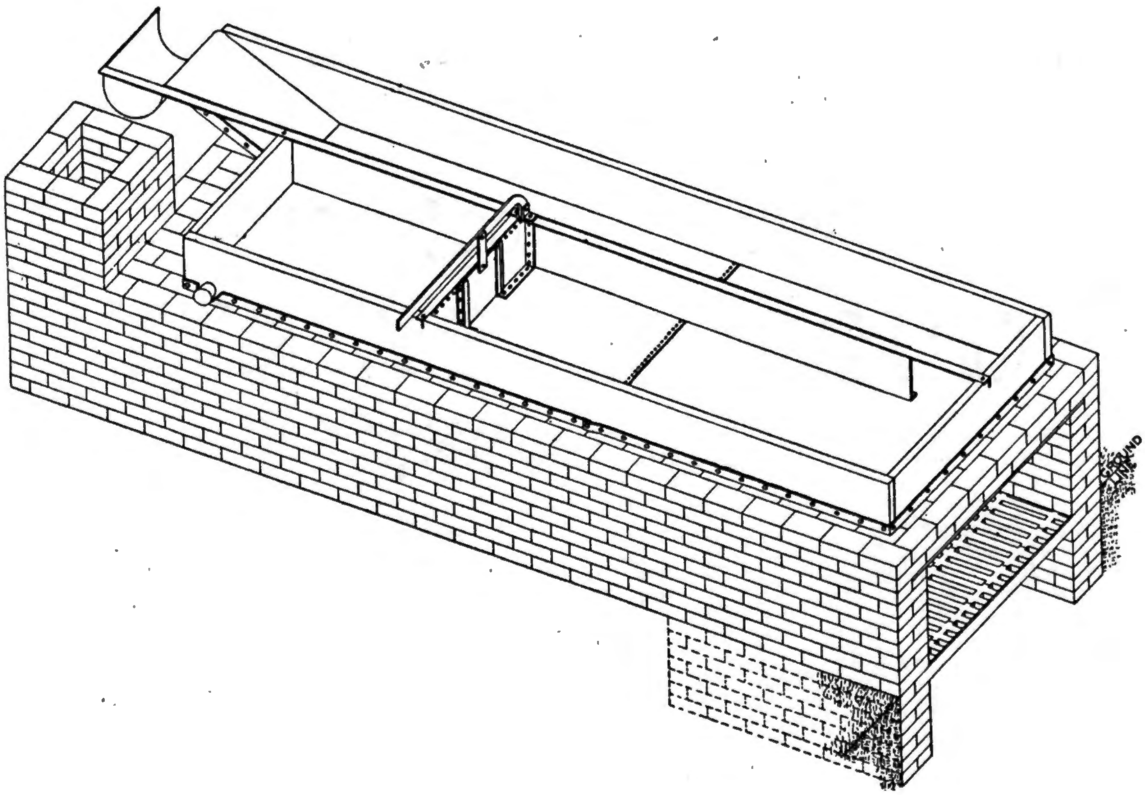

Figure 1

A Typical Continuous Stubbs-Type Evaporator That is Traditionally Used to Concentrate Sorghum Syrup

Taken from Byall et al. (7).

Over the years, other methods which involve the application of such materials as lime, filter aids, phosphoric acid, and enzymes have been used to clarify sorghum juice. These methods still require the use of heat, and sometimes it is necessary to raise the temperature of the juice to near boiling in order to develop the maximum potential of the clarifying agent employed (7, 16, 28). Thus, the importance of heat in the clarification of raw sweet sorghum juice cannot be overemphasized.

Some specific improvements in the sorghum syrup industry have been made during the past several years. For instance, propane is widely used today as a heating fuel instead of wood. However, the quality of syrup produced traditionally continues to be largely dependent upon the capabilities and experience of the producer (11, 46). As Table 1 and Figure 2 suggest, the operation is very time and labor intensive and often produces syrup of highly variable quality. Syrups thus produced may have an undesirable "cloud" due to inadequate removal of extraneous materials and may also "clabber" should the colloidal starch component gel.

Despite the fact that heat has been widely used as a clarifying agent and that Henrickson (28) referring to sorghum syrup in 1958 wrote, "There is good evidence that *color formation* is a product of *time* and *temperature*" (italics mine), no report of work designed to investigate and establish that evidence was found in the literature. In this microchip age when evaporation processes can be accomplished with vacuum technology, perhaps the time is right for sorghum syrup processors to

Table 1*

Typical Hand Harvesting Rates of Sorghum Stalks for Syrup Production in East Tennessee

Operation	Hectares per Hour (Acres per Hour)
Stripping (80% effective), 1 person	0.023 (0.056)
Cutting (1 cutter, 2 holders), 3 persons	0.081 (0.200)
Removing heads of cut cane, 1 person	0.073 (0.180)

*Taken from Wilhelm et al. (55).

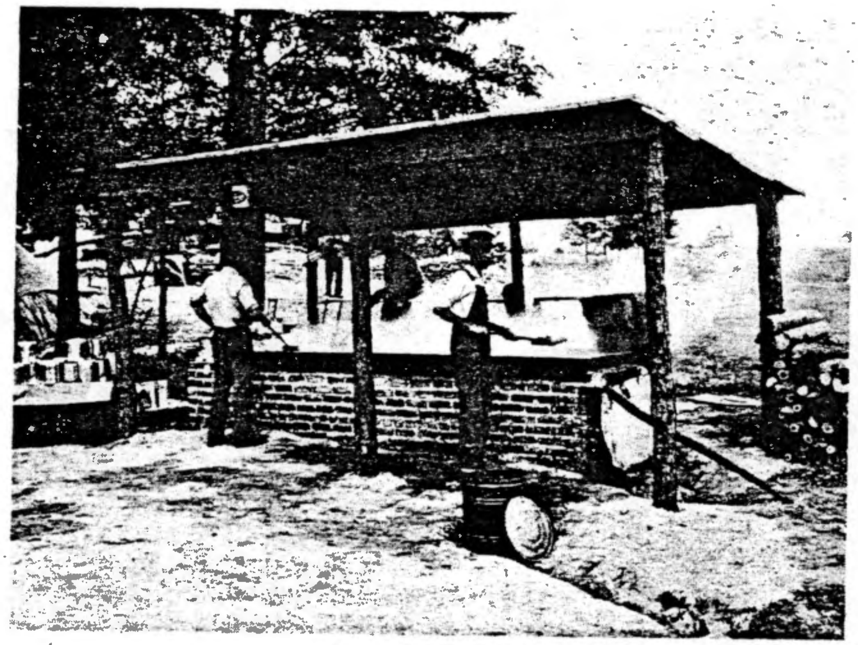

Figure 2

A Traditional Continuous-Type Sorghum Syrup Evaporator in Operation

Taken from Byall *et al.* (7).

introduce consistent labor-saving procedures which will adequately clarify the raw juice before an evaporation process is begun.

Objectives

Because of the importance of heat in sorghum syrup manufacture and due to the advances in modern technology, this study was designed to investigate the effects of temperature and time on clarification of sweet sorghum juice. Emphasis was placed on the percentage of suspended solids removed from a given quantity of raw juice heated for specific periods of time. Parameters analyzed to realize this objective were acidity (pH), total soluble solids (TSS), total solids (TS), and total ash (TA) content.

CHAPTER II

REVIEW OF LITERATURE

Origin and Taxonomic Classification of Sorghum

Sorghum is a crop plant with a well-established geographic origin. Domesticated sorghum originated on the continent of Africa where countries such as Cameroon, Ethiopia, Nigeria, Senegal, Sudan, Uganda, and Upper Volta are amply represented with authentic indigenous collections (19, 21, 31). However, satellite centers were instituted centuries ago in interior Asia and Middle Eastern countries. India, China, and Malaya were prominent sorghum production centers in Asia. Iraq was a noted Middle East center. Sorghum appeared later in southern Europe and has more recently been introduced into the Americas, Australia, and other parts of the world (5, 19, 30).

Botanically speaking, the genus Sorghum belongs to the tribe Andropogoneae of the family Gramineae. It includes both the wild and cultivated species known as A. sorghum var vulgare (6, 19, 21, 42). Another method of classifying sorghum is based on economic and agronomic uses. Under this taxonomic principle, four distinct categories of sorghum have been identified (11, 12, 19, 33).

1. Forage or sweet sorghum: Sometimes called sorgo or saccharine sorghum, this category has sweet juicy stalks which for decades have been exploited for forage, sugar, and

syrup production. Its old cultivars include Black Amber, Gooseneck, Honey, Orange, and Sumac. In Tennessee these cultivars have been largely replaced by Dale, Theis, Williams, and Tracey (39).

2. Grain sorghum: Grain sorghum is primarily bred for the production of grains which are in turn used for human and livestock food. Some prominent cultivars of grain sorghum are Caudatum, Guinea, Kaffirs, Kaolings, Kaura, and Milos.
3. Grassy sorghum: The grassy sorghums have thin stems, narrow leaves, and numerous tillers. They are essentially used as hay and for livestock grazing. Johnson and Sudan grasses are the most widely used cultivars.
4. Broom corn sorghum: Broom corn sorghums have characteristic long panicle branches which are used for the production of brooms and brushes. Among the best known cultivars are Black Spanish, California Golden, and Evergreen (19).

All cultivated sorghums of commercial importance are called Sorghum bicolor (L.) Moench (13, 21, 43). This includes sorghums that have sweet stalks which yield carbohydrates and biomass at levels that warrant harvest for syrup, sugar, and alcohol production. Also included are those sorghums that have high grain yields.

Sorghum Production

World

Sorghum has emerged as the fourth-ranking cereal crop in the world after corn (maize), rice, and wheat (31, 33). In the last few years alone, the world's sorghum production has dramatically increased. For example, the area sown to sorghum increased from an average of 38.5 million hectares during 1961-65 to 43.9 million hectares in 1976. During the same period, total production went from 35.3 to 51.8 million metric tons (30). In 1978, world sorghum production was estimated at 68.6 million metric tons. This output was harvested from 47.5 million hectares (47). Furthermore, 1982 FAO statistics (22) showed that in 1981 47.8 million hectares was sown to sorghum worldwide with an estimated production of nearly 72 million metric tons. A major force behind this accelerated output is attributed to the high yield potential of hybrid sorghum. With good management, yields of hybrid sorghums are comparable to, and sometimes better than those of rice, corn, and wheat. Yields in excess of 11,000 kilograms/hectare have been recorded, and average yields of 7,000 to 9,000 kilograms/hectare are common in areas where moisture is not a limiting factor (30, 31).

Africa, Asia, North and South America are the world's major producers of sorghum. In 1981, these continents produced over 97% of the world's sorghum output with 12.71, 15.52, 28.57, and 40.53% being produced by South America, Africa, Asia, and North America respectively. India accounted for approximately 60% of Asia's total output followed by China with 36.5%. Argentina, Columbia, and Venezuela accounted for about 95% of that produced in South America.

Nigeria

Nigeria is Africa's largest sorghum producer. In 1981, Nigeria produced over 3.8 million metric tons of sorghum on 6.025 million hectares. This accounted for 34.32% of Africa's total output and was only approached by the Sudan with 25.10% (22). Sorghum is a staple food in northern parts of West Africa. Consequently, it is one of the most widely grown crops in Nigeria, claiming about 50% of total cereal production (1, 44). In comparison to other cereals, sorghum is tolerant to poor soils and other adverse growing conditions.

Much effort has been put into improving sorghum varieties and diversifying their usage in Nigeria. Some of the varieties grown include Guinea, Sweet, Kaffir, Egyptian, Feterita, and Kaura (1, 45).

United States of America

Sorghum was first introduced in the United States in the early 1850's (5, 6, 19). Georgia, Kentucky, Tennessee, and other southern states have traditionally dominated the cultivation of sorghum for syrup production (7, 11). However, the states of Texas, Oklahoma, Kansas, Nebraska, and portions of Colorado, Missouri, and New Mexico produced 89% of United States sorghum grain in 1973 (33). Texas alone accounted for 42%.

In the United States, production of sorghum for grain has skyrocketed over the past few years. Today sorghum is regarded as the third-ranking cereal in terms of total production (33, 47). In 1981 for instance, the United States of America produced 22.4 million metric tons of sorghum from nearly 5.7 million hectares of land. This output accounted for 76.6% of total sorghum grown on the North American continent. Most of the sorghum grown in the United States goes into livestock feed and export. Less than 10% is used for food and industrial products (19, 33, 47).

Potential Uses of Sorghum

The status of sorghum in industrialized nations has for a long time been one of only "fit for feed" syndrome. This image unfortunately has been perpetrated by the following factors: 1) the tremendous amount of time and labor associated with traditional method of sorghum syrup production, 2) early frustrations encountered in the process of sugar manufacture from sorghum, 3) poor consumer acceptance of sorghum products because of traditional love for rice, corn, and wheat products, and 4) the misguided belief that all sorghum contains condensed tannins which jeopardize its nutritive worth. These factors have not only relegated the affairs of sorghum syrup to that of a mere "cottage industry," but also delayed exploitation of sorghum for other potential human uses (10, 43, 47).

Despite this rather odd background, strides have been made in recent years to develop the sorghum industry as a major contributor to some of the essential needs of man. Potential areas of contribution follow.

Food

Sorghum grains have been consumed as food for centuries in Africa and Asia. In these continents, consumption has been mainly among the low income groups who depend on it as the "staff" of life (1, 31, 33, 47). The preparation of sorghum for food is simple. Methods range from roasting and eating it like sweet corn to the manufacture of baked foods, snacks, and even tortillas (19, 47).

In northern Nigeria for instance, a dish called tuwo is prepared by stirring sorghum flour in hot water and allowing the paste to cool and gel. Pieces of the cooled gel are then eaten with a delicately prepared meat or fish soup. Also, milling tests on Nigerian sorghum grain assessed the flour as good for biscuits and shortbreads (19). In India, sorghum grain is used to prepare unleavened bread (rotti) and is sometimes cooked and eaten like rice (31, 33). In the United States, sorghum syrup is used in the preparation of brown bread, cookies, pies, and baked beans (12). Sorghum has been used as a brewing adjunct in Mexico for many years (47). It is also used to manufacture a native beer called Pito in northern parts of West Africa (1).

Sorghum grain can be processed into grits and a host of other milled products. It can be puffed, popped, extruded, and flaked to produce delightful snacks and breakfast food items. In fact, prototype sorghum products have been developed by several American food companies but have not been marketed for various reasons including the "fit for feed only" image of sorghum (47). Studies conducted in Ahmadu Bello University, Zaria, Nigeria, showed sorghum grain to be richer in protein and carbohydrate than corn (45). However, it is lacking in some limiting amino acids such as lysine and methionine (1, 19, 33, 45). Furthermore, sorghum syrup is known to be rich in iron, calcium, and food energy (9).

Feed

Sorghum is used in a variety of ways to feed farm animals. In addition to grain production, sorghum has been used for green chop, forage, silage, and grazing. The primary component of sorghum forage is cellulose. It is therefore of great value to ruminants and has been used extensively to satisfy nutritive requirements for cattle, sheep, and goats (31). But most of the use of sorghum as feed has occurred in the so-called industrialized nations. In the southwestern United States, for example, sorghum grain has been used as the basic ingredient in high energy and fattening rations in feedlots. In this region, sorghum grain constitutes 70-90% of the rations (31). In Japan, most of the sorghum imported from Argentina, Australia, Thailand, and America is used for livestock production (33, 47). The story is very much the same in Europe (22).

Sorghum grain has about 95% of the value of corn in livestock nutrition. It has been used to feed nonruminants like swine and poultry (33, 47). Experiments in Oklahoma showed that sorghum grain can be substituted entirely for corn in poultry rations (19). Numerous methods have been used to process sorghum grain for livestock feeds. Grinding, rolling, steam rolling, pressure cooking, micronizing, reconstitution, and flaking are among processing methods claimed to have boosted feed efficiency of sorghum grain by 5-10% (33).

Other Uses

Food for man and his animals are the two basic ways that sorghum is currently utilized. Other major uses include industrial applications such as in the manufacture of starch, oil, feed by-products, dyes, beverages, and the production of alcohol for fuel (13, 19, 33). Miscellaneous uses are soil conditioning and fertilization, production of brushes and brooms, and construction of shelter, fish traps, and baskets (19, 30, 31, 36).

Composition of Sorghum Juice

As Figure 3 shows, sorghum juice intended for syrup or sugar production is extracted by passing sweet sorghum cane through a mill. The expressed juice flows from underneath the mill and is collected in a pan, tank, or bucket. To make 3.8 liters (1 gallon) of syrup 22.7 to 26.5 liters (6 to 7 gallons) of juice are usually required, 18.9 to 22.7 liters (5 to 6 gallons) of water being evaporated (7, 23). In addition to sugar and water, the juice as first obtained at the mill contains dissolved and undissolved substances, some of which are extraneous.

Among undissolved extraneous substances are crushed leaves, stalk fragments, and soil particles that adhered to cane stalks. These materials are largely mechanically suspended leaving in solution inherent substances such as organic and inorganic salts, acids, albumen, gluten, proteins, starch, dextrin, gums, and waxes (7, 54). Many of these substances are considered impurities because their presence is detrimental to the quality of syrup produced.

Composition of sorghum juice can be affected by many factors. These factors include the variety of sorghum grown, age at which stalks

Figure 3

Traditional Method of Expressing Juice from Sweet Sorghum Canes for Syrup or Sugar Production

The mill shown here is a laboratory model much smaller than typical operating mills.

were harvested, type of soil and fertilizer used for cultivation, part of the stalk from which juice was extracted, cultural practices, and seasonal conditions such as a rainy as opposed to a dry growing season (8, 28, 33).

Clarification Procedures

In making sorghum syrup, it is necessary to rid the expressed saccharine solution of most inherent and extraneous impurities. The agent and means employed for this defecation process constitute the clarification procedure and must be well chosen. Chosen procedures should be adequate, easy to use, adaptable to small and large scale applications, affordable, and above all should not impart any deleterious effects to man or his animals should the clarifying agent be eaten as a result of residues left in the juice due to inadvertent excess (54).

Some of the major procedures used over the years to clarify sorghum juice are briefly discussed below.

Filtration and Sedimentation

As juice runs from underneath the mill, it is normally passed through one or two wire (or fabric) screen(s). The screen(s) remove suspended coarse substances such as crushed leaves and stalk fragments. The filtered juice is then allowed to sit for a few hours.

During this quiescent period, some proteinaceous matter, complex carbohydrates, and soil particles "settle out" and can be eliminated.

Filter Aids

Clay and fuller's earth have been used as filter aids in clarification of sweet sorghum juice. In the sugar cane syrup industry, paper pulp, or wood flour is sometimes substituted (46). For sweet sorghum juice clarification, clay is added to the juice, properly stirred for 10 to 20 minutes and allowed to settle. In the settling process, the clay sinks to the bottom of the container carrying with it most of the suspended substances. The top portion of the juice is then syphoned and strained into an evaporation pan. Sometimes the stirred mixture of clay and juice is pumped through a filter press. The resulting filtrate is clear and ready for the evaporation process (15).

There are two major advantages of clay clarification: 1) skimming is virtually eliminated, hence labor is saved and 2) a clearer and lighter colored syrup is produced. The disadvantages are: 1) syrup yield is reduced by about 5% (14) and 2) the finished syrup sometimes clabbers (gels) upon standing (17).

Lime

Lime is mostly used in the form of milk of lime or carbonate of lime. The primary objective of using lime is to neutralize the acidity of the juice. However, sorghum juice treated with lime shows a rapid settling-out of impurities as the lime combines with substances other than the neutralized acids. These substances are precipitated, leaving a more completely clarified juice (6, 46).

Sometimes heat is used to boost the effectiveness of lime. For instance, albumen in sorghum juice or semi-syrup is held in solution by acids. By neutralizing the acids with lime, albumen is destabilized. Heat then coagulates the albumen. The coagulum rises to the surface and is removed by skimming (54).

The major disadvantage of using lime as a clarifying agent is the dark color it introduces to finished syrup. However, this is offset by the fact that lime gives the syrup a mild flavor by "killing" the acid tang (6, 7, 23, 46).

Enzymes

Enzymes used in clarification of fruit juices are also used in the sorghum syrup industry on cold juice and at the semi-syrup stage. Examples are diastase (malt extract) and invertase (4, 7, 8, 16, 17, 19, 28, 34, 35). In cold juice application, diastase is added to the juice in a container, then the juice is stirred thoroughly and allowed to stand for a few hours. During the standing period, the enzyme hydrolyzes colloidal materials such as starch into simpler compounds whereby their colloidal nature is destroyed. Some of the compounds formed are solubilized while others are coagulated. Part of the coagulum precipitates and part rises to the surface of the juice and is removed by skimming. Although invertase can be used on cold juice as described, the use of this and other enzymes is preferred at the semi-syrup stage (7, 8, 19).

For semi-syrup (syrup with a density of approximately 20° Baumé) application, diastase and invertase must be added and stirred in at about 71.1 and 60°C respectively. Higher temperatures inhibit enzyme activity. After standing for 8 to 12 hours, the clear portion of the semi-syrup is drawn off into an evaporator. Enzyme treatment at the semi-syrup stage is beneficial because at this temperature starch granules swell, rupture, and become gelatinized (28). Diastase digests geletinized starch into glucose and other simple sugars, thereby increasing the sugar content of the semi-syrup. Invertase not only increases the sugar content of the semi-syrup but also prevents sucrose (table or cane sugar) from crystallizing by hydrolyzing it (sucrose) to glucose and fructose. The end product of this process is a clearer, lighter, brighter, and better tasting syrup (7, 8, 28).

It would be unscholarly, however, not to point out negative results of organoleptic and other tests conducted in Oklahoma in the 1940's and 50. Syrups produced with aid of the enzymes diastase and invertase were also utilized in the tests. Results revealed that syrups produced with enzymes were slightly inferior in quality and that enzyme treatment did not prevent clabbering (16, 17). But, Byall _et al._ (8) did report that the clabbering (jellying) problem could be controlled by the use of a high-diastatic malt extract.

Heat

Heat is perhaps the most important and most widely used clarifying agent. This is because heat is required for the evaporation of water and so must be used. But application of heat to sorghum juice if unassisted by other agents is only capable of effecting a partial clarification. This it does by solubilizing much of the starch component and coagulating certain proteins and other non-carbohydrate substances which form an insoluble sludge (6, 7, 11, 38, 54). Part of the sludge precipitates and part rises to the surface of the juice carrying with it suspended materials such as fiber, albumen, bits of leaves, and chlorophyll (6, 54). The sludge at the surface of the juice is removed by skimming.

Merits of heat are obvious when heat is used in conjunction with other agents. In the presence of heat, microscopic starch grains swell, rupture, and become gelatinized. The gelatinized form is readily digested by enzymes such as diastase (7, 28). Davies et al. (16) reported that syrup obtained from sorghum juice that was heated and treated with clay exhibited outstanding characteristics and had the best appearance. Furthermore, tests were conducted by adding clay slurry to sorghum juice at varying temperatures. The mixture was agitated continuously until flocculation occurred. Results showed that the nearer the juice was to boiling before clay slurry was added, the better the clarification obtained (17). Therefore, the importance of heat in the clarification of sweet sorghum juice is evident.

There are two major disadvantages of the use of heat as a clarifying agent: 1) the process is very time consuming and 2) color of syrup produced is marred as a result of caramelization of sugar (28, 46, 54). The caramelization problem can be ameliorated, however, by judicious use of the heat.

Other Procedures

In addition to the procedures and agents discussed above, other methods for clarifying sorghum juice have been reported in the literature. They include the use of phosphoric acid compounds, decolorizing carbon, and sulphur dioxide (6, 7, 19, 23, 46). It should be noted that little success was achieved with these methods.

CHAPTER III

PROCEDURE

Equipment and Materials

Sorghum Juice

Sorghum juice utilized in this study was procured from three different sources. Source A was located near Jefferson City, Tennessee. Juice from this source was refrigerated at about 7.2°C for approximately 12 hours before procurement for this study. This juice was used for juice batches 1, 2, and 3. Source B was a farm near Dandridge, Tennessee. The juice was not refrigerated. Source B juice was used for juice batches 4 and 8. Source C represented juice extracted in the departmental food engineering laboratory. Stalks were obtained at the Plateau Experimental Station at Crossville, Tennessee. The stalks were cut and held for about a week before the juice was expressed. This juice was used immediately after expression for juice batches 5, 6, and 7. It should be noted that juice from Sources A and B was used within 2 hours of acquisition.

Jars and Vials

Test containers used were 17 liter capacity autoclavable jar baths. Each jar was 31 cm high, had an outside diameter of 31 cm and a wall thickness of 3 mm. Sampling vials used were 75 ml conventional polyethylene vials with friction-fit snap closures. The vials were

10.5 cm high with an outside diameter of 3.5 cm. The jars and vials were purchased from Fisher Scientific Company.

Heaters and Thermometers

Immersion heaters with coiled heat elements were used. The coiled heat element was 33 cm in diameter. Each heater was 35.6 cm tall, had a power output of 1500 watts, and operated on 115 Vac. All thermometers used were standard laboratory thermometers. All met SAMA's (Scientific Apparatus Makers Association) specifications. Each thermometer was 30.5 cm long and had double scales. The temperature range was -20° to 110° and 0° to 230° for the Celsius and Fahrenheit scales respectively.

Pump and Tubing

A 1983 model ten-channel drive peristaltic pump was used in the experiment. The pump was rated at 115 Vac and 50/60 Hz. It was equipped with Masterflex standard pump heads (Cat. #7016-20), each with a variable capacity of 8.3 to 167 ml/min.

Masterflex standard silicone tubing (Cat. #K-6411-02) was used with the pump. The tubing measured 0.318 and 0.638 cm in inside and outside diameters respectively. Both the pump and silicone tubing were purchased from Cole Palmer Instrument Company.

Miscellaneous Items

Other equipment and materials used in the experiment were clamps, laboratory stands, labels, and glass tubes. The tubes were fabricated in The University of Tennessee Chemistry Department glass shop. They were 0.018 cm thick and measured 0.318 cm in outside diameter. A total of eight glass tubes were used. Four of these tubes were 32 cm long and the other four 11 cm. Each tube was slightly bent at one end to form an L-shape. The labels were self adhesive and came in a dispenser box. They were purchased from Fisher Scientific Company. Laboratory stands and clamps used were available in Agricultural Engineering laboratories.

The Agricultural Engineering Department of The University of Tennessee, Knoxville, is equipped with standard laboratory appliances such as balances, ovens, and vacuum evaporators. These and other equipment in the department were used for laboratory analysis of the treated sorghum juice.

Experimental Design

In order to measure the effects of temperature and time on clarification of sweet sorghum juice, four jars each containing 7.6 liters (2 gallons) of juice and identified as "A" through "D" were used for each replication of the experiment. Jar A was used as the control, so it was allowed to remain at the ambient temperature of approximately 26.7°C. Jar B was heated to 46.1°C, jar C to 65.6°C, and jar D to 85°C.

At the beginning of each test (time = 0 minutes) when all the jars and their contents were at ambient temperature, a juice sample was withdrawn from each jar and stored in the vials. The samples were withdrawn by dipping a 150 ml beaker into the jars. Because the juice had just been poured into the jars and thus did not have enough time to settle out any impurities, the withdrawn samples were assumed to represent samples from the middle sections of the jars at that time (t = 0 minutes). Temperatures of jars B, C, and D were then raised and held at 46.1, 65.6, and 85°C respectively, using the immersion heaters. It took about 17, 25, and 38 minutes, respectively, to reach the required temperatures for jars B, C, and D.

With aid of the glass tubes and silicone tubing, the peristaltic pump was used to subsequently withdraw juice samples from the middle and bottom portions of each jar at 30-, 60-, and 90-minute intervals. Figure 4 shows connection of the glass and silicone tubes. A hand-held 150 ml beaker was used to withdraw juice sample from the top portion of each jar at the specified time intervals. The withdrawn samples were immediately frozen to prevent changes in their properties. These samples were later analyzed for pH, total soluble solids, total solids, and total ash content.

The experimental set-up shown in Figure 5 was used for each test as described above. The test was replicated eight times.

Analyses of Treated Juice

The following analyses were made on the samples of juice withdrawn. These analyses permitted the evaluation of effects of temperature and time on clarification of the juice.

1. Acidity (pH): The pH of each sample was measured with a Sargent pH meter, model LS-30005-10. The method of measurement used was the one described in the manufacturer's instruction manual (20). However, pH measurement techniques discussed in standard methods for the examination of water

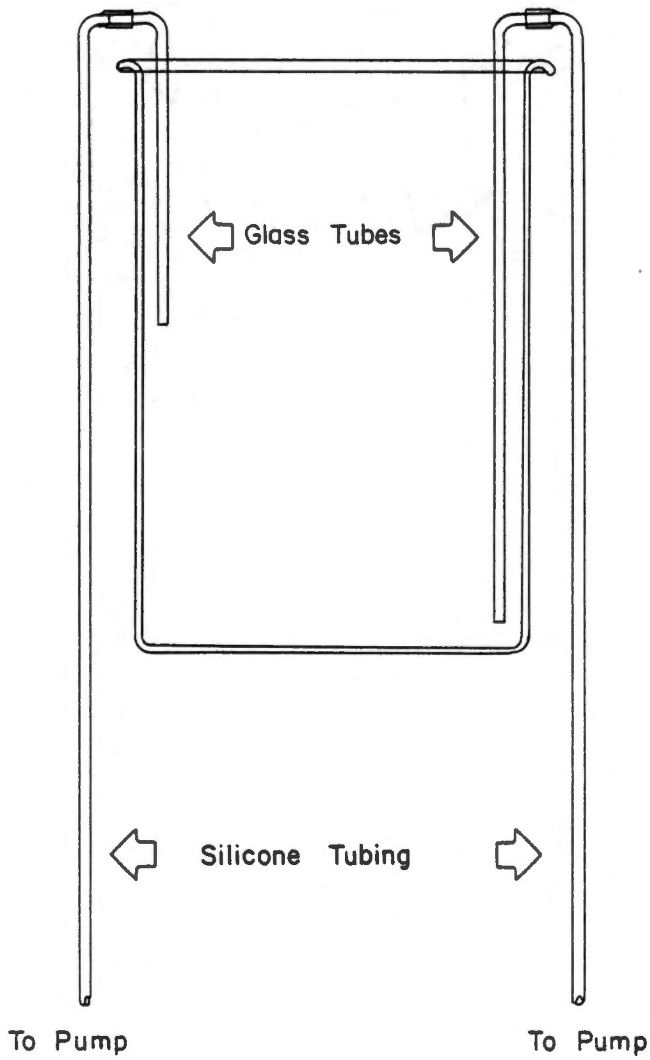

Figure 4

Sketch Showing the Connection of the Glass Tubes and Silicone Tubing

This arrangement made it possible to simultaneously withdraw juice samples from the middle and bottom portions of the jars.

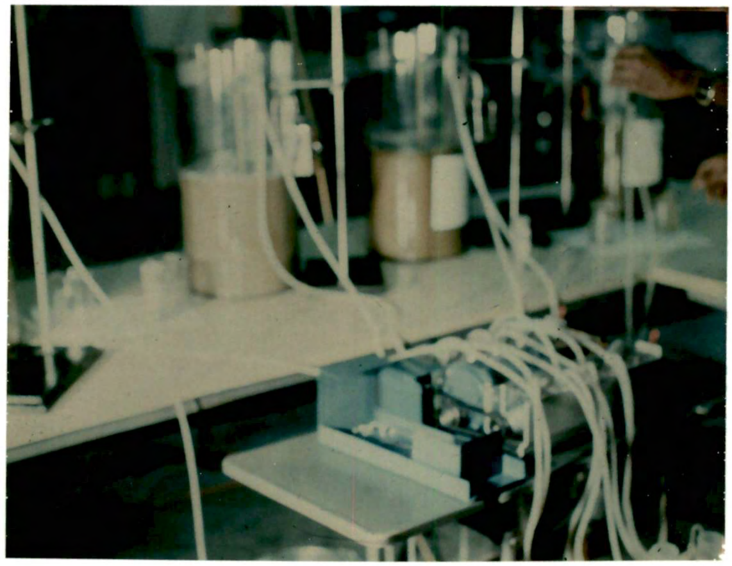

Figure 5

A Typical Experimental Set-Up Used for Each
Replication of the Tests

and waste-water (24) were consulted for background information.

2. Percent total soluble solids (PTSS): An Abbe-56 refractometer was used to measure the percentage of soluble solids. The reading from this instrument in degrees brix is a measure of all soluble substances present in the juice sample. This measurement is an indication of percent total soluble solids. The method followed was that described in the manufacturer's reference manual (3).

3. Percent total ash (PTA): The ash content of each juice sample was determined by Method I of the official final action test (2). This method was for ash analysis of molasses. However, olive oil was not used because the samples did not foam or swell. The percent total ash was computed by the equation:

$$PTA = \frac{\text{weight of ashed sample}}{\text{weight of wet sample}} \times 100$$

4. Percent total solids (PTS): Measurements for the calculations of the PTS were obtained by the method of drying quartz sand (2). This method is applicable to molasses and was described in the 13th edition of A.O.A.C. (2). Percent total solids was calculated by the equation:

$$PTS = \frac{\text{weight of dry sample}}{\text{weight of wet sample}} \times 100$$

Determination of Clarity

Since much of the impurities in the treated juice went to the top and bottom portions of the jars, clarity was determined at the middle section. The degree of clarification obtained is the change in total suspended solids. This was done by subtracting the latter total suspended solids (say at time = 30-, 60-, or 90-minutes) from the initial (time = 0 minutes) total suspended solids. Hence the clarification obtained in the middle section of the jar after 30 minutes of heat treatment is given by initial percent total suspended solids - percent total suspended solids at the 30-minute interval. The larger this difference is, the smaller the amount of total suspended solids in the middle portion of the jar and hence the better the clarification. If this difference is negative, it means there are more suspended solids at the latter time than at the beginning of the experiment.

Changes in percent total solids were also obtained by the same logic, and subjective tests that involved looking through the samples under natural light were also conducted.

Statistical Methods

As shown in Figure 6, the experiment for determining the influence of temperature and time on clarification of sweet sorghum juice was a split-split plot design. The block, whole plot, subplot, and sub-subplot were represented by juice batch, temperature, location, and time, respectively. Data collected were analyzed by analysis of

Juice Batch[1]												
Temperature (°C)[2]	26.7			46.1			65.6			85		
Location[3]	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
Time (Mins.)[4]												
0		X			X			X			X	
30	X	X	X	X	X	X	X	X	X	X	X	X
60	X	X	X	X	X	X	X	X	X	X	X	X
90	X	X	X	X	X	X	X	X	X	X	X	X

Figure 6

Statistical Design

Each X represents a withdrawn juice sample.

[1]Juice Batch = block; total of eight levels.

[2]Temperature - whole plot; total of four levels/juice batch.

[3]Location - subplot; total of three levels/temperature.

[4]Time = sub-subplot; total of four levels/location.

variance using the GLM (General Linear Model) procedure of SAS (Statistical Analysis System) package (49, 50).

The significance among means was determined by Duncan's multiple range test (49, 50, 51, 52).

CHAPTER IV

EXPERIMENTAL RESULTS

Preliminary Analysis

Table 2 shows the results of the preliminary analysis. This analysis revealed that temperature, location, and time significantly affected PTSS and PTS. Temperature also made a significant difference on PTA. Interactions of temperature and location, and time and location significantly affected PTSS and PTS. Also, the interaction of temperature and time affected pH and PTA. Juice batch made a significant difference on all the measured parameters, while the interaction of temperature, location, and time only significantly affected PTSS.

Detailed Analysis

Based on information obtained from the preliminary analysis, the decision was made to investigate the effects of the independent variables and their interactions on pH, PTSS, PTA, and PTS. The results of this investigation are presented.

Acidity (pH)

Tables 3, A-1, A-2, and A-3 show the effects of the independent variables and their interactions on pH. Table 3 shows the differences among pH means. At 5% level of probability, time and location did not have a significant effect on pH means. Source and temperature had limited influence while juice batch made significant differences.

Table 2

Preliminary Analysis of the Properties of the Treated Juice Samples

Source	DF	Mean Squares pH	PTSS	PTA	PTS
Juice Batch	7	0.398**	46.628**	0.348**	85.238**
Temperature	3	0.007	8.863**	0.244**	9.385**
Error[A] (Juice Batch * Temperature)	21	0.006	0.721	0.044	1.988
Location	2	0.000	8.307**	0.001	24.156**
Temperature * Location	6	0.001	3.737**	0.027	4.881**
Error[B] (Juice Batch * Location + Juice Batch * Temperature * Location)	56	0.001	0.699	0.027	1.477
Time	3	0.002	1.246*	0.038	3.791*
Temperature * Time	9	0.003*	0.531	0.117**	2.191
Location * Time	6	0.002	1.190**	0.002	3.321*
Temperature * Location * Time	18	0.001	0.643*	0.021	1.310
Error[C] (Juice Batch * Time + Juice Batch * Temperature * Time + Juice Batch * Location * Time + Juice Batch * Temperature * Location * Time)	256 (244-Corrected)	0.002	0.391	0.047	1.477

*Significant at 5% level of probability.

**Significant at 1% level of probability.

Table 3

Differences Among Acidity (pH) Means of the Treated Juice Samples

Variable		Means*	Duncan Grouping**
Source:	A	5.2144	a
	C	5.2072	a
	B	5.0299	b
Juice Batch:	1	5.2479	a
	6	5.2294	b
	3	5.2147	b,c
	5	5.2015	c,d
	7	5.1908	d,e
	2	5.1806	e
	8	5.0860	f
	4	4.9737	g
Temperature (°C):	65.6	5.1711	a
	85	5.1707	a
	46.1	5.1648	a
	26.7	5.1516	b
Location:	Top	5.1666	a
	Middle	5.1638	a
	Bottom	5.1632	a
Time (Mins):	90	5.1690	a
	60	5.1650	a
	30	5.1622	a
	0	5.1622	a

*The mean for each variable is arranged in descending order of magnitude.

**For each variable, means with the same letter are not significantly different at 5% level of probability.

Table A-1 shows the effects of the independent variables on pH by temperature. Juice batch significantly affected pH at all levels of temperature. At the temperatures of 46.1°C and 85°C time had a significant influence.

Tables A-2 and A-3 show the effect of the independent variables on pH by time and location respectively. Temperature made a significant difference on pH at 30 and 60 mins. At 30 mins, location at the quadratic level and the interaction of temperature and location affected pH significantly. Juice batch affected pH significantly at all times. At the top, middle, and bottom locations (Table A-3), juice batch significantly affected pH. Time and temperature did not have any impact. However, the interaction of time and temperature (at the linear and quadratic levels respectively) significantly affected pH at the middle portion of the jars.

Percent Total Soluble Solids (PTSS)

Table 4 shows the impact of the independent variables on PTSS means. As shown in this table, temperature, time, and location had limited effects, while source and juice batch had pronounced effects on mean PTSS. In Table B-1 the effects of the variables on PTSS by temperature are shown. At the temperatures of 65.6°C and 85°C, location, time, and the interaction of location and time affected percent total soluble solids (PTSS) significantly. At temperature of 46.1°C interaction of location and time (at the linear and quadratic levels, respectively) made a significant difference on PTSS. Juice batch affected PTSS at all four levels of temperature. As shown in

Table 4

Differences Among Percent Total Soluble Solids (PTSS) Means of the Treated Juice Samples

Variable		Means*	Duncan Grouping**
Source:	B	15.852	a
	C	14.769	b
	A	13.712	c
Juice Batch:	4	16.267	a
	8	15.437	b
	7	15.335	b
	6	14.558	c
	5	14.415	c
	1	14.094	d
	2	13.992	d
	3	12.917	e
Temperature (°C):	85	14.877	a
	26.7	14.796	a
	65.6	14.780	a
	46.1	14.201	b
Location:	Top	14.905	a
	Middle	14.568	b
	Bottom	14.507	b
Time (mins):	60	14.801	a
	90	14.797	a
	0	14.603	b
	30	14.464	b

*The mean for each variable is averaged in descending order of magnitude.

**For each variable, means with the same letter are not significantly different at 5% level of probability.

significantly at 30-, 60-, and 90-minute intervals. Juice batch affected PTSS at all time intervals.

Table B-3 shows the effect of the independent variables on PTSS at all locations of the jar. At the top and bottom portions of the jar, juice batch, temperature, and time affected PTSS. The interaction of temperature and time also affected PTSS at the top and bottom portions. Only juice batch affected PTSS at the middle portion of the jars.

Percent Total Ash (PTA)

Table 5 shows that location and time did not have a significant effect on PTA. Temperature and juice batch had significant impact, and source had a limited effect. In Table C-1 it is shown that at 65.6°C and 85°C, time at linear level made a significant difference on PTA. Juice batch had a significant effect on PTA at 26.7°C and 65.6°C. In Table C-2, it is shown that temperature at the linear level affected PTA at 60- and 90-minute intervals. Juice batch significantly affected PTA at 30- and 90-minute intervals.

Table C-3 shows the impact of the independent variables on PTA by location. As seen in this table, at the top portion of the jars, temperature at the linear and cubic levels significantly affected PTA. The interaction of temperature and time (at quadratic and linear levels respectively) significantly affected PTA at the top and bottom sections. At both the middle and bottom locations, temperature significantly affected PTA at the 5% level of probability.

Table 5

Differences Among Percent Total Ash (PTA) Means of the Treated Juice Samples

Variable		Means*	Duncan Grouping**
Source:	C	0.67001	a
	B	0.55413	b
	A	0.51906	b
Juice Batch:	5	0.76391	a
	7	0.63830	b
	6	0.60782	b,c
	8	0.56978	b,c
	4	0.53849	c
	3	0.52894	c
	1	0.51802	c
	2	0.51186	c
Temperature (°C):	65.6	0.65259	a
	85	0.60419	a,b
	26.7	0.55449	b,c
	46.1	0.53204	c
Location:	Bottom	0.59401	a
	Middle	0.58458	a
	Top	0.57940	a
Time (mins):	0	0.60243	a
	30	0.59593	a
	90	0.58338	a
	60	0.56040	a

*The mean for each variable is arranged in descending order of magnitude.

**For each variable, means with the same letter are not significantly different at 5% level probability.

Percent Total Solids (PTS)

Differences among PTS means is shown in Table 6. Temperature, time and location initiated little difference among PTS means. However, source and juice batch made significant differences on PTS means. Table D-1 shows the effects of the independent variables on PTS by temperature. At 46.1°C, 65.6°C, and 85°C, location made significant differences on PTS. Time had significant impact on PTS at 26.7°C and 85°C. Juice batch made significant differences at all levels of temperature while the influence of the interaction of location and time was limited to 65.6°C and 85°C.

In Table D-2, it is shown that juice batch, location, and the interaction of temperature and location at the linear levels made significant differences on PTS at 30- and 90-minute intervals. At 60-minute interval, juice batch and location also made a significant difference. At 0-minute interval, only juice batch affected PTS significantly. In Table D-3, it is shown that at the middle and bottom portions of the jars, juice batch, time, and the interaction of temperature and time made significant differences on PTS. Temperature, juice batch, and the interaction of temperature and time at the linear level affected PTS significantly at the top section of the jars.

Clarification Obtained

The clarification obtained in this study is shown in Table 7. Temperature at the quadratic and cubic levels significantly affected clarification of the juice at the 10% level of probability after 30

Table 6

Differences Among Percent Total Solids (PTS) Means of the Treated Juice Samples

Variable		Means*	Duncan Grouping**
Source:	B	17.248	a
	C	15.393	b
	A	14.505	c
Juice Batch:	4	17.682	a
	8	16.814	b
	7	16.397	b
	6	15.280	c
	1	15.236	c
	2	14.599	d
	5	14.503	d
	3	13.516	e
Temperature (°F):	185	15.799	a
	150	15.699	a
	80	15.605	a
	115	15.080	b
Location:	Top	15.981	a
	Middle	15.359	b
	Bottom	15.280	b
Time (mins):	90	15.730	a
	30	15.608	a,b
	0	15.539	a,b
	60	15.303	b

*The mean for each variable is arranged in descending order of magnitude.

**For each variable, means with the same letter are not significantly different at the 5% level of probability.

Table 7

Clarification Obtained at the Middle Section of the Jars as Affected by Temperature

		Mean Squares		
Variable	DF	Clarification after 30 minutes	Clarification after 60 minutes	Clarification after 90 minutes
Juice Batch	7	1.313	3.935	2.833
Temperature (°C)	3	2.903*	0.302	1.664
Tem	1	2.535	0.828	0.096
Tem * Tem	1	2.977*	0.055	1.805
Tem * Tem * Tem		3.198*	0.022	3.091

*Barely significant at the 10% level of probability.

minutes of heat treatment. At the 60- and 90-minute interval, the effect of temperature on clarity was not significantly different.

Effects of temperature by time on changes in percent total solids (PTS) is shown on Table 8. After 30 minutes of heat treatment, the change in PTS was significantly affected by temperatures. However, temperature did not have any significant effect on changes in PTS at the 60- and 90-minute intervals.

Figure 7 shows a typical top and bottom portion of the jars at the end of an experiment. The diagrams illustrate the concentration of impurities at these sections. It can be seen that jars B and C which were at 46.1°C and 65.6°C, respectively, had the greatest amount of precipitation. On the other hand, jars A and D which were at 26.7°C and 85°C, respectively, contained little precipitates at the end of a test. It should be stated that a noticeable amount of precipitation was observed at the bottom section of jar D during the experiment. However, the precipitate was gradually reduced to a barely noticeable amount at the end of the experiment.

Figure 8 shows color formation in the treated juice. The change in color at the end of the experiment was more dramatic in jars B and C. The juice in these jars appeared brownish at the end of each experiment. The juice in jars A and D appeared green at the end of the experiments. The greenish color was more pronounced in jar A than in jar D.

Table 8

Changes in Percent Total Solids of the Treated Juice as Affected by Temperature

Variable	DF	Mean Squares: Clarification after 30 minutes	Mean Squares: Clarification after 60 minutes	Mean Squares: Clarification after 90 minutes
Juice Batch	7	1.090	2.113	1.769
Temperature (°C)	3	3.265**	1.314	0.827
Tem		6.061*	3.252	0.219
Tem * Tem		2.398	0.287	0.405
Tem * Tem * Tem		1.336	0.403	1.857

*Significant at 5% level of probability.

**Significant at the 10% level of probability.

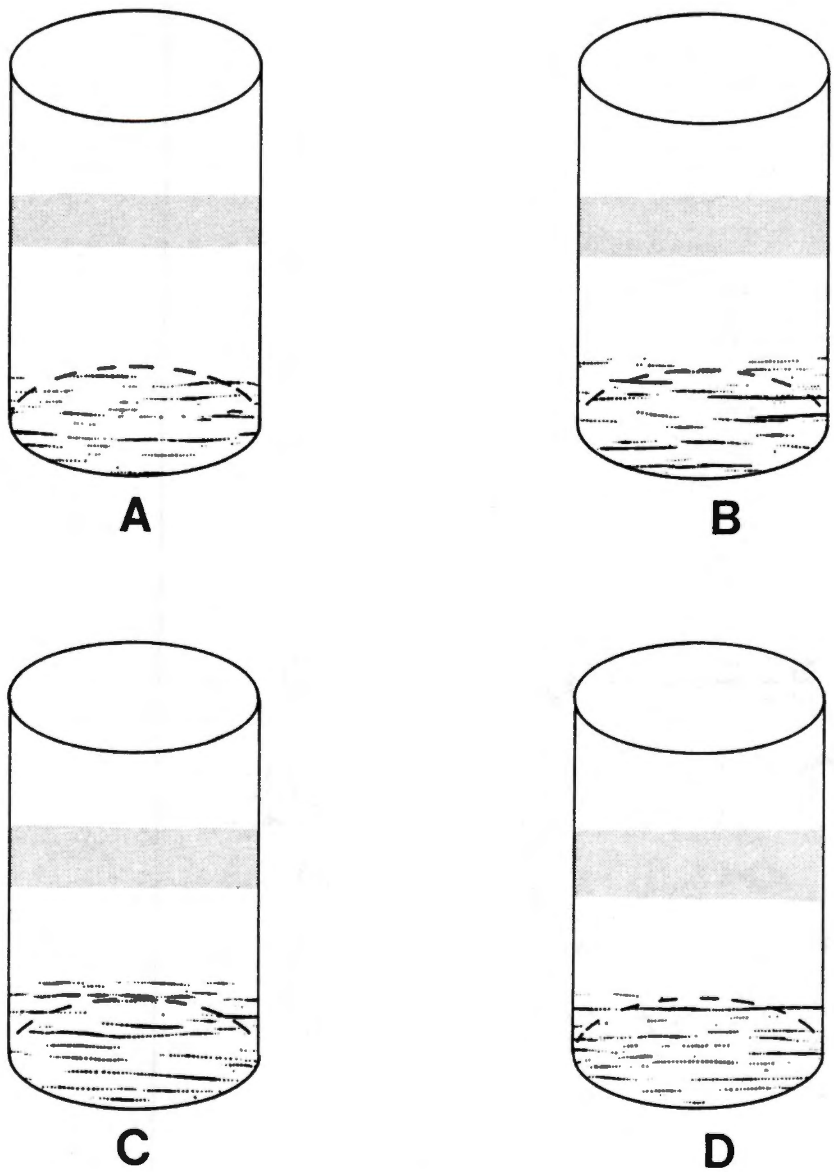

Figure 7

Diagrams Showing Relative Concentration of Impurities at the Top and Bottom Sections of the Jars

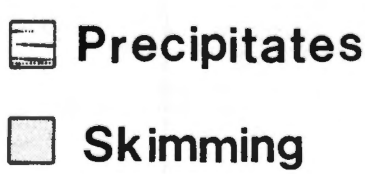

Figure 8

Color Formation in the Treated Sweet Sorghum Juice

From right to left jars A, B, C, and D.

Graphical Solution

Equations used to plot the 3-dimensional graph and contour maps of the dependent variables were generated using the GLM (general linear model) statistical procedure. First treatments with non-significant effects at about 20% level of probability were eliminated. This was done to correct for some mathematical uncertainties. The eliminated treatments were included in the error term and used to test those treatments that were significantly different at 20% level of probability.

When these treatments were tested by the new error term at the 5% level of probability, acidity (pH) was not significantly affected, hence, no equations were generated for it. Percent total soluble solids (PTSS), percent total ash (PTA), and percent total solids (PTS) were significantly affected at the 5% level of probability. The prediction equations generated for these parameters at three different sections of the jars are as follows:

<u>At the top section of the jars (Location 1)</u>--

Percent total soluble solids =

$$27.698 - 33.47 \times 10^{-2}\ tem + 6.5 \times 10^{-3}\ t - 11.17 \times 10^{-7}\ tem\ t + 2.62 \times 10^{-3}\ tem^2 + 1.8 \times 10^{-4}\ t^2 = 64.35 \times 10^{-7}\ tem^3 - 35.27 \times 10^{-7}\ t^3 + 79.96 \times 10^{-10}\ tem\ t^3$$

Percent total ash (PTA) =

$$0.3602 + 2.9 \times 10^{-3}\ tem + 74.13 \times 10^{-9}\ tem^2 - 21.71 \times 10^{-8}\ tem^2\ t - 48.11 \times 10^{-9}\ tem^3 + 11.06 \times 10^{-10}\ tem^3\ t + 15.6 \times 10^{-13}\ tem^3\ t^2$$

Percent total solids (PTS) =

$$30.556 - 35.59 \times 10^{-2} \text{ tem} - 1.64 \times 10^{-2} \text{ t} + 1.68 \times 10^{-4} \text{ tem t} - 75.92 \times 10^{-9} \text{ tem t}^2 + 2.69 \times 10^{-3} \text{ tem}^2 - 22.36 \times 10^{-5} \text{ t}^2 - 64.56 \times 10^{-7} \text{ tem}^3 + 24.3 \times 10^{-7} \text{ t}^3$$

At the middle portion of the jars (Location 2)--

Percent total soluble solids (PTSS) =

$$29.6426 - 36.42 \times 10^{-2} \text{ tem} - 10.44 \times 10^{-3} \text{ t} - 11.2 \times 10^{-7} \text{ tem t} + 26.92 \times 10^{-4} \text{ tem}^2 + 36.8 \times 10^{-5} \text{ t}^2 - 64.35 \times 10^{-7} \text{ tem}^3 - 35.27 \times 10^{-7} \text{ t}^3 + 79.96 \times 10^{-10} \text{ tem t}^3$$

Percent total ash (PTA) =

$$0.3602 + 2.91 \times 10^{-3} \text{ tem} + 14.83 \times 10^{-8} \text{ tem}^2 - 21.71 \times 10^{-8} \text{ tem}^2 \text{ t} - 48.11 \times 10^{-9} \text{ tem}^3 + 1.11 \times 10^{-9} \text{ tem}^3 \text{ t} + 1.56 \times 10^{-12} \text{ tem}^3 \text{ t}^2$$

Percent total solids (PTS) =

$$30.738 - 36.15 \times 10^{-2} \text{ tem} - 3.28 \times 10^{-2} \text{ t} + 1.69 \times 10^{-4} \text{ tem t} + 2.69 \times 10^{-3} \text{ tem}^2 - 1.8 \times 10^{-4} \text{ t}^2 - 75.92 \times 10^{-9} \text{ tem t}^2 - 64.56 \times 10^{-7} \text{ tem}^3 + 24.3 \times 10^{-7} \text{ t}^3$$

At the bottom section of the jars (Location 3)--

Percent total soluble solids (PTSS) =

$$31.584 - 30.07 \times 10^{-2} \text{ tem} - 2.75 \times 10^{-2} \text{ t} - 1.12 \times 10^{-6} \text{ tem t} + 2.77 \times 10^{-3} \text{ tem}^2 + 5.52 \times 10^{-4} \text{ t}^2 - 6.43 \times 10^{-6} \text{ tem}^3 - 3.53 \times 10^{-6} \text{ t}^3 + 79.96 \times 10^{-10} \text{ tem t}^3$$

Percent total ash (PTA) =

$$0.3602 + 2.9 \times 10^{-3} \text{ tem} + 2.22 \times 10^{-7} \text{ tem}^2 - 21.71 \times 10^{-8} \text{ tem}^2 \text{ t} - 4.81 \times 10^{-8} \text{ tem}^3 + 1.11 \times 10^{-9} \text{ tem}^3 \text{ t} + 1.56 \times 10^{-12} \text{ tem}^3 \text{ t}^2$$

Percent total solids (PTS) =

$$30.920 - 36.71 \times 10^{-2} \text{ tem} - 4.93 \times 10^{-2} + 16.88 \times 10^{-5} \text{ tem t} + 26.94 \times 10^{-4} t^2 - 13.68 \times 10^{-5} t^2 - 75.92 \times 10^{-9} \text{ tem } t^2 - 64.57 \times 10^{-7} \text{ tem}^3 + 2.43 \times 10^{-6} t^3$$

For all the equations, tem and t represent temperature (°C) and time (minutes) respectively. The 3-dimensional graph and contour maps plotted with these equations are presented in Figures B-1 to B-6 and D-1 to D-6 in the Appendix.

CHAPTER V

DISCUSSION AND RECOMMENDATIONS

Discussion

The differences in the amount of precipitation might be attributed to temperature and time. The contention is that at 46.1°C and 65.6°C respectively, jars B and C had just enough heat to initiate the coagulation of colloidal and other substances in the juice. Part of the coagulated material settled to the bottom of the jars and part rose to the top as skimmings. Since the heat input for these jars was too low to start vigorous boiling, much of the sediment remained precipitated. In jar D, the initial effect of heat was the same as in jars B and C. However, the heat input necessary to maintain a temperature of 85°C was high enough to encourage localized boiling. This boiling activity in time generated turbulent convection currents which destabilized the sediments, sending them back into suspension. This explains the later disappearance of precipitates at the bottom section of jar D. In the case of jar A, the control temperature of 26.7°C was simply too low to initiate a marked coagulation and subsequent sedimentation of substances in the juice. Thus, the small amount of precipitation obtained was that which resulted only from gravitational force. All the jars had sizeable concentrations of substances at the top section. The amount of skimmings as observed during the experiment increased with temperature and time.

The variable that affected most of the parameters measured was juice batch. This is not very surprising. The juice batches were acquired from three different sources at different times on different days, and some of the batches were refrigerated prior to acquisition while others were not. Also, the processors could have handled the juice differently for different batches. The handling of the juice (a factor that can affect the measured parameters and even clarity) was outside the control of this experiment.

The clarity obtained at the middle section of the jars is shown in Table 7, p. 41. We see that temperature at the quadratic and cubic levels slightly affected the degree of clarification obtained after 30 minutes of heat treatment at the 10% level of probability. However, at the 60- and 90-minute intervals, differences in clarity among temperature levels were not significant. This means that temperature affected clarification process within 30 minutes of heat treatment. After this 30-minute period (i.e., when most of the impurities are coagulated and precipitated or sent to the surface as skimmings), the clarification process is no longer time dependent. In jars B, C, and D, this must have been caused by the convection currents which with time destabilized some of the precipitates and sent them back into suspension. For jar A (the control unit), since heat was not added, there was no convection current generated. The suspended solids then continued to settle under gravitational influence but did not settle out enough to make a significant difference at the 60- and 90-minute intervals.

This logic applies to the change in total solids. The data are presented in Table 8, p. 43.

Table 9 shows a summary of the range and means of all variables by location. The mean total solids at the bottom section of the jars was slightly lower than the mean total solids at the middle section; 15.28% vs. 15.36%, respectively. These data suggest that there were more total solids (or impurities) at the middle portion of the jars than at the bottom. However, this suggestion is physically impossible as Figure 7 , p. 44, has indicated. The contradiction might have been caused by measurement errors.

Figure 8 shows color formation in the treated juice. The change in color can be attributed to temperature and time. It is possible that the coagulation and subsequent sedimentation of green coloring matter (chlorophyll) along with other substances in jars B and C are responsible for the brownish color. In jar A, the temperature was too low to initiate coagulation or sedimentation, hence the chlorophyll remained in suspension, giving the juice a characteristic green color. In jar D, the turbulent current generated by high temperature destabilized the sediments. With time, the destabilized sediments which includes coagulated chlorophyll could be reintroduced into the body of the juice in suspension form. This fact would give the juice in jar D a green color.

Also, natural enzymes in the juice such as chlorophyllase (32) could have played some part in the color formation. The 85°C temperature of jar D will denature most enzymes, thus inhibiting enzyme activity on chlorophyll. The chlorophyll if undigested or unhydrolyzed by

Table 9

Range and Mean of All Variables of the Treated Juice by Location

	Location								
	Top			Middle			Bottom		
Variable	Minimum Value	Maximum Value	Mean	Minimum Value	Maximum Value	Mean	Minimum Value	Maximum Value	Mean
Juice batch	1.00	8.00		1.00	8.00		1.00	8.00	
Temperature (°C)	26.70	85.00		26.70	85.00		26.70	85.00	
Time (minutes)	0.00	90.00		0.00	90.00		0.00	90.00	
Acidity (pH)	4.90	5.32	5.16	4.90	5.32	5.16	4.92	5.32	5.16
Total soluble solids (%)	11.50	18.90	14.90	11.50	17.10	14.57	11.50	17.10	14.50
Total ash (%)	0.46	2.21	0.57	0.43	2.21	0.58	0.44	2.21	0.59
Total solids (%)	10.14	21.53	15.98	10.26	19.00	15.36	9.98	18.27	15.27

enzymes will remain in suspension in the juice and will give the juice a green coloration. In jar A, the 26.7°C temperature may not be high enough to activate chlorophyll digesting enzymes. The chlorophyll will then remain in suspension and give the juice a green color. However, in jars B and C, the respective temperatures of 46.1°C and 65.6°C could activate some of the chlorophyll hydrolyzing enzymes. The hydrolyzation and subsequent solubilization of the chlorophyll could cause the browning of the juice in jars B and C.

Recommendations

A major problem encountered in the experiment was maintaining jars B, C, and D at the required temperatures. This was because the heaters had no thermostat controls. Also, there was much difference between the time jar B reached its optimum temperature and the time jar C and jar D reached their required temperatures. This problem was caused by the fact that all the heaters had the same "little" power output of 1500 watts. For future experiments, heating systems with thermostat control and "high" variable power output should be used. This will make it possible to quickly bring up and then maintain the temperature of each jar at the required level.

The treated juice should be cooked to the finished syrup. By monitoring the time it took to reach the finished syrup and by evaluating the quality of the syrup statistically and organoleptically, one can objectively determine what temperature and time yield the best clarification.

Also, the juice should be treated at temperatures higher than 85°C, and more research materials should be used. This practice will help establish the highest temperature of diminishing clarity. Furthermore, at time = 0 minutes, the assumption that all the dependent variables for each jar are the same at all the locations could be wrong. Therefore, for future experiments juice samples should be withdrawn from each location of the jars at the initial time (t = 0 minutes). In addition, the samples should be held for up to 30 minutes after heating is discontinued. This would permit additional settling without convective currents, and further tests with additional sorghum juice samples should be conducted to investigate whether the prediction equations generated in this study are applicable and valid.

CHAPTER VI

SUMMARY

Raw sweet sorghum juice from three different sources was heated in four different jars. The jars identified as "A" through "D" were heated at 26.7°C, 46.1°C, 65.6°C, and 85°C respectively. Jar A served as the control. At the beginning of the experiment (time = 0 minutes), a juice sample was withdrawn from each jar and stored. The temperatures of jars B, C, and D were then raised and maintained respectively at 46.1°C, 65.6°C, and 85°C. Juice samples were subsequently withdrawn from the top, middle, and bottom portions of each jar at 30-, 60-, and 90-minute intervals.

The acidity (pH), percent total soluble solids (PTSS), percent total solids (PTS), and percent total ash (PTA) content of each withdrawn juice sample were measured. The data obtained were evaluated by statistical procedure to determine if temperature and time have any effects on clarification of sweet sorghum juice. Based on the statistical analysis of this study, the following inferences can be made:

1. Temperature and time do affect the clarification of sweet sorghum juice. Physical observation of the experimental units showed that when a jar of raw sorghum juice was heated, much of the impurities was coagulated. Part of the coagulated material precipitated to the bottom and part rose to the surface thus leaving the middle portion fairly well clarified. The statistical analysis revealed that after this coagulation period (which was about 30 minutes),

the clarification process was no longer temperature dependent.

2. Temperature and time affect color formation in sweet sorghum juice.

3. The acidity (pH) of a heated sweet sorghum juice is the same at all sections of the container. However, percent total soluble solids (PTSS), percent total ash (PTA), and percent total solids (PTS) of heated sweet sorghum juice (and possibly of other heated natural juices) at the top, middle, and bottom sections of the container at a given temperature and time, where tem and t represent temperature and time respectively, can be predicted with the following equations:

At the top section (Location 1)--

Percent total soluble solids (PTSS) =

$$27.698 - 33.47 \times 10^{-2}\ tem + 6.5 \times 10^{-3}\ t - 11.17 \times 10^{-7}\ tem\ t + 2.62 \times 10^{-3}\ tem^2 + 1.8 \times 10^{-4}\ t^2 - 64.35 \times 10^{-7}\ tem^3 - 35.27 \times 10^{-7}\ t^3 + 79.96 \times 10^{-10}\ tem\ t^3$$

Percent total ash (PTA) =

$$0.3602 + 2.9 \times 10^{-3}\ tem + 74.13 \times 10^{-9}\ tem^2 - 21.71 \times 10^{-8}\ tem^2\ t - 48.11 \times 10^{-9}\ tem^3 + 11.06 \times 10^{-10}\ tem^3\ t + 15.6 \times 10^{-13}\ tem^3\ t^2$$

Percent total solids (PTS) =

$$30.556 - 35.59 \times 10^{-2}\ tem - 1.64 \times 10^{-2}\ t + 1.68 \times 10^{-4}\ tem\ t - 75.92 \times 10^{-9}\ tem\ t^2 + 2.69 \times 10^{-3}\ tem^2 - 22.36 \times 10^{-5}\ t^2 - 64.56 \times 10^{-7}\ tem^3 + 24.3 \times 10^{-7}\ t^3$$

At the middle portion of the jars (Location 2)--

Percent total soluble solids (PTSS) =

$$29.6426 - 36.42 \times 10^{-2}\ tem - 10.44 \times 10^{-3}\ t - 11.2 \times 10^{-7}\ tem\ t + 26.92 \times 10^{-4}\ tem^2 + 36.8 \times 10^{-5}\ t^2 - 64.35 \times 10^{-7}\ tem^3 - 35.27 \times 10^{-7}\ t^3 + 79.96 \times 10^{-10}\ tem\ t^3$$

Percent total ash (PTA) =

$$0.3602 + 2.91 \times 10^{-3}\ tem + 14.83 \times 10^{-8}\ tem^2 - 21.71 \times 10^{-8}\ tem^2\ t - 48.11 \times 10^{-9}\ tem^3 + 1.11 \times 10^{-9}\ tem^3\ t + 1.56 \times 10^{-12}\ tem^3\ t^2$$

Percent total solids (PTS) =

$$30.738 - 36.15 \times 10^{-2}\ tem - 3.28 \times 10^{-2}\ t + 1.69 \times 10^{-4}\ tem\ t + 2.69 \times 10^{-3}\ tem^2 - 1.8 \times 10^{-4}\ t^2 - 75.92 \times 10^{-9}\ tem\ t^2 - 64.56 \times 10^{-7}\ tem^3 + 24.3 \times 10^{-7}\ t^3$$

At the bottom section of the jars (Location 3)--

Percent total soluble solids (PTSS) =

$$31.584 - 30.07 \times 10^{-2}\ tem - 2.75 \times 10^{-2}\ t - 1.12 \times 10^{-6}\ tem\ t + 2.77 \times 10^{-3}\ tem^2 + 5.52 \times 10^{-4}\ t^2 - 6.43 \times 10^{-6}\ tem^3 - 3.53 \times 10^{-6}\ t^3 + 79.96 \times 10^{-10}\ tem\ t^3$$

Percent total ash (PTA) =

$$0.3602 + 2.9 \times 10^{-3}\ tem + 2.22 \times 10^{-7}\ tem^2 - 21.71 \times 10^{-8}\ tem^2\ t - 4.81 \times 10^{-8}\ tem^3 + 1.11 \times 10^{-9}\ tem^3\ t + 1.56 \times 10^{-12}\ tem^3\ t^2$$

Percent total solids (PTS) =

$$30.920 - 36.71 \times 10^{-2}\ tem - 4.93 \times 10^{-2}\ t + 16.88 \times 10^{-5}\ tem\ t + 26.94 \times 10^{-4}\ tem^2 - 13.68 \times 10^{-5}\ t^2 - 75.92 \times 10^{-9}\ tem\ t^2 - 64.57 \times 10^{-7}\ tem^3 + 2.43 \times 10^{-6}\ t^3$$

For all the equations, tem and t represent temperature (°C) and time (minutes) respectively. The 3-dimensional graph and contour maps plotted with these equations are presented in Figures B-1 through D-6 in the Appendix.

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APPENDIXES

APPENDIX A

Table A-1

Influence of Juice Batch, Location, Time, and the Interaction of Location and Time on Acidity (pH) of Treated Juice Samples by Temperature

Source	DF	Mean Squares 26.7°C	46.1°C	65.6°C	85°C
Juice Batch	7	0.112**	0.106**	0.101**	0.094**
Location	2	0.000	0.001	0.000	0.000
Loc	1	0.001	0.001	0.000	0.000
Loc * Loc	1	0.000	0.002	0.000	0.000
Time	3	0.002	0.004*	0.000	0.003*
T	1	0.005	0.006*	0.002	0.010**
T * T	1	0.000	0.004	0.000	0.000
T * T * T	1	0.000	0.000	0.000	0.000
Location * Time	6	0.001	0.000	0.001	0.000
Loc * T	1	0.000	0.000	0.000	0.000
Loc * Loc * T	1	0.000	0.000	0.003	0.000
Loc * T * T	1	0.001	0.001	0.000	0.001
Loc * Loc * T * T	1	0.000	0.003	0.004	0.000
Loc * T * T * T	1	0.006	0.000	0.002	0.000
Loc * Loc * T * T* T	1	0.000	0.000	0.001	0.000

*Significant at 5% level of probability.

**Significant at 1% level of probability.

Table A-2

Influence of Juice Batch, Temperature, Location, and the Interaction of Temperature and Location on Acidity (pH) of Treated Juice Samples by Time

Source	DF	Mean Squares 0 mins	30 mins	60 mins	90 mins
Juice Batch	7	0.091**	0.086**	0.113**	0.117**
Temperature	3	0.007	0.002	0.005	0.002
Tem	1	0.000	0.004*	0.012*	0.006
Tem * Tem	1	0.014	0.001	0.000	0.001
Tem * Tem * Tem	1	0.006	0.000	0.001	0.000
Location	2	---	0.002	0.000	0.000
Loc	1	---	0.000	0.001	0.000
Loc * Loc	1	---	0.005*	0.000	0.001
Temperature * Location	6	---	0.002*	0.001	0.000
Tem * Loc	1	---	0.006*	0.000	0.000
Tem * Tem * Loc	1	---	0.000	0.000	0.000
Tem * Tem * Tem * Loc	1	---	0.007*	0.000	0.000
Tem * Loc * Loc	1	---	0.000	0.001	0.000
Tem * Tem * Loc * Loc	1	---	0.002	0.001	0.001
Tem * Tem * Tem * Loc * Loc	1	---	0.000	0.003	0.001

*Significant at 5% level of probability.

**Significant at 1% level of probability.

Table A-3

Influence of Juice Batch, Temperature, Time, and Interaction of Temperature and Time on Acidity (pH) of Treated Juice Samples by Location

Source	DF	Mean Squares Top (1)	Middle (2)	Bottom (3)
Juice Batch	7	0.13091**	0.13333**	0.13555**
Temperature	3	0.00208	0.00173	0.00468
Tem	1	0.00410	0.00366	0.01344
Tem * Tem	1	0.00165	0.00028	0.00320
Tem * Tem * Tem	1	0.00049	0.00124	0.00365
Time	3	0.00062	0.00337	0.00095
T	1	0.00064	0.00512	0.00068
T * T	1	0.00000	0.00416	0.00103
T * T * T	1	0.00121	0.00083	0.00115
Temperature * Time	9	0.00194	0.00159	0.00161
Tem * T	1	0.00195	0.00102	0.00006
Tem * Tem * T	1	0.00431	0.00159	0.00663
Tem * Tem * Tem * T	1	0.00045	0.00586*	0.00141
Tem * T * T	1	0.00003	0.00000	0.00457
Tem * Tem * T * T	1	0.00000	0.00394	0.00079
Tem * Tem * Tem * T * T	1	0.00361	0.00141	0.00004
Tem * T * T * T	1	0.00228	0.00000	0.00073
Tem * Tem * T * T * T	1	0.00028	0.00012	0.00000
Tem * Tem * Tem * T * T * T	1	0.00451	0.00037	0.00026

*Significant at 5% level of probability.

**Significant at 1% level of probability.

APPENDIX B

Table B-1

Influence of Juice Batch, Location, Time, and the Interaction of Location and Time on PTSS of Treated Juice Samples by Temperature

Source	DF	Mean Squares 26.7°C	46.1°C	65.6°C	85°C
Juice Batch	7	12.92660**	8.24590**	15.10557**	12.51586**
Location	2	1.41171	2.12663	6.19837**	9.78313**
Loc	1	1.55273	3.91023	11.46910**	15.84314**
Loc * Loc	1	1.22543	0.21108	1.03196	4.06142*
Time	3	0.48881	0.60326	0.45696	1.29070**
T	1	0.00701	0.14201	0.98201	3.56788**
T * T	1	0.00164	0.00075	0.30935	0.54783
T * T * T	1	1.45262	1.81253	0.07331	0.00091
Location * Time	6	0.27746	0.64953	0.93757**	1.25539**
Loc * T	1	0.43640	0.03740	1.00512*	3.18323**
Loc * Loc * T	1	0.25954	0.16797	0.34142	0.41301
Loc * T * T	1	0.02662	2.80004*	4.17669**	0.99987
Loc * Loc * T * T	1	0.00118	0.11208	0.05999	0.76692
Loc * T * T * T	1	0.31229	0.08770	0.02470	1.85121*
Loc * Loc * T * T * T	1	0.62874	0.69196	0.01751	0.31812

*Significant at 5% level of probability.

**Significant at 1% level of probability.

Table B-2

Influence of Juice Batch, Temperature, Location, and the Interation of Temperature and Location on PTSS of Treated Juice by Time

Source	DF	Mean Squares 0 mins	30 mins	60 mins	90 mins
Juice Batch	7	16.11522**	10.13284**	16.43971**	8.40211**
Temperature	3	1.30094	2.41594**	1.59571**	4.75515**
Tem	1	0.02269	0.89269	0.06576	6.40976**
Tem * Tem	1	1.73344	2.83594*	2.47837**	4.56794**
Tem * Tem * Tem	1	2.14669	3.51919**	2.29620**	5.41307**
Location	2	---	5.92542**	4.92928**	1.45936
Loc	1	---	11.39063	9.76621**	2.75901
Loc * Loc	1	---	0.46021	0.09236	0.15972
Temperature * Location	6	---	2.22625*	1.42033**	1.99397*
Tem * Loc	1	---	7.75013	3.46514**	9.27042**
Tem * Tem * Loc	1	---	1.75563	1.86483**	0.02280
Tem * Tem * Tem * Loc	1	---	0.23113	0.03314	0.02069
Tem * Loc * Loc	1	---	3.38437	1.81541**	2.54680
Tem * Tem * Loc * Loc	1	---	0.00187	0.33461	0.09831
Tem * Tem * Tem * Loc * Loc	1	---	0.23438	1.00884**	0.00477

*Significant at 5% level of probability.

**Significant at 1% level of probability.

Table B-3

Influence of Juice Batch, Temperature, Time, and Interaction of Temperature and Time on Treated Juice Samples by Location

Source	DF	Mean Squares		
		Top (1)	Middle (2)	Bottom (3)
Juice Batch	7	18.59370**	15.67168**	15.52705**
Temperature	3	9.18177**	2.50945	4.59795**
Tem	1	22.35025	0.95327	0.52215
Tem * Tem	1	1.16281	3.28320	8.69408**
Tem * Tem * Tem	1	4.03225*	3.29190	5.78202**
Time	3	1.50385*	0.60029	1.56946**
T	1	2.55025*	0.31952	0.01284
T * T	1	1.90125	0.51258	3.49238**
T * T * T	1	0.06006	0.96877	1.20318*
Temperature * Time	9	1.31448*	0.29175	0.23785
Tem * T	1	6.93781**	0.01015	0.00127
Tem * Tem * T	1	0.10000	0.13514	0.12128
Tem * Tem * Tem * T	1	0.19531	0.00263	0.19778
Tem * T * T	1	0.31506	0.92264	0.36180
Tem * Tem * T * T	1	0.78125	0.17258	1.36301*
Tem * Tem * Tem * T * T	1	0.00306	0.07439	0.00031
Tem * T * T * T	1	3.25125*	0.00263	0.00016
Tem * Tem * T * T * T	1	0.00156	0.22877	0.04794
Tem * Tem * Tem * T * T * T	1	0.24500	1.07678	0.04716

*Significant at 5% level of probability.

**Significant at 1% level of probability.

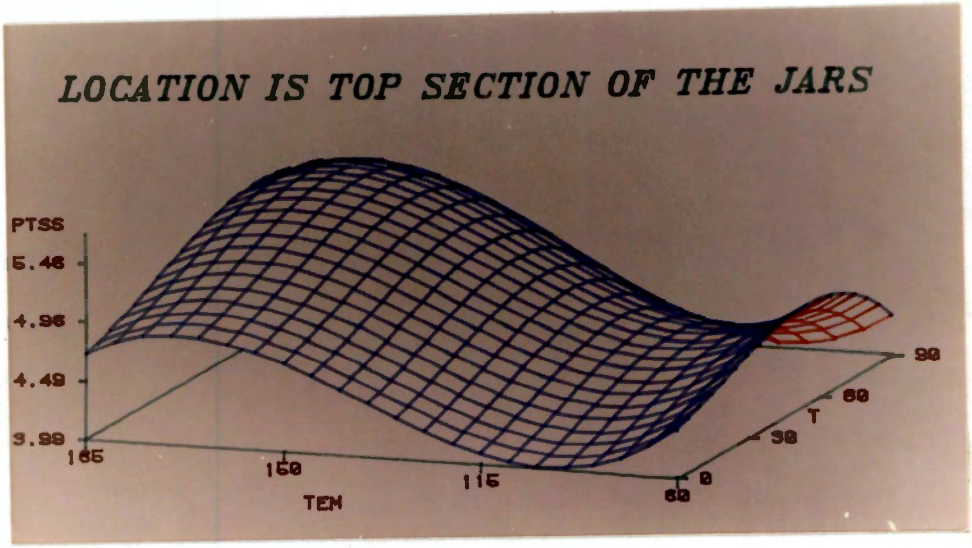

Figure B-1

3-Dimensional Graph of Percent Total Soluble Solids (PTSS), Temperature (TEM), and Time (T) at the Top Section of the Jars

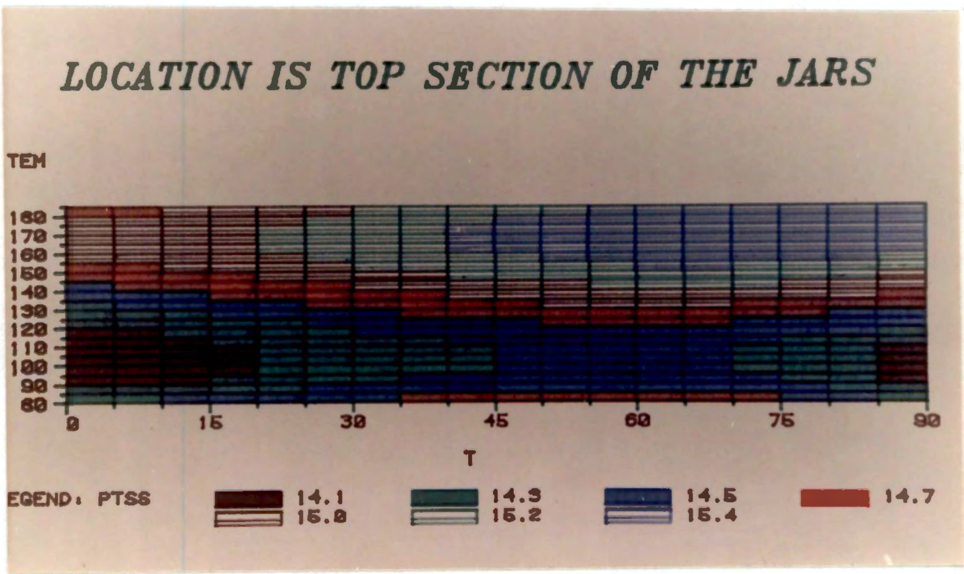

Figure B-2

Contour Map of Temperature (TEM) vs. Time (T) at the Top Section of the Jars

Contours are percent total soluble solids (PTSS).

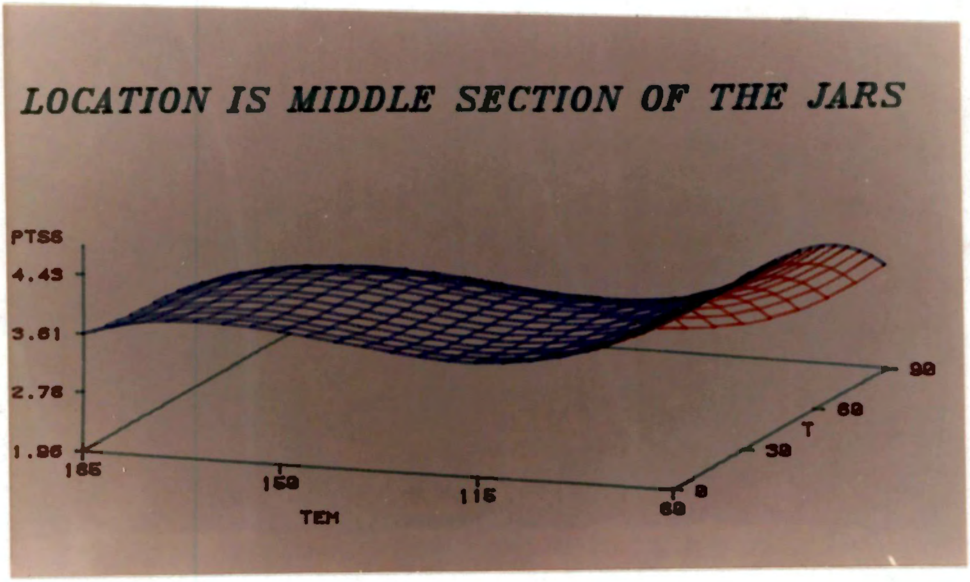

Figure B-3

3-Dimensional Graph of Percent Total Soluble Solids (PTSS), Temperature (TEM), and Time (T) at the Middle Section of the Jars

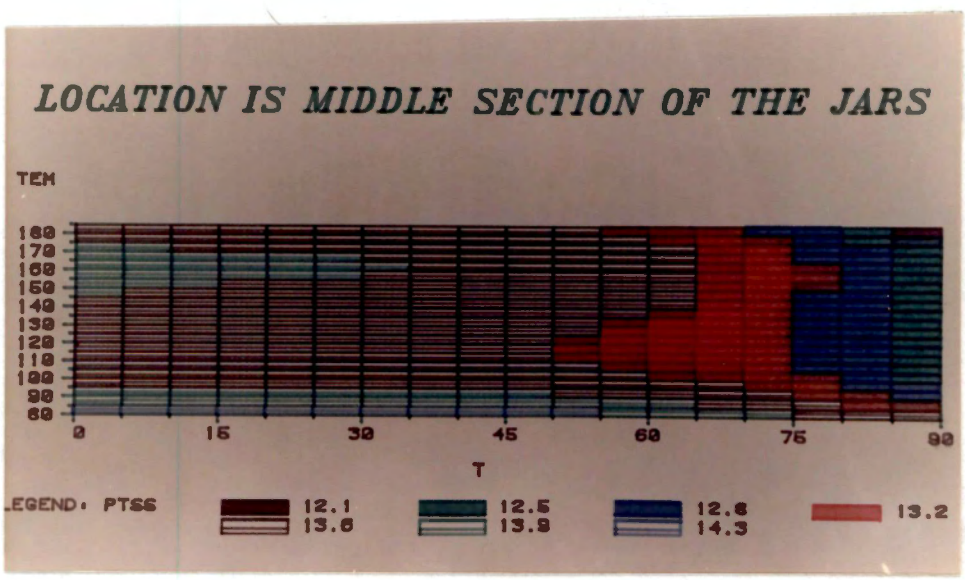

Figure B-4

Contour Map of Temperature (TEM) vs. Time (T) at the Middle Section of the Jars

Contours are percent total soluble solids (PTSS).

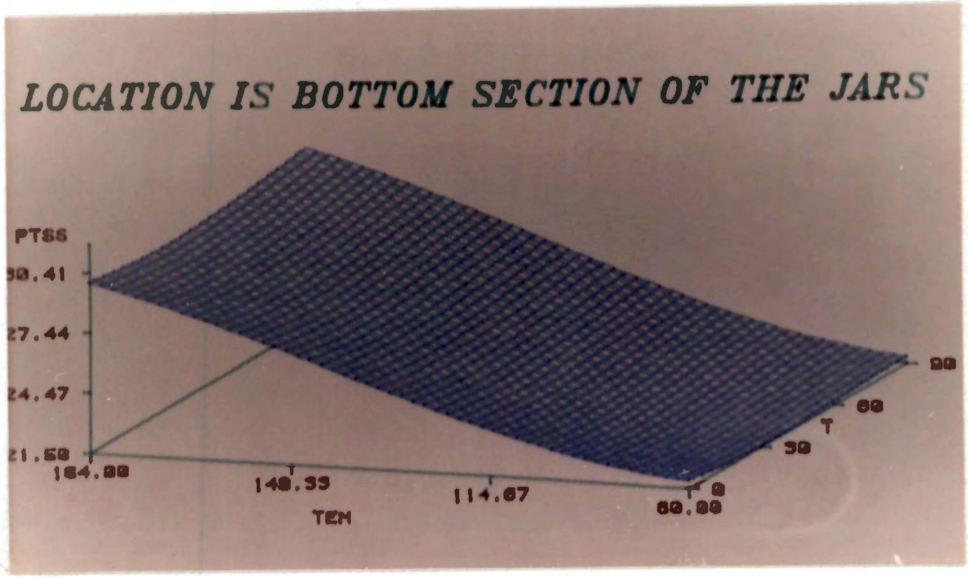

Figure B-5

3-Dimensional Graph of Percent Total Soluble Solids (PTSS),
Temperature (TEM), and Time (T) at the
Bottom Section of the Jars

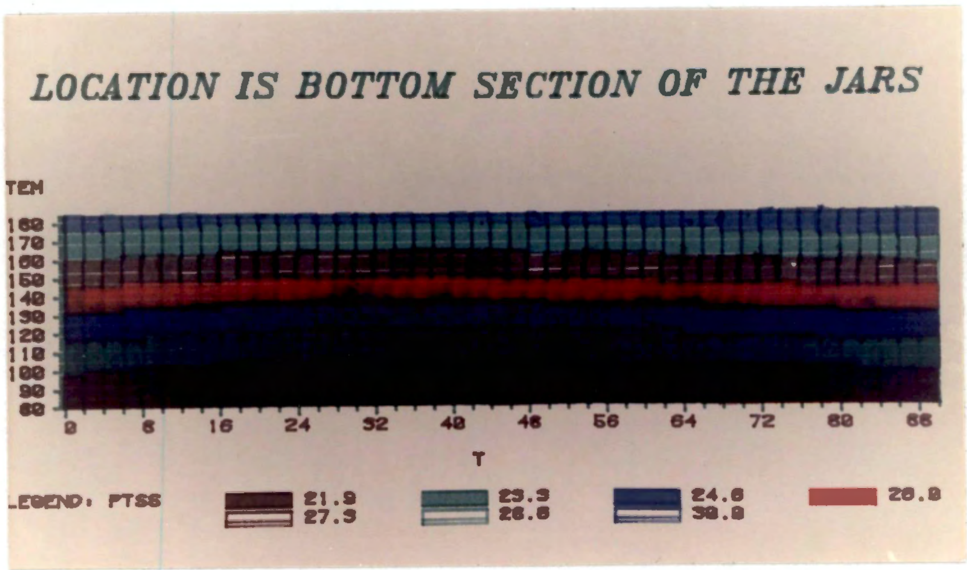

Figure B-6

Contour Map of Temperature (TEM) vs. Time (T) at the
Bottom Section of the Jars

Contours are percent total soluble solids (PTSS).

APPENDIX C

Table C-1

Influence of Juice Batch, Temperature, Location, Time, and the Interaction of Location and Time on PTA of Treated Juice Samples by Temperature

Source	DF	Mean Squares			
		26.7°C	46.1°C	65.6°C	85°C
Juice Batch	7	0.03521*	0.02408	0.34774**	0.07392
Location	2	0.01196	0.00045	0.05018	0.02281
Loc	1	0.01354	0.00218	0.01206	0.01409
Loc * Loc	1	0.00744	0.00005	0.06651	0.03406
Time	3	0.01706	0.02823	0.29824	0.04733
T	1	0.01714	0.00917	0.77269*	0.14312*
T * T	1	0.01365	0.01855	0.11484	0.00172
T * T * T	1	0.01388	0.05238	0.00439	0.0000004
Location * Time	6	0.01125	0.01024	0.02977	0.01687
Loc * T	1	0.02565	0.00732	0.02387	0.000006
Loc * Loc * T	1	0.01536	0.00982	0.00043	0.001274
Loc * T * T	1	0.01305	0.00523	0.00029	0.03336
Loc * Loc * T * T	1	0.00897	0.00766	0.02518	0.02795
Loc * T * T * T	1	0.00237	0.02752	0.00498	0.01652
Loc * Loc * T * T * T	1	0.00212	0.00387	0.12384	0.02210

*Significant at 5% level of probability.

**Significant at 1% level of probability.

Table C-2

Influence of Juice Batch, Temperature, Location, and the Interaction of Temperature and Location on PTA of Treated Juice Samples by Time

		Mean Squares			
Source	DF	0 mins	30 mins	60 mins	90 mins
Juice Batch	7	0.32025	0.13707*	0.01993	0.08356**
Temperature	3	0.42091	0.05124	0.06167	0.07066*
Tem	1	0.10177	0.04529	0.13944*	0.07028*
Tem * Tem	1	0.32152	0.05908	0.03711	0.14475
Tem * Tem * Tem	1	0.83945	0.04934	0.00868	0.01238
Location	2	---	0.00921	0.00155	0.00008
Loc	1	---	0.01672	0.00116	0.00014
Loc * Loc	1	---	0.00170	0.00193	0.00003
Temperature * Location	6	---	0.05408	0.01257	0.02108
Tem * Loc	1	---	0.00008	0.02016	0.04778
Tem * Tem * Loc	1	---	0.00302	0.04437	0.02459
Tem * Tem * Tem * Loc	1	---	0.01741	0.00491	0.00004
Tem * Loc * Loc	1	---	0.00433	0.00440	0.01329
Tem * Tem * Loc * Loc	1	---	0.10770	0.00059	0.03981
Tem * Tem * Tem * Loc * Loc	1	---	0.19195	0.00100	0.00099

*Significant at 5% level of probability.

**Significant at 1% level of probability.

Table C-3

Influence of Juice Batch, Temperature, Time, and the Interaction of Temperature and Time on PTA of Treated Juice Samples by Location

Source	DF	Mean Squares Top (1)	Middle (2)	Bottom (3)
Juice Batch	7	0.04478	0.11245	0.28853**
Temperature	3	0.09471**	0.15996*	0.03342*
Tem	1	0.13240*	0.10739	0.10273*
Tem * Tem	1	0.00465	0.08225	0.02069
Tem * Tem * Tem	1	0.14709*	0.29024*	0.05985
Time	3	0.01083	0.01755	0.01575
T	1	0.01131	0.02029	0.02427
T * T	1	0.01913	0.00679	0.00030
T * T * T	1	0.00208	0.02556	0.02269
Temperature * Time	9	0.03363	0.04975	0.07638
Tem * T	1	0.00249	0.00319	0.01677
Tem * Tem * T	1	0.10964*	0.14076	0.34655*
Tem * Tem * Tem * T	1	0.08152	0.18790	0.08084
Tem * T * T	1	0.00638	0.00855	0.03309
Tem * Tem * T * T	1	0.00531	0.00049	0.00301
Tem * Tem * Tem * T * T	1	0.05025	0.00068	0.13662
Tem * T * T * T	1	0.00035	0.00287	0.03132
Tem * Tem * T * T * T	1	0.02413	0.06418	0.00384
Tem * Tem * Tem * T * T * T	1	0.02259	0.03915	0.03535

*Significant at 5% level of probability.

**Significant at 1% level of probability.

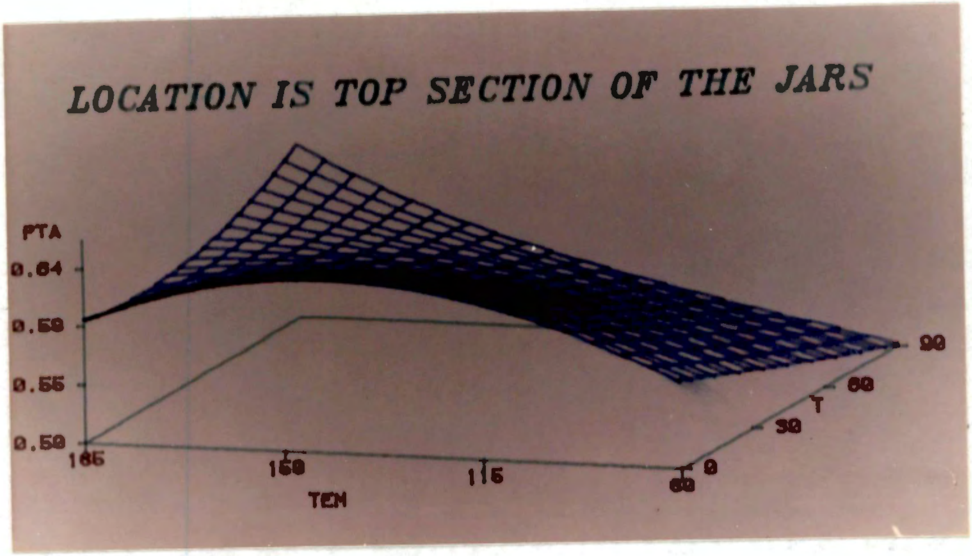

Figure C-1

3-Dimensional Graph of Percent Total Ash (PTA), Temperature (TEM), and Time (T) at the Top Section of the Jars

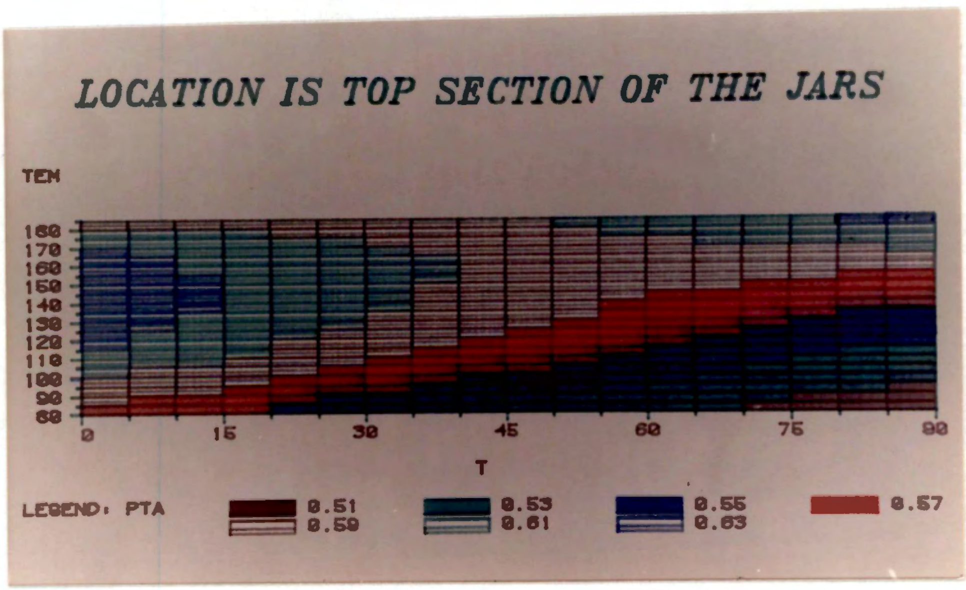

Figure C-2

Contour Map of Temperature (TEM) vs. Time (T) at the Top Section of the Jars

Contours are percent total ash (PTA).

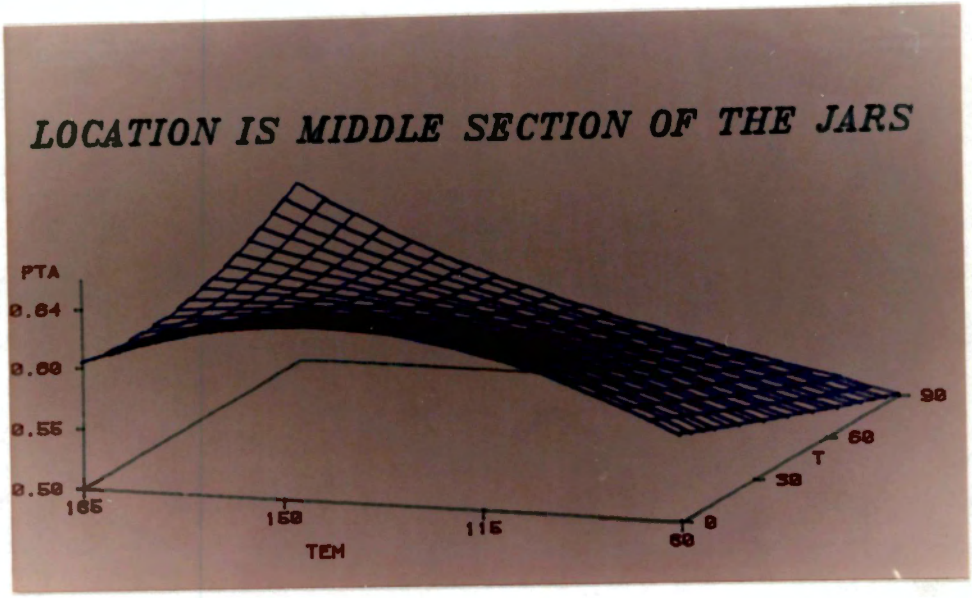

Figure C-3

3-Dimensional Graph of Percent Total Ash (PTA),
Temperature (TEM), and Time (T) at the
Middle Section of the Jars

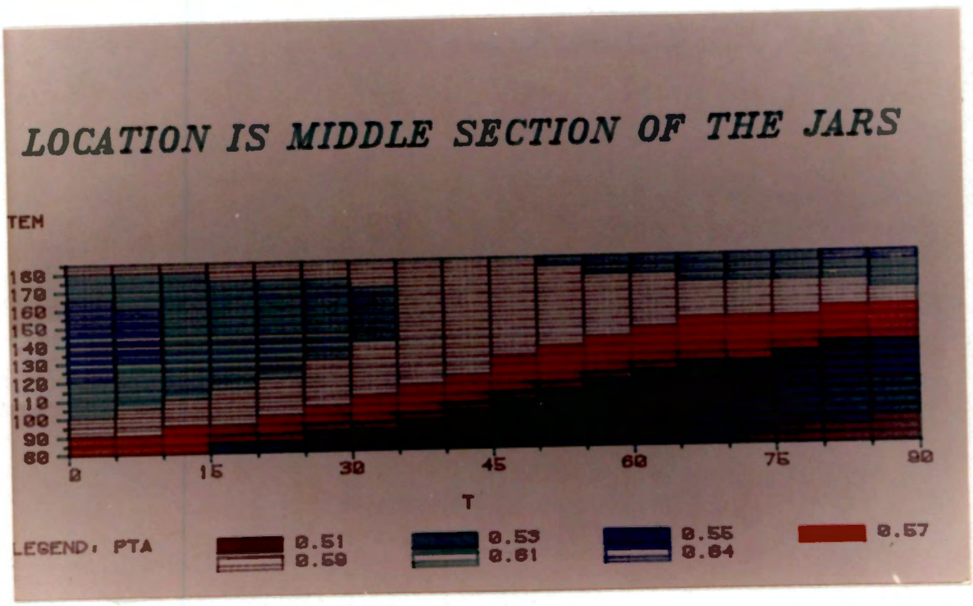

Figure C-4

Contour Map of Temperature (TEM) vs. Time (T) at the
Middle Section of the Jars

Contours are percent total ash (PTA).

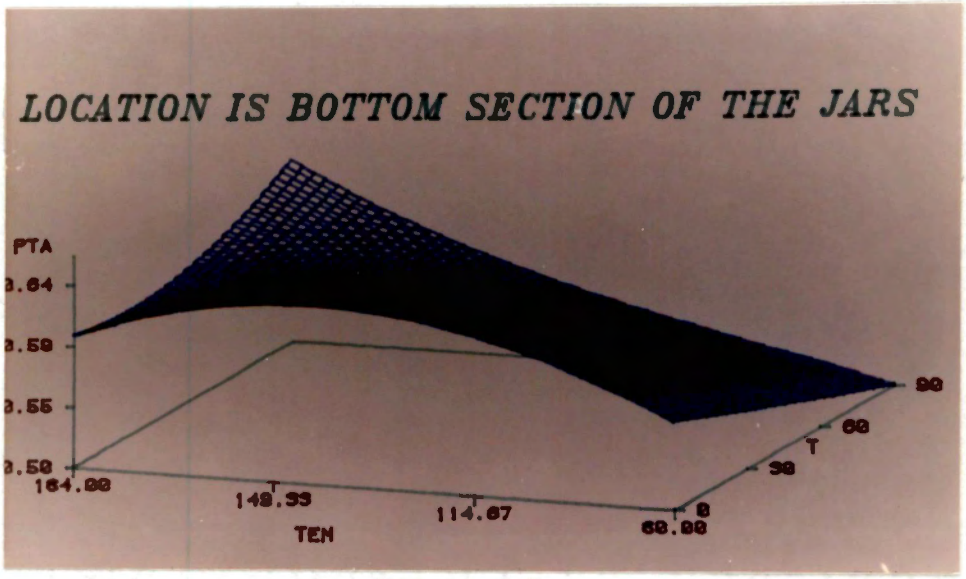

Figure C-5

3-Dimensional Graph of Percent Total Ash (PTA), Temperature (TEM), and Time (T) at the Bottom Section of the Jars

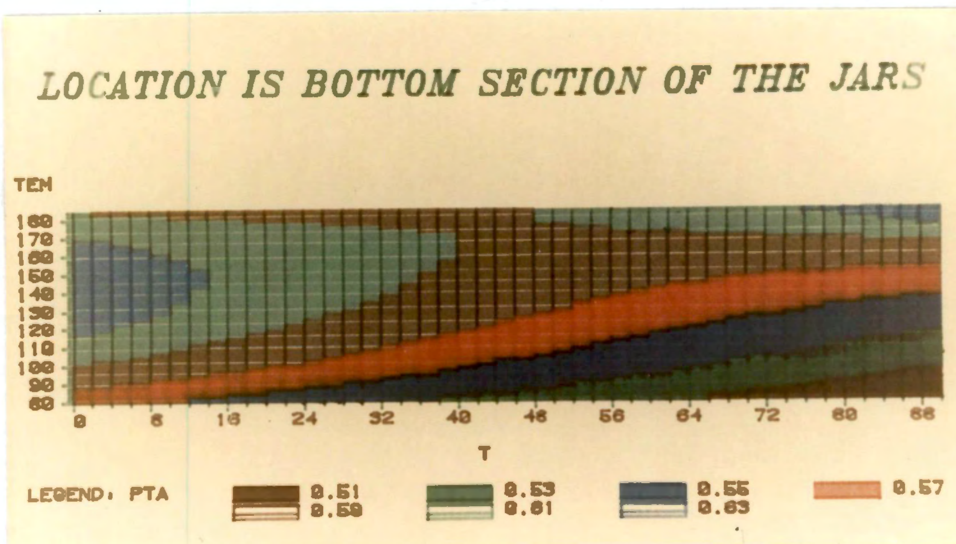

Figure C-6

Contour Map of Temperature (TEM) vs. Time (T) at the Bottom Section of the Jars

Contours are percent total ash (PTA).

APPENDIX D

Table D-1

Influence of Juice Batch, Location, Time, and the Interaction of Location and Time on PTS of Treated Juice Samples by Temperature

Source	DF		Mean Squares		
		26.7°C	46.1°C	65.6°C	85°C
Juice Batch	7	25.37842**	25.09450**	22.32756**	18.40472**
Location	2	0.58387	4.44817*	15.51033**	18.25860**
Loc	1	0.31229	7.40110*	25.86764**	23,70881**
Loc * Loc	1	0.46794	1.58002	3.99840	13.44404*
Time	3	4.49640*	1.25367	0.87316	3.74298
T	1	7.86511*	0.22387	0.15200	4.66812
T * T	1	0.16524	0.00483	1.61913	6.58642*
T * T * T	1	5.28981	3.43218	0.74435	0.53245
Location * Time	6	0.47636	0.81953	2.49810	3.45897*
Loc * T	1	0.02405	1.65086	9.15840*	3.76537
Loc * Loc * T	1	0.06145	0.00032	2.78883	4.48370
Loc * T * T	1	1.47296	1.08554	2.25694	0.81671
Loc * Loc * T * T	1	0.55815	0.62772	0.00786	0.88870
Loc * T * T * T	1	0.33165	0.01271	0.33689	10.63538*
Loc * Loc * T * T * T	1	0.40992	1.54005	0.43969	0.16397

*Significant at 5% level of probability.

**Significant at 1% level of probability.

Table D-2

Influence of Juice Batch, Temperature, Location, and the Interaction of Temperature and Location on PTS of Treated Juice Samples by Time

Source	DF	Mean Squares			
		0 mins	30 mins	60 mins	90 mins
Juice Batch	7	19.91878**	22.95072**	30.62070**	18.81332**
Temperature	3	3.02788	2.16958	2.67620	7.79286*
Tem	1	0.15552	2.05539	3.28283	20.37851**
Tem * Tem	1	3.67384	2.09155	1.20294	2.52454
Tem * Tem * Tem	1	5.25427	2.36181	3.33711	2.37601
Location	2	---	11.10503**	10.30847**	11.89630**
Loc	1	---	22.14879**	17.34756**	19.48221**
Loc * Loc	1	---	0.06128	3.26938	4.31039
Temperature * Location	6	---	2.41899	2.82855	3.44419
Tem * Loc	1	---	7.77816*	0.27191	13.04436**
Tem * Tem * Loc	1	---	0.32919	3.90522	0.82444
Tem * Tem * Tem * Loc	1	---	0.21684	1.91892	0.04506
Tem * Loc * Loc	1	---	2.96704	10.66420*	5.12049
Tem * Tem * Loc * Loc	1	---	2.44577	0.01646	0.31737
Tem * Tem * Tem * Loc * Loc	1	---	0.776913	0.19458	1.31340

*Significant at 5% level of probability.

**Significant at 1% level of probability.

Table D-3

Influence of Juice Batch, Temperature, Time, and the Interaction of Temperature and Time on PTS of Treated Juice Samples by Location

Source	DF	Mean Squares		
		Top (1)	Middle (2)	Bottom (3)
Juice Batch	7	34.97505**	31.54468**	22.5092**
Temperature	3	13.53677**	1.31843	4.24480
Tem	1	29.80371**	2.08278	0.21319
Tem * Tem	1	1.84560	0.72752	9.45847*
Tem * Tem * Tem	1	8.96099	1.14498	4.74015
Time	3	3.96432	3.09564*	3.32075
T	1	6.94097	3.03739	2.56774
T * T	1	0.25116	0.57379	7.12766*
T * T * T	1	4.70082	5.67574*	0.26686
Temperature * Time	9	2.5582	0.91965	1.37314
Tem * T	1	17.14198**	0.21272	2.16483
Tem * Tem * T	1	1.02160	0.04016	0.60843
Tem * Tem * Tem * T	1	0.17155	0.63647	0.30373
Tem * T * T	1	0.75694	5.60065*	0.49550
Tem * Tem * T * T	1	0.04922	0.52403	0.01024
Tem * Tem * Tem * T * T	1	0.02984	0.04573	0.13442
Tem * T * T * T	1	0.50929	0.11365	7.21450*
Tem * Tem * T * T * T	1	2.61504	0.67535	0.356156
Tem * Tem * Tem * T * T * T	1	0.72873	0.42804	1.07041

*Significant at 5% level of probability.

**Significant at 1% level of probability.

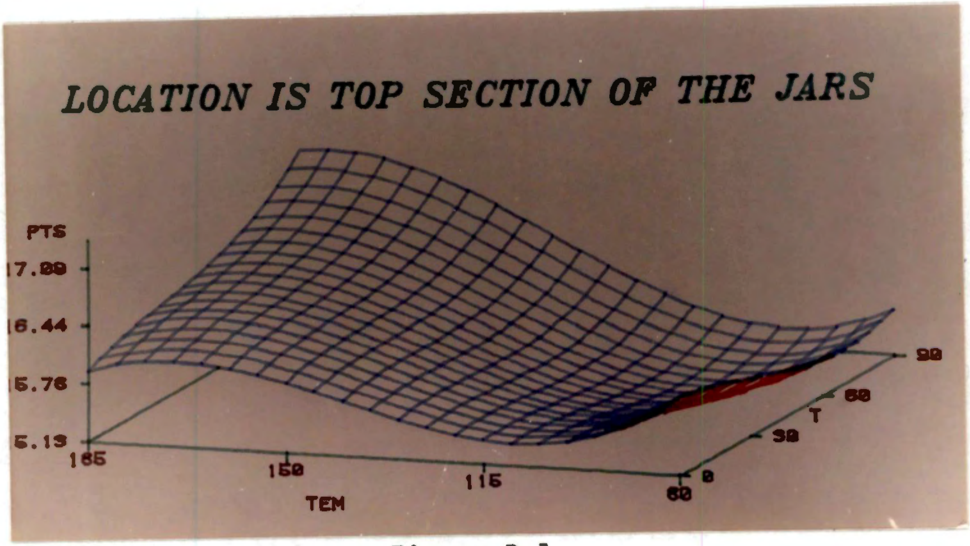

Figure D-1

3-Dimensional Graph of Percent Total Solids (PTS), Temperature (TEM), and Time (T) at the Top Section of the Jars

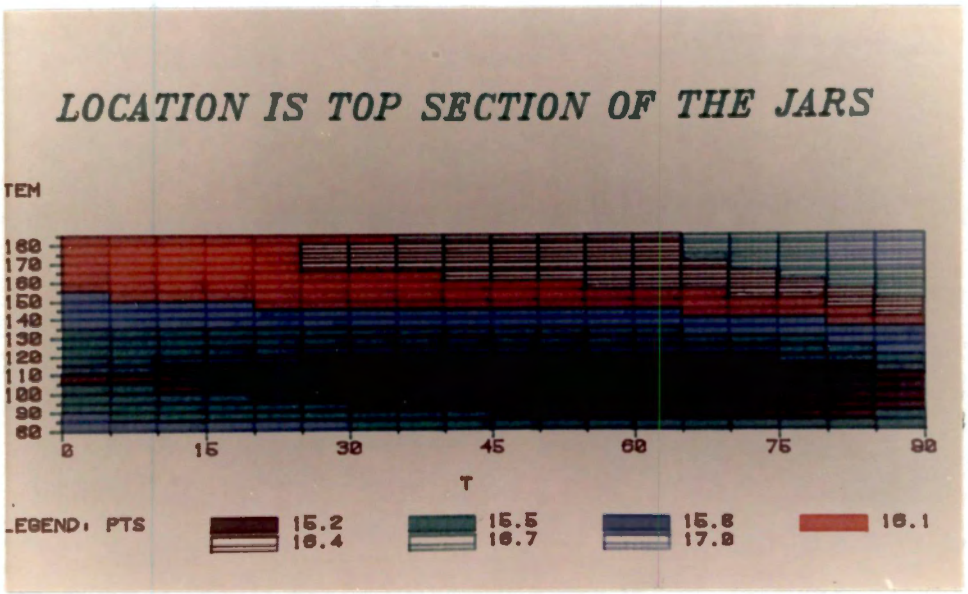

Figure D-2

Contour Map of Temperature (TEM) vs. Time (T) at the Top Section of the Jars

Contours are percent total solids (PTS).

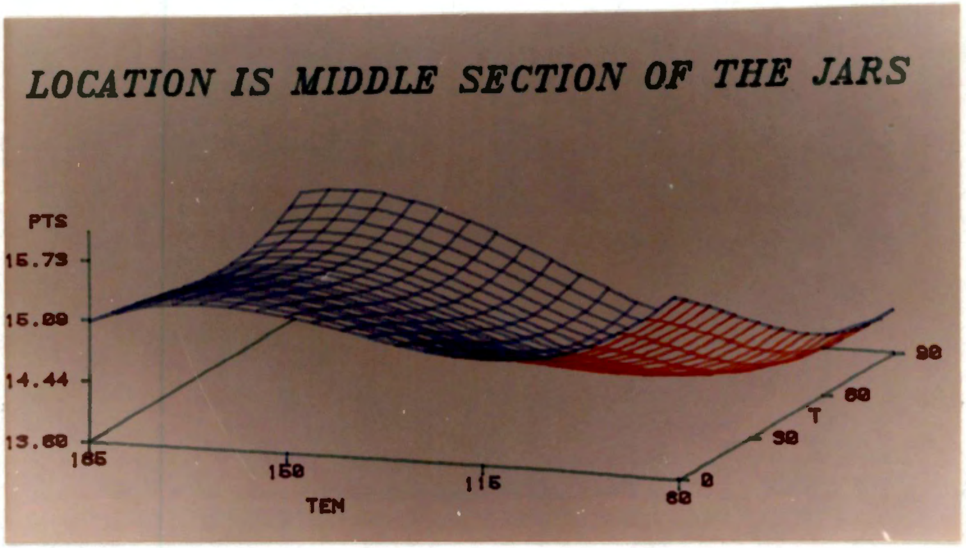

Figure D-3

3-Dimensional Graph of Percent Total Solids (PTS), Temperature (TEM), and Time (T) at the Middle Section of the Jars

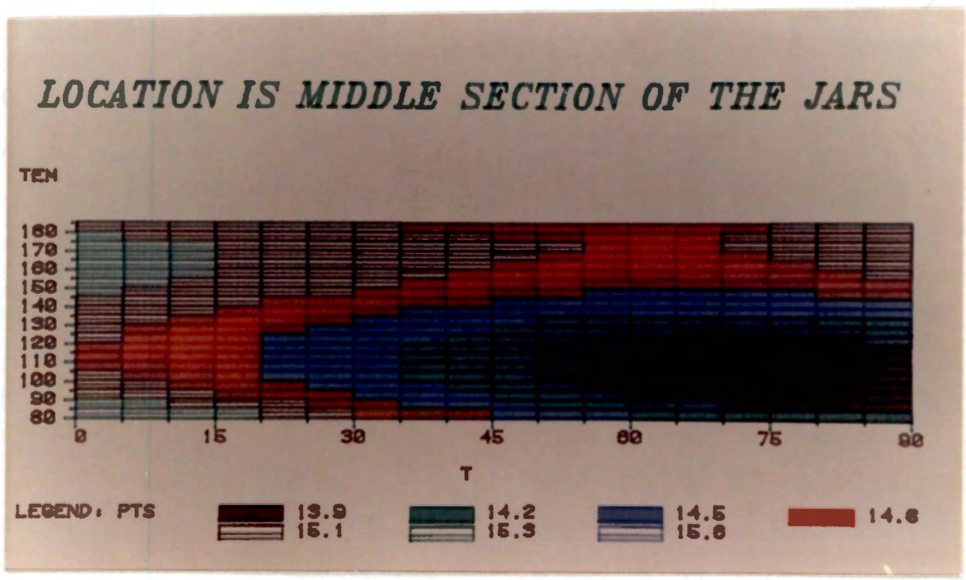

Figure D-4

Contour Map of Temperature (TEM) vs. Time (T) at the Middle Section of the Jars

Contours are percent total solids (PTS).

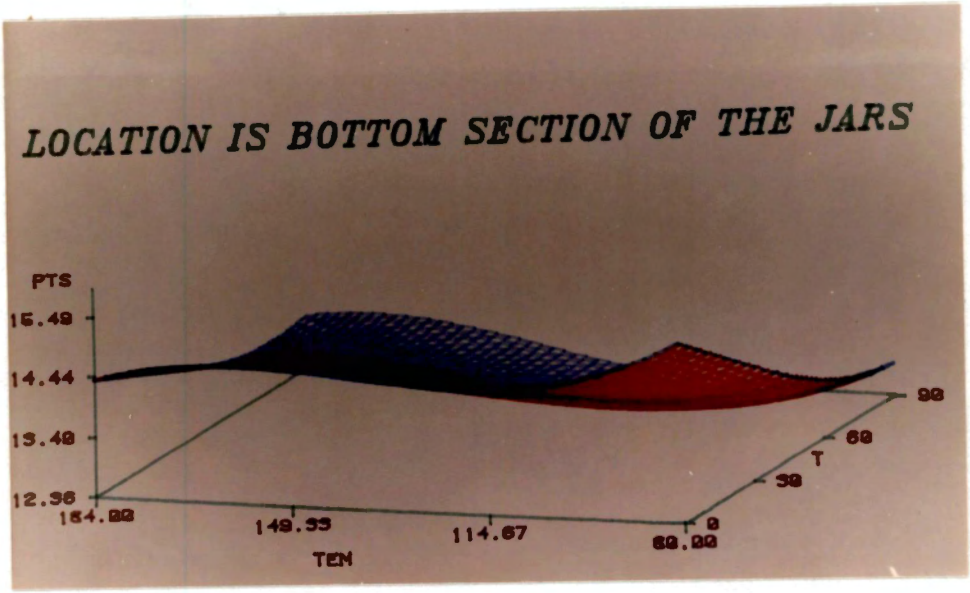

Figure D-5

3-Dimensional Graph of Percent Total Solids (PTS),
Temperature (TEM), and Time (T) at the
Bottom Section of the Jars

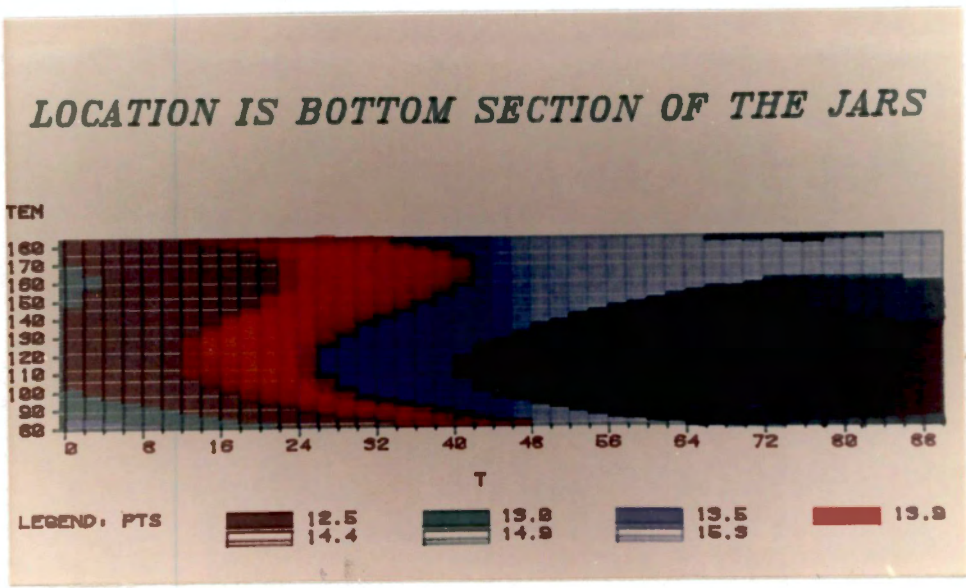

Figure D-6

Contour Map of Temperature (TEM) vs. Time (T) at the
Bottom Section of the Jars

Contours are percent total solids (PTS).

APPENDIX E

Table E-1

Raw Data as Measured from the Treated Juice Samples by Source, Juice Batch, Temperature, Location, and Time

Source	Juice Batch	Tempt °C	Location	Time (Mins)	Acidity (pH)	PTSS	PTA	PTS
A	1	26.7	1	0	5.22	14.5	0.5160	15.74
A	1	26.7	2	0	5.22	14.5	0.5160	15.74
A	1	26.7	3	0	5.22	14.5	0.5160	15.74
A	1	26.7	1	30	5.30	14.4	0.5464	15.81
A	1	26.7	2	30	5.21	14.4	0.5222	15.80
A	1	26.7	3	30	5.11	14.0	0.5110	15.80
A	1	26.7	1	60	5.20	14.4	0.5313	15.52
A	1	26.7	2	60	5.21	14.5	0.5171	15.44
A	1	26.7	3	60	5.18	14.4	0.5026	16.08
A	1	26.7	1	90	5.28	14.0	0.4982	15.28
A	1	26.7	2	90	5.20	14.0	0.5065	15.11
A	1	26.7	3	90	5.28	14.5	0.5243	15.49
A	1	46.1	1	0	5.22	13.7	0.4945	15.06
A	1	46.1	2	0	5.22	13.7	0.4945	15.06
A	1	46.1	3	0	5.22	13.7	0.4945	15.06
A	1	46.1	1	30	5.21	14.3	0.5013	14.90
A	1	46.1	2	30	5.21	14.4	0.5031	15.81
A	1	46.1	3	30	5.29	12.5	0.4405	14.20
A	1	46.1	1	60	5.20	14.4	0.5261	15.19
A	1	46.1	2	60	5.22	14.0	0.4755	14.83
A	1	46.1	3	60	5.20	13.0	0.4792	14.41
A	1	46.1	1	90	5.22	14.5	0.5100	15.30
A	1	46.1	2	90	5.19	13.6	0.5025	15.27
A	1	46.1	3	90	5.28	13.8	0.4734	15.21
A	1	65.6	1	0	5.31	14.0	0.5009	14.35
A	1	65.6	2	0	5.31	14.0	0.5009	14.35
A	1	65.6	3	0	5.31	14.0	0.5009	14.35
A	1	65.6	1	30	5.30	13.6	0.5463	13.39
A	1	65.6	2	30	5.20	13.9	0.5556	15.83
A	1	65.6	3	30	5.19	13.5	0.5420	15.44
A	1	65.6	1	60	5.20	15.3	0.6324	17.84
A	1	65.6	2	60	5.29	13.5	0.4969	13.10
A	1	65.6	3	60	5.27	13.3	0.4669	13.51
A	1	65.6	1	90	5.28	14.6	0.5382	15.86
A	1	65.6	2	90	5.31	14.9	0.5406	14.88
A	1	65.6	3	90	5.31	14.3	0.5161	15.45
A	1	85	1	0	5.25	13.5	0.4869	14.72
A	1	85	2	0	5.25	13.5	0.4869	14.72
A	1	85	3	0	5.25	13.5	0.4869	14.72

Table E-1 (Continued)

Source	Juice Batch	Tempt °C	Location	Time (Mins)	Acidity (pH)	PTSS	PTA	PTS
A	1	85	1	30	5.18	13.7	0.5108	16.18
A	1	85	2	30	5.28	14.3	0.5040	16.03
A	1	85	3	30	5.27	13.9	0.5240	14.11
A	1	85	1	60	5.28	15.0	0.5350	16.08
A	1	85	2	60	5.32	14.1	0.5700	15.92
A	1	85	3	60	5.32	13.6	0.5480	15.38
A	1	85	1	90	5.32	15.4	0.6384	17.78
A	1	85	2	90	5.28	14.9	0.6085	13.22
A	1	85	3	90	5.31	14.5	0.5253	16.28
A	2	26.7	1	0	5.11	14.0	0.5277	16.07
A	2	26.7	2	0	5.11	14.0	0.5277	16.07
A	2	26.7	3	0	5.11	14.0	0.5277	16.07
A	2	26.7	1	30	5.18	14.5	0.5311	14.38
A	2	26.7	2	30	5.10	14.0	0.5223	16.16
A	2	26.7	3	30	5.12	13.5	0.5035	16.64
A	2	26.7	1	60	5.21	14.3	0.5361	14.89
A	2	26.7	2	60	5.25	14.5	0.5338	14.30
A	2	26.7	3	60	5.18	14.4	0.4837	9.98
A	2	26.7	1	90	5.23	14.5	0.5187	11.51
A	2	26.7	2	90	5.18	14.2	0.5178	15.68
A	2	26.7	3	90	5.22	14.0	0.4939	11.38
A	2	46.1	1	0	5.24	13.3	0.4906	13.15
A	2	46.1	2	0	5.24	13.3	0.4906	13.15
A	2	46.1	3	0	5.24	13.3	0.4906	13.15
A	2	46.1	1	30	5.12	13.7	0.5017	15.38
A	2	46.1	2	30	5.12	13.6	0.4967	15.28
A	2	46.1	3	30	5.20	13.0	0.4669	13.82
A	2	46.1	1	60	5.12	13.5	0.5094	15.39
A	2	46.1	2	60	5.21	14.0	0.5078	11.01
A	2	46.1	3	60	5.25	13.2	0.4499	13.61
A	2	46.1	1	90	5.18	14.0	0.5102	18.31
A	2	46.1	2	90	5.20	14.6	0.5212	14.40
A	2	46.1	3	90	5.10	13.3	0.4953	14.48
A	2	65.6	1	0	5.10	13.3	0.4917	15.18
A	2	65.6	2	0	5.10	13.3	0.4917	15.18
A	2	65.6	3	0	5.10	13.3	0.4917	15.18
A	2	65.6	1	30	5.21	15.0	0.5473	10.26
A	2	65.6	2	30	5.15	14.0	0.4986	15.98
A	2	65.6	3	30	5.23	13.8	0.5049	14.70
A	2	65.6	1	60	5.20	15.1	0.5405	15.00
A	2	65.6	2	60	5.10	14.0	0.5184	15.68
A	2	65.6	3	60	5.18	14.0	0.5248	16.29

Table E-1 (Continued)

Source	Juice Batch	Tempt °C	Location	Time (Mins)	Acidity (pH)	PTSS	PTA	PTS
A	2	65.6	1	90	5.12	14.5	0.5192	17.31
A	2	65.6	2	90	5.22	14.1	0.4947	14.33
A	2	65.6	3	90	5.13	14.4	0.5234	14.22
A	2	85	1	0	5.25	13.5	0.5090	15.39
A	2	85	2	0	5.25	13.5	0.5090	15.39
A	2	85	3	0	5.25	13.5	0.5090	15.39
A	2	85	1	30	5.10	15.0	0.5748	17.20
A	2	85	2	30	5.12	13.3	0.4718	14.74
A	2	85	3	30	5.25	13.7	0.5021	13.71
A	2	85	1	60	5.18	14.7	0.5361	10.14
A	2	85	2	60	5.20	14.2	0.5117	10.26
A	2	85	3	60	5.31	14.3	0.5214	16.45
A	2	85	1	90	5.25	15.5	0.5867	17.55
A	2	85	2	90	5.23	14.4	0.5205	15.24
A	2	85	3	90	5.22	14.5	0.5155	15.70
A	3	26.7	1	0	5.23	12.7	0.5246	12.93
A	3	26.7	2	0	5.23	12.7	0.5246	12.93
A	3	26.7	3	0	5.23	12.7	0.5246	12.93
A	3	26.7	1	30	5.22	12.9	0.5382	14.17
A	3	26.7	2	30	5.26	13.0	0.4303	12.30
A	3	26.7	3	30	5.22	13.0	0.5255	12.98
A	3	26.7	1	60	5.10	12.5	0.5171	13.40
A	3	26.7	2	60	5.21	12.2	0.5115	13.23
A	3	26.7	3	60				
A	3	26.7	1	90	5.22	12.5	0.5114	12.72
A	3	26.7	2	90	5.24	13.2	0.5402	13.08
A	3	26.7	3	90				
A	3	46.1	1	0	5.21	13.0	0.5428	13.37
A	3	46.1	2	0	5.21	13.0	0.5428	13.37
A	3	46.1	3	0	5.21	13.0	0.5428	13.37
A	3	46.1	1	30	5.21	12.5	0.4986	12.43
A	3	46.1	2	30	5.18	13.4	0.5606	14.14
A	3	46.1	3	30	5.21	11.5	0.4672	12.69
A	3	46.1	1	60	5.23	12.8	0.4950	13.36
A	3	46.1	2	60	5.12	12.4	0.5036	13.12
A	3	46.1	3	60				
A	3	46.1	1	90	5.19	13.3	0.5480	13.35
A	3	46.1	2	90	5.22	13.0	0.5457	13.44
A	3	46.1	3	90				
A	3	65.6	1	0	5.22	13.0	0.5212	13.62
A	3	65.6	2	0	5.22	13.0	0.5212	13.62
A	3	65.6	3	0	5.22	13.0	0.5212	13.62

Table E-1 (Continued)

Source	Juice Batch	Tempt °C	Location	Time (Mins)	Acidity (pH)	PTSS	PTA	PTS
A	3	65.6	1	30	5.24	13.6	0.6002	15.03
A	3	65.6	2	30	5.18	12.7	0.5328	12.36
A	3	65.6	3	30	5.27	11.6	0.4887	11.87
A	3	65.6	1	60	5.23	14.0	0.5877	16.15
A	3	65.6	2	60	5.25	12.0	0.4829	12.36
A	3	65.6	3	60				
A	3	65.6	1	90	5.20	13.5	0.5808	15.02
A	3	65.6	2	90	5.25	12.7	0.5100	13.16
A	3	65.6	3	90				
A	3	85	1	0	5.18	13.2	0.5264	14.28
A	3	85	2	0	5.18	13.2	0.5264	14.28
A	3	85	3	0	5.18	13.2	0.5264	14.28
A	3	85	1	30	5.22	15.1	0.6671	16.79
A	3	85	2	30	5.24	12.5	0.5019	12.78
A	3	85	3	30	5.22	12.3	0.4704	12.47
A	3	85	1	60	5.22	13.7	0.5667	14.64
A	3	85	2	60	5.21	11.8	0.4822	12.44
A	3	85	3	60				
A	3	85	1	90	5.25	14.6	0.6227	15.70
A	3	85	2	90	5.26	12.7	0.5257	12.86
A	3	85	3	90				
B	4	26.7	1	0	4.93	17.0	0.5238	17.66
B	4	26.7	2	0	4.93	17.0	0.5238	17.66
B	4	26.7	3	0	4.93	17.0	0.5238	17.66
B	4	26.7	1	30	4.98	11.5	0.5221	18.20
B	4	26.7	2	30	4.97	17.1	0.5422	19.00
B	4	26.7	3	30	4.96	16.9	0.5309	18.27
B	4	26.7	1	60	4.90	17.0	0.5146	17.34
B	4	26.7	2	60	4.90	17.0	0.5106	17.61
B	4	26.7	3	60	5.00	17.0	0.5567	17.66
B	4	26.7	1	90	4.98	15.4	0.4730	16.03
B	4	26.7	2	90	4.99	17.0	0.5253	17.29
B	4	26.7	3	90	4.97	16.9	0.5178	17.84
B	4	46.1	1	0	4.98	15.0	0.4958	17.61
B	4	46.1	2	0	4.98	15.0	0.4958	17.61
B	4	46.1	3	0	4.98	15.0	0.4958	17.61
B	4	46.1	1	30	4.99	16.5	0.4776	15.80
B	4	46.1	2	30	5.00	11.5	0.5173	17.76
B	4	46.1	3	30	5.01	14.7	0.4613	16.27
B	4	46.1	1	60	4.96	17.0	0.5077	17.11
B	4	46.1	2	60	4.92	16.8	0.4910	17.19
B	4	46.1	3	60	4.92	16.6	0.5158	17.17

Table E-1 (Continued)

Source	Juice Batch	Tempt °C	Location	Time (Mins)	Acidity (pH)	PTSS	PTA	PTS
B	4	46.1	1	90	4.93	16.4	0.4889	17.56
B	4	46.1	2	90	4.97	11.6	0.5239	18.72
B	4	46.1	3	90	4.92	16.8	0.5030	17.89
B	4	65.6	1	0	4.99	16.6	0.5298	17.54
B	4	65.6	2	0	4.99	16.6	0.5298	17.54
B	4	65.6	3	0	4.99	16.6	0.5298	17.54
B	4	65.6	1	30	5.00	17.5	0.6572	21.16
B	4	65.6	2	30	4.99	15.8	0.5056	16.37
B	4	65.6	3	30	5.00	16.3	0.5033	15.73
B	4	65.6	1	60	4.95	17.7	0.6003	19.31
B	4	65.6	2	60	4.98	16.3	0.5207	16.91
B	4	65.6	3	60	4.99	16.3	0.5510	17.07
B	4	65.6	1	90	5.00	18.5	0.6648	21.23
B	4	65.6	2	90	5.00	16.5	0.5212	16.90
B	4	65.6	3	90	4.98	16.0	0.4921	16.58
B	4	85	1	0	4.99	17.1	0.5616	17.93
B	4	85	2	0	4.99	17.1	0.5616	17.93
B	4	85	3	0	4.99	17.1	0.5616	17.93
B	4	85	1	30	5.01	17.9	0.7042	20.27
B	4	85	2	30	4.99	15.3	0.5352	16.17
B	4	85	3	30	4.97	15.0	0.5236	16.56
B	4	85	1	60	5.01	17.7	0.6427	19.99
B	4	85	2	60	4.98	16.6	0.5534	16.94
B	4	85	3	60	4.96	16.4	0.5691	16.80
B	4	85	1	90	5.00	18.9	0.7185	21.53
B	4	85	2	90	5.00	15.7	0.5451	16.76
B	4	85	3	90	4.99	15.6	0.5263	15.54
C	5	26.7	1	0	5.21	14.3	0.6508	15.96
C	5	26.7	2	0	5.21	14.3	0.6508	15.96
C	5	26.7	3	0	5.21	14.3	0.6508	15.96
C	5	26.7	1	30	5.13	14.5	0.6540	15.63
C	5	26.7	2	30	5.13	15.0	0.7585	15.96
C	5	26.7	3	30	5.16	15.0	0.7565	15.64
C	5	26.7	1	60	5.20	14.5	0.5289	12.03
C	5	26.7	2	60	5.26	15.0	0.5160	12.26
C	5	26.7	3	60	5.22	15.0	0.5619	10.78
C	5	26.7	1	90	5.15	14.5	0.5290	15.38
C	5	26.7	2	90	5.26	15.0	0.5506	12.18
C	5	26.7	3	90	5.13	15.0	1.3310	17.09
C	5	46.1	1	0	5.29	14.0	0.5254	11.78
C	5	46.1	2	0	5.29	14.0	0.5254	11.78
C	5	46.1	3	0	5.29	14.0	0.5254	11.78

Table E-1 (Continued)

Source	Juice Batch	Tempt °C	Location	Time (Mins)	Acidity (pH)	PTSS	PTA	PTS
C	5	46.1	1	30	5.18	15.0	0.6310	16.30
C	5	46.1	2	30	5.22	14.0	0.5635	15.69
C	5	46.1	3	30	5.18	12.5	1.7220	14.15
C	5	46.1	1	60	5.28	13.6	0.5005	13.33
C	5	46.1	2	60	5.16	14.0	0.5214	14.96
C	5	46.1	3	60	5.28	13.0	0.4856	11.76
C	5	46.1	1	90	5.28	14.0	0.5102	14.08
C	5	46.1	2	90	5.23	14.3	0.5256	11.07
C	5	46.1	3	90	5.27	13.0	0.4900	10.28
C	5	65.6	1	0	5.13	15.0	2.2150	16.32
C	5	65.6	2	0	5.13	15.0	2.2150	16.32
C	5	65.6	3	0	5.13	15.0	2.2150	16.32
C	5	65.6	1	30	5.19	15.3	0.5653	16.65
C	5	65.6	2	30	5.18	14.3	0.9881	15.78
C	5	65.6	3	30	5.15	14.0	0.5640	15.41
C	5	65.6	1	60	5.26	15.5	0.5402	14.47
C	5	65.6	2	60	5.28	14.1	0.5214	13.44
C	5	65.6	3	60	5.26	13.6	0.4686	11.08
C	5	65.6	1	90	5.27	15.0	0.5365	14.72
C	5	65.6	2	90	5.29	14.6	0.5172	13.72
C	5	65.6	3	90	5.17	14.4	0.5297	15.98
C	5	85	1	0	5.12	14.3	0.5403	15.40
C	5	85	2	0	5.12	14.3	0.5403	15.40
C	5	85	3	0	5.12	14.3	0.5403	15.40
C	5	85	1	30	5.20	15.5	0.5795	13.98
C	5	85	2	30	5.20	14.5	0.5093	13.86
C	5	85	3	30	5.24	14.4	0.5202	13.57
C	5	85	1	60	5.22	15.5	0.5622	16.01
C	5	85	2	60	5.15	14.0	0.7212	15.36
C	5	85	3	60	5.16	13.7	1.7230	15.27
C	5	85	1	90	5.17	15.1	0.7245	17.68
C	5	85	2	90	5.17	14.5	0.8070	16.46
C	5	85	3	90	5.14	14.2	1.3590	15.75
C	6	26.7	1	0	5.23	14.9	0.5427	15.95
C	6	26.7	2	0	5.23	14.9	0.5427	15.95
C	6	26.7	3	0	5.23	14.9	0.5427	15.95
C	6	26.7	1	30	5.27	14.6	0.5314	17.12
C	6	26.7	2	30	5.26	14.5	0.5476	15.69
C	6	26.7	3	30	5.24	14.3	0.5196	13.76
C	6	26.7	1	60	5.25	14.0	0.5093	15.83
C	6	26.7	2	60	5.25	15.0	0.5563	16.35
C	6	26.7	3	60	5.25	14.9	0.5403	16.63

Table E-1 (Continued)

Source	Juice Batch	Tempt °C	Location	Time (Mins)	Acidity (pH)	PTSS	PTA	PTS
C	6	26.7	1	90	5.23	13.5	0.5414	16.16
C	6	26.7	2	90	5.23	15.0	0.5310	14.62
C	6	26.7	3	90	5.23	15.0	0.5212	15.24
C	6	46.1	1	0	5.23	14.0	0.5030	15.83
C	6	46.1	2	0	5.23	14.0	0.5030	15.83
C	6	46.1	3	0	5.23	14.0	0.5030	15.83
C	6	46.1	1	30	5.22	13.6	0.6516	15.52
C	6	46.1	2	30	5.22	14.5	0.6531	14.95
C	6	46.1	3	30	5.20	14.3	0.4981	13.94
C	6	46.1	1	60	5.16	15.0	0.5429	15.06
C	6	46.1	2	60	5.22	15.1	0.5469	14.62
C	6	46.1	3	60	5.26	13.4	0.4905	13.44
C	6	46.1	1	90	5.21	13.8	0.4830	14.97
C	6	46.1	2	90	5.24	15.0	0.6447	17.11
C	6	46.1	3	90	5.26	13.4	0.4679	14.79
C	6	65.6	1	0	5.24	14.2	0.5052	15.37
C	6	65.6	2	0	5.24	14.2	0.5052	15.37
C	6	65.6	3	0	5.24	14.2	0.5052	15.37
C	6	65.6	1	30	5.27	14.0	0.4956	15.31
C	6	65.6	2	30	5.21	14.7	2.1880	15.31
C	6	65.6	3	30	5.25	13.6	0.8378	15.57
C	6	65.6	1	60	5.25	14.5	0.6678	14.27
C	6	65.6	2	60	5.22	15.0	0.7040	14.58
C	6	65.6	3	60	5.17	14.3	0.7752	14.81
C	6	65.6	1	90	5.23	15.1	0.5267	16.53
C	6	65.6	2	90	5.22	15.0	0.5215	16.21
C	6	65.6	3	90	5.24	14.5	0.5140	13.87
C	6	85	1	0	5.20	15.0	0.5663	14.08
C	6	85	2	0	5.20	15.0	0.5663	14.08
C	6	85	3	0	5.20	15.0	0.5663	14.08
C	6	85	1	30	5.25	14.3	0.5151	13.62
C	6	85	2	30	5.21	15.0	0.5224	14.36
C	6	85	3	30	5.20	14.5	1.5260	14.66
C	6	85	1	60	5.22	15.2	0.5471	16.74
C	6	85	2	60	5.23	15.0	0.5530	13.94
C	6	85	3	60	5.22	15.0	0.5317	15.45
C	6	85	1	90	5.23	16.0	0.5689	15.59
C	6	85	2	90	5.23	15.0	0.5382	16.66
C	6	85	3	90	5.26	14.9	0.5139	16.46
C	7	26.7	1	0	5.12	14.7	0.4758	15.23
C	7	26.7	2	0	5.12	14.7	0.4758	15.23
C	7	26.7	3	0	5.12	14.7	0.4758	15.23

Table E-1 (Continued)

Source	Juice Batch	Tempt °C	Location	Time (Mins)	Acidity (pH)	PTSS	PTA	PTS
C	7	26.7	1	30	5.21	15.3	0.5233	16.34
C	7	26.7	2	30	5.18	15.5	0.5070	16.69
C	7	26.7	3	30	5.18	15.3	0.5095	16.24
C	7	26.7	1	60	5.18	15.5	0.5196	16.52
C	7	26.7	2	60	5.21	15.5	0.5507	16.32
C	7	26.7	3	60	5.14	15.5	0.5561	16.34
C	7	26.7	1	90	5.21	14.2	0.8658	16.83
C	7	26.7	2	90	5.22	15.3	0.5683	15.94
C	7	26.7	3	90	5.21	15.3	0.8857	16.06
C	7	46.1	1	0	5.19	15.5	0.5283	16.64
C	7	46.1	2	0	5.19	15.5	0.5283	16.64
C	7	46.1	3	0	5.19	15.5	0.5283	16.64
C	7	46.1	1	30	5.21	15.7	0.5518	17.13
C	7	46.1	2	30	5.19	15.0	0.5993	16.39
C	7	46.1	3	30	5.22	15.2	0.5330	16.06
C	7	46.1	1	60	5.21	15.5	0.5480	16.25
C	7	46.1	2	60	5.18	15.2	0.5141	15.88
C	7	46.1	3	60	5.20	14.5	0.4967	15.24
C	7	46.1	1	90	5.22	14.2	0.5582	15.22
C	7	46.1	2	90	5.15	14.8	0.5053	15.08
C	7	46.1	3	90	5.20	15.0	0.5394	15.90
C	7	65.6	1	0	5.21	15.7	1.0760	16.84
C	7	65.6	2	0	5.21	15.7	1.0760	16.84
C	7	65.6	3	0	5.21	15.7	1.0760	16.84
C	7	65.6	1	30	5.20	16.5	0.5527	17.66
C	7	65.6	2	30	5.22	15.4	0.5476	16.31
C	7	65.6	3	30	5.23	14.5	0.8119	15.31
C	7	65.6	1	60	5.21	16.0	0.6103	17.98
C	7	65.6	2	60	5.21	15.5	0.6176	16.34
C	7	65.6	3	60	5.23	14.7	0.5616	15.32
C	7	65.6	1	90	5.20	15.1	0.6825	16.37
C	7	65.6	2	90	5.19	15.2	1.1320	16.18
C	7	65.6	3	90	5.18	16.5	0.5780	17.81
C	7	85	1	0	5.14	15.5	0.6074	16.63
C	7	85	2	0	5.14	15.5	0.6074	16.63
C	7	85	3	0	5.14	15.5	0.6074	16.63
C	7	85	1	30	5.20	16.0	0.5537	17.28
C	7	85	2	30	5.16	14.5	0.5024	16.41
C	7	85	3	30	5.18	15.1	0.5949	16.39
C	7	85	1	60	5.22	16.2	0.5807	18.22
C	7	85	2	60	5.21	15.1	0.9207	15.72
C	7	85	3	60	5.20	15.4	0.5389	16.78

Table E-1 (Continued)

Source	Juice Batch	Tempt °C	Location	Time (Mins)	Acidity (pH)	PTSS	PTA	PTS
C	7	85	1	90	5.20	16.7	0.8726	18.24
C	7	85	2	90	5.20	16.0	1.0430	16.90
C	7	85	3	90	5.22	15.0	0.5432	16.38
B	8	26.7	1	0	5.10	16.5	0.5802	16.74
B	8	26.7	2	0	5.10	16.5	0.5802	16.74
B	8	26.7	3	0	5.10	16.5	0.5802	16.74
B	8	26.7	1	30	5.10	16.0	0.5687	17.51
B	8	26.7	2	30	5.10	15.5	0.5838	17.27
B	8	26.7	3	30	5.02	15.5	0.5652	17.17
B	8	26.7	1	60	5.10	16.0	0.5714	16.62
B	8	26.7	2	60	5.03	16.0	0.5678	18.25
B	8	26.7	3	60	5.03	15.9	0.5564	17.35
B	8	26.7	1	90	5.02	15.5	0.5298	16.81
B	8	26.7	2	90	5.01	16.3	0.5742	17.93
B	8	26.7	3	90	5.04	15.0	0.5413	17.09
B	8	46.1	1	0	5.12	15.7	0.5819	16.65
B	8	46.1	2	0	5.12	15.7	0.5819	16.65
B	8	46.1	3	0	5.12	15.7	0.5819	16.65
B	8	46.1	1	30	5.10	15.0	0.5830	16.40
B	8	46.1	2	30	5.02	15.0	0.5331	16.85
B	8	46.1	3	30	5.10	14.4	0.5222	15.71
B	8	46.1	1	60	5.12	15.0	0.5600	16.34
B	8	46.1	2	60	5.10	15.5	0.5651	16.80
B	8	46.1	3	60	5.07	14.0	0.4945	15.45
B	8	46.1	1	90	5.05	12.8	0.4610	14.52
B	8	46.1	2	90	5.11	15.9	0.5754	16.39
B	8	46.1	3	90	5.03	13.9	0.4804	14.85
B	8	65.6	1	0	5.11	15.5	0.5628	16.18
B	8	65.6	2	0	5.11	15.5	0.5628	16.18
B	8	65.6	3	0	5.11	15.5	0.5628	16.18
B	8	65.6	1	30	5.13	17.0	0.7754	20.22
B	8	65.6	2	30	5.08	15.0	0.5419	16.74
B	8	65.6	3	30	5.08	14.6	0.5099	16.14
B	8	65.6	1	60	5.08	16.6	0.6309	19.01
B	8	65.6	2	60	5.10	15.6	0.5748	16.62
B	8	65.6	3	60	5.12	14.9	0.5326	16.02
B	8	65.6	1	90	5.08	16.7	0.6478	19.67
B	8	65.6	2	90	5.07	14.6	0.5415	16.83
B	8	65.6	3	90	5.03	14.7	0.5188	15.96
B	8	85	1	0	5.12	15.1	0.5735	17.04
B	8	85	2	0	5.12	15.1	0.5735	17.04
B	8	85	3	0	5.12	15.1	0.5735	17.04

Table E-1 (Continued)

Source	Juice Batch	Tempt °C	Location	Time (Mins)	Acidity (pH)	PTSS	PTA	PTS
B	8	85	1	30	5.10	17.9	0.8002	19.69
B	8	85	2	30	5.08	14.1	0.5144	15.83
B	8	85	3	30	5.13	14.5	0.5349	15.08
B	8	85	1	60	5.08	16.1	0.6436	17.89
B	8	85	2	60	5.08	15.1	0.5484	16.33
B	8	85	3	60	5.12	15.0	0.5459	15.72
B	8	85	1	90	5.07	16.5	0.6205	17.91
B	8	85	2	90	5.10	15.5	0.5760	16.42
B	8	85	3	90	5.10	15.0	0.5636	15.87

Table E-2

Change in Percent Total Solids of the Treated Juice at the Middle Portion of the Jars by Source and Juice Batch

Source	Juice Batch	Temperature °C	Change in* PTS after 30 minutes	Change in* PTS after 60 minutes	Change in* PTS after 90 minutes
A	1	26.7	-0.06	0.30	0.63
A	1	46.1	-0.75	0.23	-0.21
A	1	65.6	-1.48	1.25	-0.53
A	1	85	-1.31	-1.20	1.50
A	2	26.7	-0.09	1.77	0.39
A	2	46.1	-2.13	2.14	-1.25
A	2	65.6	-0.80	-0.50	0.85
A	2	85	0.65	5.13	0.15
A	3	26.7	0.63	-0.30	-0.15
A	3	46.1	-0.77	0.25	-0.07
A	3	65.6	1.26	1.26	0.46
A	3	85	1.50	1.84	1.42
B	4	26.7	-1.34	0.05	0.37
B	4	46.1	-0.15	0.42	-1.11
B	4	65.6	1.17	0.63	0.64
B	4	85	1.76	0.99	1.17
C	5	26.7	0.00	3.70	3.78
C	5	46.1	-3.91	-3.18	0.71
C	5	65.6	0.54	2.88	2.60
C	5	85	1.54	0.04	-1.06
C	6	26.7	0.26	-0.40	1.33
C	6	46.1	0.88	1.21	-1.28
C	6	65.6	0.06	0.79	-0.84

Table E-2 (Continued)

Source	Juice Batch	Temperature °C	Change in* PTS after 30 minutes	Change in* PTS after 60 minutes	Change in* PTS after 90 minutes
C	6	85	-0.28	0.14	-2.58
C	7	26.7	-1.46	-1.09	-0.71
C	7	46.1	0.25	0.76	1.56
C	7	65.6	0.53	0.50	0.66
C	7	85	0.22	0.91	-0.27
B	8	26.7	-0.53	-1.51	-1.19
B	8	46.1	-0.20	-0.15	0.26
B	8	65.6	-0.56	-0.44	-0.65
B	8	85	1.21	0.71	0.62

*Negative values mean there are more total solids at the time considered than at the beginning (time = 0 mins) of the experiment.

Table E-3

Percent Total Nonsoluble Solids (PTNSS) and Clarity of the Treated Juice at the Middle Section of the Jars by Source and Temperature

Source	Juice Batch	Temperature °C	(PTNSS) = PTS0-PTSS0) Percent total[1] nonsoluble solids after 0 minutes	(PTNSS30 = PTS30-PTSS30) Percent total[1] nonsoluble solids after 30 minutes	(PTNSS60 = PTS60-PTSS60) Percent total[1] nonsoluble solids after 60 minutes	(PTNSS90 = PTS90-PTSS90) Percent total[1] nonsoluble solids after 90 minutes	(PTNSS0-PTNSS30) Clarity[2] after 30 minutes	(PTNSS0-PTNSS60) Clarity[2] after 60 minutes	(PTNSS0-PTNSS90) Clarity[2] after 90 minutes
A	1	26.7	1.24	1.40	0.94	1.11	-0.16	0.30	0.13
A	1	46.1	1.36	1.41	0.83	1.67	-0.05	0.53	-0.31
A	1	65.6	0.35	1.93	-0.40	-0.02	-1.58	0.75	0.37
A	1	85	1.22	1.73	1.82	-1.68	-0.51	-0.60	2.90
A	2	26.7	2.07	2.16	-0.20	1.48	-0.09	2.27	0.59
A	2	46.1	-0.15	1.68	-2.99	-0.20	-1.83	2.84	0.05
A	2	65.6	1.88	1.98	1.68	0.23	-0.10	0.20	1.65
A	2	85	1.89	1.44	-3.94	0.84	0.45	5.83	1.05
A	3	26.7	0.23	-0.70	1.03	-0.12	0.93	-0.80	0.35
A	3	46.1	0.37	0.74	0.72	0.44	-0.37	-0.35	-0.07
A	3	65.6	0.62	-0.34	0.36	0.46	0.96	0.26	0.16
A	3	85	1.08	0.28	0.64	0.16	0.80	0.44	0.92
B	4	26.7	0.66	1.90	0.61	0.29	-1.24	0.05	0.37
B	5	46.1	2.61	6.26	0.39	7.12	-3.65	2.22	-4.51
B	4	65.6	0.94	0.57	0.61	0.40	0.37	0.33	0.54
B	4	85	0.83	0.87	0.34	1.06	-0.04	0.49	-0.23
C	5	26.7	1.66	0.96	-2.74	-2.82	0.70	4.40	4.48
C	5	46.1	-2.22	1.69	0.96	-3.23	-3.91	-3.18	1.01
C	5	65.6	1.32	1.48	-0.66	-0.88	-0.16	1.98	2.20
C	5	85	1.10	-0.64	1.36	1.96	1.74	-0.26	-0.86
C	6	26.7	1.05	1.19	1.35	-0.38	-0.14	-0.30	1.43
C	6	46.1	1.83	0.45	-0.48	2.11	1.38	2.31	-0.28
C	6	65.6	1.17	0.61	-0.42	1.21	0.56	1.59	-0.04
C	6	85	-0.92	-0.64	-1.06	1.66	-0.28	0.14	-2.58
C	7	26.7	0.53	1.19	0.82	0.64	-0.66	-0.29	-0.11
C	7	46.1	1.14	1.39	0.68	0.28	-0.25	0.46	0.86
C	7	65.6	1.14	0.91	0.84	0.98	0.23	0.30	0.16
C	7	85	1.13	1.91	0.62	0.90	-0.78	0.51	0.23
B	8	26.7	0.24	1.77	2.25	1.63	-1.53	-2.01	-1.39
B	8	46.1	0.95	1.85	1.30	0.49	-0.90	-0.35	0.46
B	8	65.6	0.68	1.74	1.02	2.23	-1.06	-0.34	-1.55
B	8	85	1.94	1.73	1.23	0.92	0.21	0.71	1.02

[1]Negative values mean that there are no suspended solids at the time considered.

[2]Negative values mean that there are more suspended solids at the time considered than at the initial time t = 0 minutes.

VITA

S. Nwanele Aso was born on November 27, 1957, in the town of Elelenwo in Rivers State, Nigeria. In 1963, he started his elementary education at State School Elelenwo (then St. Mark's School Elelenwo). His elementary education was interrupted by the infamous Nigerian civil war from 1966 to 1969. In 1970 he returned to State School Elelenwo and received his first school leaving certificate in 1971. He enrolled into County Grammar School Ikwerre-Etche in 1972 for secondary education. He graduated from this institution in 1976 with division one in the West African School Certificate Examination (WASCE).

In the fall of 1977 he enrolled into Utah State University, Logan, but transferred to The University of Tennessee, Knoxville, in the summer of 1978. Nwanele received his Bachelor's degree in agricultural engineering from The University of Tennessee, Knoxville, in December 1981 and enrolled into the Master's program in the spring of 1982 at the same institution. He completed the requirements for the degree of Master of Science in Agricultural Engineering (with concentration in food engineering) in August 1983.

The author believes in science. He does not subscribe to human heroes because he feels that each man or woman is the architect of his or her own fortune. However, he admires people like Burky Fuller, Isaac Newton, Washington Carver, Albert Einstein, Martin Luther King, Jr., Jacques Cousteau, Obafemi Owolowo, Ronald A. Fisher, Murtala Muhamed, Nnamdi Azikiwe, Carl Sagan, and Carl Lewis. He also admires Malcolm

Forbes and Alex Haley, listens to music like Roots Radical and Black Boy by Jimmy Cliff and Michael Walden respectively, and loves the Swahili word uhuru in all its ramifications.

His favorite mottos include:

1. There is no excellence without great labour. This is the fiat of faith from which no power of genius can absolve you. . . .
2. You can not fail for trying hard enough. . . .