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To the Graduate Council:

I am submitting herewith a thesis written by James Osto Harwell entitled "Composition of sorghum cane juice intended for syrup production." 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 Food Science and Technology.

Melvin R. Johnston, Major Professor

We have read this thesis and recommend its acceptance:

Jimmy L. Collins, Ivon E. McCarty

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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

August 9, 1966

To the Graduate Council:

I am submitting herewith a thesis written by James Osto Harwell entitled "Composition of Sorghum Cane Juice Intended for Syrup Production." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Food Technology.

M. R. Johnston

Major Professor

We have read this thesis and recommend its acceptance:

Jimmie L. Collins

Ivan E. McCarty

William E. Goble

Accepted for the Council:

Hilton A. Smith

Dean of the Graduate School

# COMPOSITION OF SORGHUM CANE JUICE INTENDED FOR SYRUP PRODUCTION

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A Thesis

Presented to

the Graduate Council of

The University of Tennessee

---

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

---

by

James Osto Harwell

August 1966

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# CHAPTER I

## INTRODUCTION

The problems involved in making a high quality sorghum syrup are many. One of the problems most neglected or least understood is that concerning the relationship of various constituents contained in the juice and the finished syrup. On the whole, the literature indicates that earlier investigators made little attempt to correlate composition of the juice and quality of syrup.

Although the production of sorghum syrup has never been considered to have commercial importance, it continues to be produced on a limited scale in at least 35 states. Six southeastern states, Alabama, Mississippi, Arkansas, Tennessee, North Carolina and Georgia produce approximately 50 percent of the sorghum today.

The production of sorghum syrup has never been considered an important cash crop in Tennessee, and, consequently, the cane is not grown extensively in many areas of the state. Benton county, the largest syrup producing county in the state, reported that 25 percent of the row crop income for 1964 was derived from the production of sorghum (17). Other leading counties producing syrup in 1959 were Warren, Fayette, Tipton, Shelby and DeKalb. These 6 counties produced approximately 50 percent of the total for the state (15).

No information is available pertaining to consumer demand for sorghum syrup; however, from observations and conversations with producers, it is apparent that there is a commercial potential for high quality sorghum syrup. In order to develop this potential, it will be necessary to eliminate practices contributing to the production of inferior syrups. One of the contributing factors, as reported by research workers, is the influence of various chemical constituents of the juice. More data pertaining to the presence of these constituents and their influence on syrup quality are vital to overall improvement of quality and to the further development of the industry.

With this factor in mind, the objectives of this study were (1) to determine the presence of certain chemical constituents in the juice, and (2) the concentrations of these constituents in the various internodes. By knowing where these constituents are most concentrated, steps deemed necessary for the alteration or elimination of the juice can be initiated.

# CHAPTER II

# REVIEW OF THE LITERATURE

Sorghum is one of the few domesticated plants for which the geographic origin is well defined. The center of origin of domesticated sorghum is the continent of Africa. Other centers were established centuries ago in interior Asia, India, China, Malaya; and more recently in Southern Europe, the Americas, Australia and other parts of the world. The recognized wild types of sorghum are limited to Africa, south of the Sahara, and range far down into the temperate zone of South Africa (3).

## I. TAXONOMIC CLASSIFICATION OF SORGHUM

The sorghums belong to the grass family Gramineae. The four groups of sorghum grown in the United States are:

1. Grain sorghums, or non-saccharine sorghums, grown especially for their rounded, starchy seed for livestock feed.

2. Sweet sorghums, or saccharine sorghums, grown for their use in syrup making because they are the solid-stemmed type with sugary juice. These sorghums also are grown extensively for use in making silage for livestock feed.

3. Grassy sorghums, included in this group, are Johnson grass and Sudan grass, grown for livestock grazing and hay.

4. Broomcorn, used for making brooms.

Grain-, sweet-, and broomcorn sorghums are classified as *Sorghum vulgare* (11, 35).

## II. INTRODUCTION OF SORGHUM INTO THE UNITED STATES

Sorghum seed was first distributed in the United States in 1857 by the commissioner of patents, Washington, D. C. The seed was brought here from France. It had been previously brought to France from Africa (17).

The first group of seed introduced included one variety from China and 15 varieties from South Africa for the production of sugar. Later, many races of sorghum were brought to the United States, among them were representatives of the solid stemmed, sugary juice types. None of the latter entries have proved superior to the original introductions or varieties selected from the original introductions (3).

During the 90 year period since the first group of 16 varieties was introduced, an immense number of variant forms have evolved by selection, by planned hybridization and new introductions. No less than 389 "domestic varieties," or at least plant materials with that many designations, have been assembled at the Meridian, Mississippi Agricultural Experimental Station (3).

## III. DEVELOPMENT OF THE SORGHUM SYRUP INDUSTRY

Sorghum syrup is produced from the raw, whole juice extracted from the stalks by passing them through a mill, removing the impurities, and concentrating the juice to the desired density, by evaporation, without the removal of any of the sugars. This method distinguishes sorghum syrup from molasses which is the liquid remaining after part of the sugar has been removed in the manufacture of sugar (6, 27).

The sorghum syrup industry developed from the economic necessity of the early settlers to supply their own sweets. The individual farmer produced enough syrup to supply his immediate needs. If small surpluses developed, they were sold in the adjacent neighborhood. Consequently, sorghum production has always been largely a secondary crop on most farms.

The continued failure of the small producer to exploit more fully the major cash crop potential offered by sorghum syrup may, in part, explain the rather slow development and improvement of the industry. According to a study by Keller (15), the net per acre returns to labor amounted to $98.64 (labor cost was $1.00 per hour, land charge was $150.00 per acre, average yield was 95 gallons per acre).

The sorghum industry has made little progress since its introduction into the United States. For example, the first method for extracting the juice from stalks was by the use of presses made from wood. Black locust was generally used because it was one of the harder woods and would last longer. Shortly thereafter, mills were made of cast iron and steel and were operated by horses hitched to a sweep. Some of these presses are still in use today where syrup is made on a small scale. In more recent years, horizontal mills have been developed which are larger and operated either by a gasoline engine or electric motor. Mills have progressed to the point where one midwestern grower has developed a machine which cuts, grinds, and leaves the refuse in the field; then he hauls the juice to the processing plant in a tank (1).

The early method for cooking the juice into syrup was in pots, kettles, and metal boxes. About 1875, the fire heated evaporator, sometimes referred to as a pan, came into general use. This pan was a flat, thin metal (galvanized, iron or copper) container, with baffles spaced equidistant (6 inches apart) over the entire length of the pan. The baffles controlled the flow rate of the juice by forcing it to travel in a zig-zag pattern from the raw juice end of the pan to the finishing end. The baffles also facilitated skimming.

The development of the evaporator is generally considered the most significant innovation adapted by the syrup industry. Although several modifications have been made available, the evaporator in its original shape is used at many of the small syrup production centers today.

The advantages offered by the evaporator over the pots, kettles and boxes are:

1. Rapid evaporation, which is essential to make a light colored syrup.

2. Syrup is concentrated in a thin layer, thus increasing the rate of boiling and foaming which affords better opportunity for thorough skimming.

3. Heat is applied to the bottom of the evaporator, thus imparting an upward motion to the coagulated material which facilitates skimming (28).

The disadvantages are:

1. More attention is required to maintain a properly regulated flow of juice.

2. Increased danger of scorching the syrup and altering its flavor and color.

3. More careful attention to regulating firing of furnace.

4. Requires more skill to obtain uniform syrup density.

The evaporator was generally considered to be a continuous process, but due to the scale of operation and lack of training and skill of operators, it very seldom operated this way. This method of evaporation is still used in the small scale sorghum syrup industry.

The use of gas and steam as fuel for cooking syrup has eliminated much of the work involved. In years past, one of the most laborious tasks was obtaining and transporting the wood to be used for the evaporator fuel. With the use of gas or steam, the heat can be regulated and maintained at the desired temperature over the entire surface of the evaporator, thereby minimizing the labor requirements and other disadvantages associated with the use of wood for fuel.

## IV. STATUS OF SORGHUM PRODUCTION

The sorghum industry has fluctuated considerably over the years, and has generally paralleled existing economic patterns. In periods of economic stress, war and depression, production has increased, whereas in periods of prosperity production has declined. About 1879, sorghum was proportionately a much more important crop than it has been since this time. Although the purpose for which the plant was brought to America was never realized, sorghum did become an important crop plant. During the Civil War and immediately afterwards, it provided the farmer "long sweetnin" in the form of thick syrup (3).

According to the 1909 Census of Agriculture, 16,532,000 gallons of syrup were produced in 1909. In 1920, production was increased to 49,505,000 gallons, according to estimates by the U.S. Department of Agriculture. The average price received by producers that same year was $1.07 per gallon, making the value of the crop in that year approximately $52,922,000. This large increase in production and the price received per gallon were due to the scarcity of sugar following World War I.

Subsequent to 1920, there was a decrease in both production and price received by producers. In 1925, 24,926,000 gallons of syrup were produced, having an average value of 94.9 cents per gallon; and in 1928, 26,972,000 gallons were produced at an average value of 91.5 cents per gallon (6).

During the 20 year period 1932-1951, sorghum syrup production varied considerably from year to year. Annual production ranged from 21,326,000 gallons in 1933 to 2,595,000 gallons in 1952. Price per gallon received by farmers ranged from 48.1 cents per gallon in 1933 to $2.22 in 1952. The peak annual income from sorghum syrup for this period was $21,670,000 in 1946, received for 10,171,000 gallons (23).

# V. AREAS OF SORGHUM CANE PRODUCTION

Some sorghum is grown for syrup in at least 35 states. The adaptability of sorghum to widely diverse soil and climatic conditions is illustrated by the fact that it is grown as far south as Alabama, as far north as Minnesota, and as far west as New Mexico. However, sorghum grown for syrup production today is concentrated chiefly in the southeastern states.

Six states, Alabama, Mississippi, Arkansas, Tennessee, North Carolina, and Georgia, sometimes referred to as the "Sorgo Sirup Belt," produce approximately 50 percent of the total annual amount of sorghum syrup (23). Mississippi and Alabama have been the largest producers for many years.

The production of sweet sorghum for syrup in Tennessee is not very extensive as compared to some of the common crops, and it never has been considered an important cash crop. However, it could become an important source of income on some farms and in some areas of the state. Benton county, which is one of the leading syrup producing counties in Tennessee, reported that 25 percent of the row crop income for 1964 was derived from the production of sorghum (17).

In 1959, the Census of Agriculture reported a total of 2,980 acres of sorghum grown in Tennessee, with a total production of 215,378 gallons of syrup. About 63 percent of this total was sold, while about 37 percent was produced for home consumption. At prevailing prices, the total sales of sorghum syrup for the State in 1959 was slightly over $250,000 (15).

Sorghum syrup produced in Tennessee, as in other parts of the country, is chiefly consumed in the area of production (22). The chief reason is that sorghum syrup is still being produced primarily to satisfy only the table need for "sweentnin" of the individual producer and it is not being produced on a commercial basis. The small surplus available is easily disposed of at point of production to local consumers. Consequently, none is available to distant markets. Another reason for the lack of widespread distribution is that, due to the small scale of production, the lack of uniformity and poor quality syrup makes development of wide distribution difficult.

Sorghum has found wide acceptance as a forage crop as well as for syrup production. It occupies about 2 million acres in the subhumid parts of the Great Plains (3). About 20,000,000 acres of sorghum are grown in the United States each year (35). This figure is a total for all sorghums grown for various products.

## VI. SOME OF THE MAJOR PROBLEM AREAS IN SYRUP PRODUCTION

Problems inherent in the production of a high quality syrup from sorghum cane are many and varied. Due to insufficient research efforts, possibly as a result of continued farm-unit scale of production, the problems are neither realized or understood.

Problems encountered in syrup production can be divided into two categories: (1) production of stalks up to and including the extraction of the juice, and (2) production of syrup.

The major research efforts of past years have been largely directed towards the production of the crop with much less effort expended towards the elucidation and definition of the influence of the various factors on the production of syrup. As a result, many of the problems concerned with the production of sorghum cane are fairly well defined, whereas correlation of juice composition with quality of the resulting syrup is not.

The raw juice, as it is received from the mill, is a complex system containing in addition to sugar and water, soil particles, stalk fiber particles, organic and inorganic salts, organic acids, starch and other complex carbohydrates, proteins, pigments, gums and waxes. Many of these constituents are deemed as undersirable impurities and must be removed or altered in some manner for production of a high quality syrup.

Since the syrup is produced from the whole raw juice extracted from the stalks, it is quite conceivable that any factor influencing quality of juice will exert its influence on the quality of finished syrup.

The problem of cultural practices as related to juice yield per ton of stalk and its influence on syrup quality is as old as the industry. The misconception and reluctance concerning the use of chemical fertilizer has undoubtedly contributed to low juice yield. Cowgill (6) found that retarded growth always resulted in a decrease in the proportion of internodes to nodes and that juice from nodes always was darker and contained more "impurities" than did juice from internodes. His study indicated that syrup made from stalks that developed slowly or intermittently was invariably of inferior quality. Woodle (34) and Stokes (23) found that although sorghum responded to applications of barnyard manure, it should not be recommended for direct application to sorghum because a syrup of poor quality would be produced.

Clarification of the raw juice is a necessary step in the production of quality syrup, and much research effort has been devoted toward this accomplishment. Impurities are present in the juice in both suspension and solution. Undissolved impurities can be physically separated from the raw juice, whereas those in solution calls for some alteration of the juice to initiate their removal. Many schemes and many substances have been proposed for clarification. Use of some accomplished their intended objective while the use of others is questionable. The prescribed method for removal of undissolved impurities are, straining of the raw juice immediately after grinding and permitting the juice to remain in large settling tanks undisturbed for various periods of time before decanting for evaporation (4, 12, 13, 27, 28, 30, 34).

When heat is applied to the raw juice, much of the starch is rendered soluble, but certain of the proteins and other non-sugar substances become coagulated. If permitted to settle, some of the coagulated material rises to the surface where it can be skimmed or brushed off, other material sinks to the bottom and cannot be removed (27).

Lime is sometimes added to the juice to partially neutralize its acidity. This action also aids in the precipitation of the organic matter. Phosphoric acid compounds, carbonate of lime, sulphur, and vegetable carbons have been used to some extent in juice clarification. Although the addition of chemicals tend to facilitate clarification, they generally adversely effect the flavor and color of the syrup (4).

Various types of clays and diatomaceous earth compounds have been used as an aid in juice clarification. Webster, Davies, and Sielinger (30) found that an improved syrup resulted from the use of various clays in juice clarification, although the yield of syrup was somewhat reduced. They concluded that the use of clay, under laboratory conditions, was both practical and desirable since it reduced the amount of scum produced during heating and reduced jellying and/or clabbering of the finished syrup. Organoleptic evaluation indicated the treated samples were superior to non-treated samples. However, the disadvantages of using clays in small scale operations were listed as being, transportation of clay to the farm, necessity of settling tanks, and the time and effort required to transfer the heated juice to and from the tanks. Gaessler, Reid and Cuthbert (9, 10) evaluated the qualities necessary for a clay in order to secure good juice clarification as follows: sand, 26 percent; silt, 21 percent; 5 micron clay, 53 percent; 2 micron clay, 48.5 percent; and pH of about 7.45. Willaman, West, and Bull (32) stated that clay of proper analysis for good clarification was difficult to find and did not recommend its use.

Jellying or clabbering of syrup often presents a serious problem to the syrup producer. Sherwood (18, 19) was among the first to prove that starch is the causative agent in jellying. Willaman and Davison (33) reported that the starch content ranges from 0.32 to 1.15 percent in normal syrups and from 1.17 to 3.36 percent in syrup that jelled. Walton and Ventre (26) found that starch is responsible for slow boiling and scorching of syrup during evaporation. Numerous workers have since reported on the occurrence and distribution of starch in the sorghum stalk and its influence on syrup quality.

Sugar crystallization is another serious problem of syrup producers in many areas. Walton and Ventre (27) found that crystallization in sorghum syrup could occur from either an excess of reducing sugars or sucrose. Ventre, Byall, and Walton (25) reported that when the ratio of sucrose to reducing sugar in syrup was 1.15 or greater, sucrose crystallized. As a factor of quality the crystallization of dextrose was as important as sucrose. The authors also reported that sucrose crystallization occurs most frequently in syrup made from the upper portions of the stalk and that the number of parts of the stalks yielding syrup that crystallized increases with maturity.

In the cane technology field, it is generally accepted that crystallization in high density syrups can be prevented by attaining a sucrose to reducing sugar ratio of approximately 1:1. The problem of crystallization may be eliminated by proper varietal selections based on sugar balance of the juice with other factors being equal. Johnson, Sperow, and McLaren (14) determined the sucrose and reducing sugar content of six varieties of sorghum grown in West Virginia and found only two of the six varieties with a proper balance of sugars to prevent crystallization. They also indicated that possibly the naturally occurring enzyme systems of the stalk, coupled with the practices of the producer in handling the stalks after harvest, could be a significant factor in the crystallization of particular sugars.

Since the enzyme invertase occurs naturally in sorghum stalks, most of the suggested procedures for the prevention of crystallization in syrup is based upon its activity. These procedures are summarized in the various U.S.D.A. publications (27, 30, 34). However, the conversion of sucrose by the enzyme invertase will assist in the prevention of crystallization of sucrose; but it will not prevent, and in fact may induce, dextrose crystallization.

The equipment and process used to evaporate the juice and the skill of the operator are other factors contributing to the quality of syrup. The basic objective of the syrup producer should be to complete the removal of water from the juice as rapidly as possible. Much of the syrup is still being produced on antiquated equipment, possibly this fact results from an inadequate understanding of the complex nature of the juice. The methods presently employed in syrup evaporation are summarized in various U.S.D.A. publications (4, 6, 12, 13, 23, 27, 28, 34).

## VII. CHEMICAL ANALYSES OF SORGHUM JUICE

A review of literature indicates that very little work has been done on the chemical analysis of sorghum juice as related to the production of a high quality syrup.

Webster, Davies, and Sielinger (29) stated that the first step toward industrial development of large scale production of syrup from sweet sorghum as well as toward a better homemade syrup, is a more thorough knowledge of the chemical composition of juices and syrups made from the various varieties now being grown. This information would also be helpful to the plant breeder seeking to develop improved varieties.

Webster, Davies, and Sielinger (29) determined the effect of variety on yield of juice, brix, oven solids, ash, pH, titratable acidity, sugars (reducing, sucrose, and total), non-sugar solids, nitrogen, and quantity of syrup per acre. Their evaluations were made on several varieties at different stages of maturity for the years 1943, 1944, and 1945. Results of their work follows:

Generally the yield of juices was around 45 percent at the optimum stage of maturity, after which the yield declined. This decline in yield was greater for the early maturing varieties than for the late maturing varieties.

Solids increased as the season progressed and most juices contained from 14 to 20 percent solids with the exception of one which was 24 percent.

The percentage of ash varied in much the same manner as did the solids, increasing gradually as the season progressed. Some varieties, however, varied more than others.

On samples where pH determinations were made, the pH value varied from 4.95 to 5.30. Ordinarily pH values increased as the season progressed, but not to the extent of the increase found in titratable acidity, which showed a marked increase as the season progressed.

The sugar content of the juices varied from less than 10 percent to nearly 20 percent, and maturity brought with it a concomitant increase in sugars. A general decrease was found in percentage of reducing sugars and an increase in percentage of sucrose as the season progressed in all varieties; however, large varietal differences occurred in the ratio of the two sugars.

At the time of publication, the data for nitrogen content were incomplete, but on the work completed results showed that almost invariably the juices that were most difficult to process were those that were high in nitrogen. Such samples were more difficult to finish and required much greater care in handling to avoid scorching. This study indicates that a juice low in nitrogen is preferred.

In evaluating the various varieties for producing high quality syrup, considerations were made concerning time of maturity, acid content, color, clabbering, yield per acre, and the crystallization of finished product. Of the 12 varieties studied, two were recommended, with further studies recommended for several others.

Coleman and Stokes (5) studied the effects of various storage periods and conditions of storage of stalks prior to grinding on the yield of juice and quality of syrup obtained from several varieties of sorghum cane. Since the methods of harvesting and processing cane vary considerably from area to area in the sorghum belt, it was felt that a study of this nature could be of significant value to the industry.

In this study, Coleman and Stokes (5) determined the percent extraction, brix, sucrose, total sugars and titratable acidity of the juice after various storage times under various storage conditions for seven varieties. The storage time varied from 0 to 16 days and the conditions of the cane during storage were: stripped, unstripped, protected, unprotected, wet and dry, and combinations of these.

Results show that juice decreased in stalks stored dry, due to evaporation, while brix values increased. Sucrose losses were negligible for stalks kept wet, and only slight for stalks stored dry. Acidity was not affected by length of storage, or by wet and dry treatments. Inversion took place more rapidly in some varieties than in others. In general, dextrose and levulose increased during the first 10 days of storage, whereas sucrose decreased.

Determinations made on the syrup included clarity, viscosity, color, syrup produced per ton of stalks and finishing temperature of syrup for various treatments.

Conclusions drawn from the effect of various conditions on the finished syrup were as follows: (1) Improved syrup quality with reduced crystallization, resulting from storing the stalks dry for 6 days, while storing the stalks wet counteracted the normal benefits of storage on syrup quality; (2) Protecting the stalks had no beneficial effect on syrup yield and quality; (3) Removal of the top fourth of the stalk reduced the yield of syrup but slightly improved syrup quality; (4) Storage for 6 days improved quality as measured by finishing temperature, clarity and viscosity but caused slightly darker syrup; and (5) No inversion of sugars took place in the syrup, and syrup yields were increased by storage of the stalks for 6 days for some varieties.

Conclusions from this study definitely indicate that the various treatments used in harvesting and storing sorghum cane has a direct bearing on the quality of the finished syrup made from the juice.

Webster, Benefiel, and Davies (31) conducted a study on the chemical composition and yield of juice as related to time of harvest of 8 varieties of sorghum cane. They determined the brix, acidity, ash, reducing sugars, sucrose, total sugars, and percentage of juice extracted.

The data for 8 varieties were so voluminous that all of it was not published; however, some generalizations made concerning the results from the study were as follows: (1) Solids in the juice increase irregularly until near the close of the season when a slight decrease often occurs; (2) Titratable acidity values normally increase during the harvest season, often doubling or tripling before the season ended. This increase in acidity has often been quoted as the reason for poor quality syrup made late in the season; (3) Total sugars and sucrose increased generally throughout the season to a maximum and then remained relatively constant during the last month. Reducing sugars sometimes increased, but more often decreased as the harvest season progressed.

It was found that almost invariably a regular reduction in percent extractable juice occurred as the season progressed.

Webster, Benefiel, and Davies (31) surmised that the most important factor influencing the yield of syrup at any given time is climate. Favorable climate gives a longer growing season thus producing more juice to be made into syrup. The recommended time of harvest from results of their study is from September 1st to the 25th.

Ventre, Byall, and Walton (25) determined the effects of sugar and starch content, in relation to crystallization and jellying, of the syrup produced from juice obtained from stalks harvested in the milky, dough-to-ripe, and dead ripe stages of maturity. On the basis of the data obtained from 67 samples of syrup made from various parts of the stalk and from 10 samples made from the whole stalk, their conclusions were as follows: (1) The starch content and jellying of sorghum syrups are correlated and the upper portions of the stalk produce syrups of highest starch content; (2) Sucrose crystallization occurs most frequently in syrups made from the upper part of the stalk; (3) Dextrose crystallization occurs most frequently in syrups made from the lower portions of the stalk; and (4) Jellying and crystallization of either sucrose and dextrose may occur in the same syrup. The authors also found that the portions of the stalk yielding syrups that jelled and those in which sucrose crystallization occurred increased with maturity, whereas the portions of the stalk producing syrups which crystallized dextrose decreased with maturity.

A review of the literature reveals that data concerning the acid composition of sorghum juice and its influence on syrup quality are seriously limited. Research workers to date have limited their efforts largely to determinations of pH and titratable acidity of the juice as affected by various cultural practices with little or no attempt to correlate these data with syrup quality.

On the basis of the voluminous data compiled by researchers in the sugar cane industry on the acid composition of sugar cane and how it influences various processes in the manufacturing of sugar, one can surmise that the significance of the various acids of sorghum has received far less attention than is merited by their possible importance.

As reported by Martin (16), the organic acids, both nitrogenous and the non-nitrogenous, are significant factors in sugar manufacture from sugar cane. The nitrogenous acids, although present in very small quantities, affects clarification, color formation, centrifuging, and possibly the amount of crystal formation. The non-nitrogenous acids are present in greater quantities and affect sugar manufacture in much the same manner as the nitrogenous acids. Of the non-nitrogenous acids found in sugar cane, aconitic acid is the most abundant. Yoder (36) showed that aconitic acid amounted to at least 0.05 percent by volume of Louisiana cane juice. Fort _et al_. (8) analyzed composite samples from 26 factories located throughout the sugar belt of Louisiana and found amounts of aconitic acid ranging from 3.3 to 7.0 percent of the dry solids of molasses.

CHAPTER III

# MATERIALS AND METHODS

## I. MATERIALS

The cane utilized in this study was grown by Johnny Foust, Anderson County, Tennessee, under the supervision of the Agricultural Extension Service. The two varieties, Tracy and Mer 59-1, were grown under similar conditions in adjacent plots in the same field. Both varieties were harvested at comparable stages of maturation. The cane was stripped and headed in the field, cut, and transported to the Food Technology Department pilot plant for extraction.

## II. METHODS OF ANALYSIS

The stalks were cut at the nodes, numbered consecutively from the butt to and including the peduncle, and segregated in batches according to number for pressing. After each batch was weighed, the internodes were passed through a small pilot plant size three roller press, and the juice was collected and weighed. The percentage of juice extracted was calculated.

Alcohol insoluble solids (AIS) were determined by weighing a 20-gram sample of juice into a 600 ml condensor flask, followed by the addition of 140 ml of 80 percent ethyl alcohol. The mixture was then boiled for 30 minutes on the reflux condensor. The flask was then removed from the condensor and the AIS was filtered on No. 1 Whatman filter paper and rinsed with two portions of 80 percent alcohol by the use of a water aspirator (2).

The filtered sample was then placed in a tared evaporating dish and placed in the oven for 2 hours at 100° C. After drying, the dish was removed from the oven, cooled in a desiccator, and weighed. The insoluble material was calculated as percent AIS.

Ash was determined by weighing a 10-gram sample of juice into a tared platinum dish, evaporating to a syrupy consistency on a water bath to prevent caramelization, and transferring to a muffle furnace. The sample was ignited for four hours at 550° C, transferred to a desiccator, cooled, and weighed. The amount of material remaining was calculated and expressed as percent ash (2).

Total solids were determined by weighing a 10-gram sample of juice into a tared evaporating dish containing 10 to 20 grams of quartz sand and evaporating to dryness on a water bath. The sample was then placed in a 70° C vacuum oven operated at 20 inches mercury for 16 hours where drying was completed. The sample was transferred to a desiccator, cooled, and weighed. The amount of insoluble material was calculated and expressed as percent total solids (2).

The pH was determined on the raw juice by use of a Beckman Zeromatic pH meter.

Total acidity was determined on a 10-ml aliquot of juice. The juice was pipetted into a 150 ml beaker, 40 ml of boiled distilled water were added, and the mixture was titrated with 0.1 N NaOH to a pH of

8.1 using the pH meter. The results were expressed as ml of 0.1 N NaOH required to neutralize 10 ml of juice (2).

Brix or soluble solids of the juice was determined by use of an Abbe Refractometer. The brix readings were recorded at a constant temperature by passing tap water through the jacket surrounding the prisms and corrected to readings at 20° C by use of conversion tables (24).

Glucose was determined colormetrically by employing the Fermco S.F.G. Test, Method II, using the enzyme preparation chromogen (7). Absorbance values were obtained by use of a Bausch and Lomb Spectronic 20 colorimeter set at 540 mμ. The absorbance values were converted to percent glucose by referring to a standard curve.

Glucose produced from sucrose was determined, after inversion by use of the enzyme invertase, by measuring glucose as described above, deducting the amount of glucose found before inversion from the amount found after inversion.

When sucrose reacts with acids and certain other reagents, it hydrolyzes and is converted into a mixture of equal parts of glucose and fructose. By this reaction sucrose is hydrolyzed or inverted. The mixture is called invert sugar. The expression invert sugar, reducing sugar, and glucose are frequently used synonymously in the cane sugar industry (21).

Total sugars is the expression used to indicate the sum of free glucose plus 2 times glucose from sucrose.

Each factor measured was analyzed as a factorial arrangement of a completely randomized design. The effect of factors studied was tested for significance by analysis of variance. Significance among means was determined by use of Duncan's Multiple Range test. Statistical methods employed were those described by Snedecor (20).

CHAPTER IV

# EXPERIMENTAL RESULTS

In discussing the results in this experiment the internodes will be referred to as positions. Position 1 is the internode nearest the ground and continuing up the stalk through position 12, the peduncle.

For further comparison and discussion the stalk was divided into four sections. Section 1 is composed of positions 1, 2, and 3; section 2, positions 4, 5, and 6; section 3, positions 7, 8, and 9; and section 4, positions 10, 11, and 12.

## I. PERCENTAGE OF JUICE EXTRACTED

The data in Table I present the analysis of variance of the combined varieties which show no significant difference between varieties or between positions for percent juice extraction. However, when taking the varieties individually, wide differences were noted in mean values of juice obtained from different positions of the two varieties. Also, the percent extraction did not necessarily follow the same pattern between positions of the two varieties. For example, the positions yielding the highest and lowest percentage of juice in Mer 59-1 variety were numbers 3 and 4, with 54 percent and number 11, with 31 percent, respectively. Whereas in Tracy, position 6, with 52 percent, was the highest yielding and position 9 was lowest with a yield of 35 percent. By subdividing the stalks into sections, as

TABLE I

RELATIONSHIP OF PERCENT EXTRACTION TO VARIETY AND POSITION (INTERNODE) ON STALK (STEM)

| Internode | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mer 59-1 | 40.000 | 52.000 | 54.000 | 54.000 | 52.000 | 47.000 | 45.000 | 42.000 | 63.000 | 36.000 | 31.000 | 32.000 |
| Tracy | 40.000 | 43.000 | 47.000 | 49.000 | 51.000 | 52.000 | 51.000 | 50.000 | 35.000 | 43.000 | 37.000 | 37.000 |

Analysis of Variance Summary

| Source | DF | MS | F ratio |
|---|---|---|---|
| Variety | 1 | 7.0417 | 0.133 N.S. |
| Position | 11 | 82.4659 | 1.563 N.S. |
| Error | 11 | 52.7689 | |

| Internode | 11 | 12 | 10 | 1 | 8 | 7 | 6 | 2 | 5 | 3 | 4 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 31.0 | 32.0 | 36.0 | 40.0 | 42.0 | 45.0 | 47.0 | 52.0 | 52.0 | 54.0 | 54.0 | 63.0 |

Statistical significance 0.05 level ____________________ previously mentioned, it is interesting to note that the Mer 59-1 variety produced an average of 49, 51, 50, and 32; and Tracy produced 43, 51, 45, and 39 percent juice from sections 1, 2, 3, and 4, respectively. The mean value for juice extracted from the 12 positions was 45.667 percent for the Mer 59-1 variety and 44.583 percent for Tracy.

## II. ALCOHOL INSOLUBLE SOLIDS

Analysis of variance shows a significant difference in percent AIS content of the juice between varieties and between positions. The results of Duncan's Multiple Range test (Table II) shows no significant difference between positions 7 through 12 and 2 through 5. The lowest and highest AIS values for the Mer 59-1 variety were 0.117 percent in position 4 and 0.447 percent in position 12. In Tracy, position 2 was low with 0.227 percent and position 11 was highest with 0.787 percent AIS. Generally speaking, both varieties followed the same pattern in AIS content. Position 7 in both varieties appeared to be in the transitive position between the lower AIS content in the lower position and the higher AIS values in the upper positions. The ratio of AIS in the upper six positions to the lower six positions in the Mer 59-1 variety was 1.8:1 and 2.2:1 in Tracy. Section 4 of the stalks contained 38 percent of the total AIS found in the Mer 59-1 variety and 36.4 percent of the total AIS found in Tracy.

TABLE II

RELATIONSHIP OF ALCOHOL INSOLUBLE SOLIDS TO VARIETY AND POSITION (INTERNODE) ON STALK (STEM)

| Internode | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 1 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mer 59-1 | 0.287 | 0.197 | 0.163 | 0.117 | 0.143 | 0.213 | 0.240 | 0.240 | 0.323 | 0.383 | 0.390 | 0.447 |
| Tracy | 0.297 | 0.237 | 0.257 | 0.280 | 0.280 | 0.290 | 0.477 | 0.567 | 0.687 | 0.750 | 0.787 | 0.393 |

Analysis of Variance Summary

| Source | DF | MS | F ratio |
|---|---|---|---|
| Variety | 1 | 0.5814 | 16.194** |
| Position | 11 | 0.1244 | 3.465* |
| Error | 11 | 0.0359 | |

| Internode | 4 | 3 | 5 | 2 | 6 | 1 | 7 | 8 | 12 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 0.198 | 0.210 | 0.212 | 0.217 | 0.252 | 0.292 | 0.358 | 0.403 | 0.420 | 0.505 | 0.567 | 0.588 |

Statistical significance 0.05 level

## III. ASH

The analysis of variance indicates a significant difference in percent ash content of the juice between varieties and positions on the stalk. Duncan's Multiple Range test (Table III) shows no significant difference between positions 1, 2, 3, 11 and 12, or between positions 4 through 10 with the exception of position 8.

The mean for positions of the combined varieties shows that sections 1 and 4 contain the highest percentage of ash while sections 2 and 3 are lower, indicating that the center section of the stalk is lowest in percentage of ash. This fact is established by comparing the high and low positions for the two varieties. The Mer 59-1 variety had a high of 1.030 percent ash at position 1, then the ash content progressively decreased to a low of 0.683 at position 8. From position 8 there was a progressive increase in the ash value to 1.027 percent at position 12. Tracy showed a high of 1.110 percent at position 1, the ash content decreased to a low of 0.523 at position 6, followed by a progressive increase to position 12.

Generally, both varieties followed the same pattern with high yields at the lower position, decreasing toward the center of the stalk and then increasing to the top position of the stalk.

## IV. TOTAL SOLIDS

The analysis of variance of percent total solids extracted from the juice shows a highly significant difference between varieties but no significant difference among positions (Table IV).

TABLE III

RELATIONSHIP OF ASH TO VARIETY AND POSITION (INTERNODE) ON STALK (STEM)

| Internode | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mer 59-1 | 1.030 | 1.110 | 0.940 | 0.797 | 0.763 | 0.900 | 0.783 | 0.683 | 0.797 | 0.840 | 0.960 | 1.027 |
| Tracy | 1.110 | 1.040 | 0.863 | 0.743 | 0.607 | 0.523 | 0.587 | 0.650 | 0.760 | 0.800 | 0.787 | 0.710 |

Analysis of Variance Summary

| Source | DF | MS | F ratio |
|---|---|---|---|
| Variety | 1 | 0.2628 | 10.462** |
| Position | 11 | 0.1173 | 4.669* |
| Error | 11 | 0.0251 | |

| Internode | 8 | 5 | 7 | 6 | 4 | 9 | 10 | 12 | 11 | 3 | 1 | 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 0.667 | 0.685 | 0.685 | 0.712 | 0.770 | 0.778 | 0.820 | 0.868 | 0.873 | 0.902 | 1.070 | 1.075 |
| Statistical significance 0.05 level | | | | | | | | — | — | — | — | — |
| | | — | — | — | — | — | — | — | — | — | | |
| | — | — | — | — | — | — | — | — | — | | | |

## TABLE IV

RELATIONSHIP OF TOTAL SOLIDS TO VARIETY AND POSITION (INTERNODE) ON STALK (STEM)

| Internode | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mer 59-1 | 12.440 | 8.927 | 8.917 | 8.597 | 9.673 | 9.703 | 10.187 | 10.750 | 11.403 | 10.550 | 10.250 | 9.257 |
| Tracy | 12.513 | 14.207 | 14.503 | 14.523 | 13.603 | 13.150 | 15.190 | 15.510 | 14.383 | 13.807 | 13.017 | 11.493 |

Analysis of Variance Summary

| Source | DF | MS | F ratio |
|---|---|---|---|
| Variety | 1 | 259.9987 | 62.880** |
| Position | 11 | 3.3552 | 0.811 N.S. |
| Error | 11 | 4.1348 | |

| Internode | 12 | 6 | 4 | 2 | 11 | 5 | 3 | 10 | 1 | 7 | 9 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 10.375 | 11.427 | 11.560 | 11.567 | 11.633 | 11.638 | 11.710 | 12.178 | 12.477 | 12.688 | 12.713 | 13.310 |

Statistical significance 0.05 level ______________________________

The means for positions indicate no definite trend as to highs and lows for positions. The Mer 59-1 had an overall average for the 12 positions of 10.024 percent total solids, while the Tracy had an average of 13.875. The ratio of percent total solids for Mer 59-1 to Tracy was 3:4.

## V. pH

The analysis of variance for pH shows there was a significant difference between varieties but no difference between positions. The 12 positions in the Mer 59-1 variety had an average pH value of 5.377, while the average for 12 positions in the Tracy variety was 5.203.

Means for positions of the combined varieties (Table V) indicate that positions 2 through 7 had the highest pH value, while the upper positions on the stalk showed a lower pH.

Considering the two varieties individually, position 6 for both varieties was highest in pH, with a progressive decrease in pH toward both ends of the stalk.

## VI. TOTAL ACIDITY

The analysis of variance (Table VI) shows a significant difference in total acidity between varieties and positions of the stalk. In comparing means for positions of the combined varieties, the positions with the highest total acidity are sections 1 and 4, while sections 2 and 3 are considerably lower. For comparison, section 4 had an average of 3.760 total acidity, whereas, section 2 averaged 2.284.

TABLE V

RELATIONSHIP OF pH TO VARIETY AND POSITION (INTERNODE) ON STALK (STEM)

| Internode | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mer 59-1 | 5.200 | 5.400 | 5.500 | 5.400 | 5.500 | 5.500 | 5.400 | 5.350 | 5.340 | 5.300 | 5.330 | 5.300 |
| Tracy | 5.300 | 5.250 | 5.220 | 5.260 | 5.300 | 5.360 | 5.160 | 5.100 | 5.140 | 5.100 | 5.050 | 5.200 |

Analysis of Variance Summary

| Source | DF | MS | F ratio |
|---|---|---|---|
| Variety | 1 | 0.1803 | 33.627** |
| Position | 11 | 0.0123 | 2.292 N.S. |
| Error | 11 | 0.0054 | |

| Internode | 11 | 10 | 8 | 9 | 1 | 12 | 7 | 2 | 4 | 3 | 5 | 6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 5.190 | 5.200 | 5.225 | 5.240 | 5.250 | 5.250 | 5.280 | 5.325 | 5.330 | 5.360 | 5.400 | 5.430 |
| Statistical significance 0.05 level | | | | | | | | | | | | |

TABLE VI

RELATIONSHIP OF TOTAL ACIDITY TO VARIETY AND POSITION (INTERNODE) ON STALK (STEM)

| Internode | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mer 59-1 | 3.760 | 3.243 | 2.610 | 1.910 | 1.740 | 1.750 | 2.070 | 2.240 | 2.550 | 2.840 | 2.970 | 3.490 |
| Tracy | 3.990 | 4.093 | 3.697 | 3.150 | 2.643 | 2.510 | 3.313 | 3.860 | 4.543 | 4.867 | 4.860 | 3.533 |

Analysis of Variance Summary

| Source | DF | MS | F ratio |
|---|---|---|---|
| Variety | 1 | 24.1051 | 38.074** |
| Position | 11 | 2.5731 | 4.064* |
| Error | 11 | 0.6331 | |

| Internode | 6 | 5 | 4 | 7 | 8 | 3 | 12 | 9 | 2 | 10 | 1 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 2.130 | 2.192 | 2.530 | 2.692 | 3.050 | 3.153 | 3.512 | 3.547 | 3.668 | 3.853 | 3.857 | 3.915 |
| Statistical significance 0.05 level | | | | | ——— | ——— | ——— | ——— | ——— | ——— | ——— | ——— |
| | | | | ——— | ——— | ——— | ——— | ——— | ——— | | | |
| | | | ——— | ——— | ——— | ——— | ——— | ——— | | | | |
| | ——— | ——— | ——— | ——— | ——— | ——— | ——— | | | | | |

In comparing the average acidity for the 12 positions for individual varieties, Mer 59-1 had an average of 2.598 while Tracy was higher with an average of 3.755. These figures indicate that Tracy has approximately a 3:2 ratio over Mer 59-1 in total acidity.

In looking at the high and low values for total acidity, as related to positions on the stalk, the Mer 59-1 variety had a high of 3.760 at position 1 and a low of 1.740 at position 5, while Tracy had a high of 4.867 at position 10 and a low of 2.510 at position 6.

Both varieties followed the same general pattern in total acidity. Each variety contained a high total acidity in the lower position, decreasing to the lowest total acidity at positions 5 and 6, then progressively increasing through the remaining positions.

## VII. BRIX

Table VII shows a highly significant difference for varieties and no significant difference for positions for brix readings. This high significant difference was elucidated by the overall average of the 12 positions for the two varieties. Mer 59-1 had an average of 9.966 brix, while Tracy averaged 13.690. The average brix reading for Tracy was 1.37 times that for Mer 59-1.

The mean for positions of the two varieties varied from a low of 10.580 brix for position 12 to a high of 12.870 for position 8. There was no definite trend in brix content among the sections except that section 3 plus position 1 produced a reading of 12 or above.

TABLE VII

RELATIONSHIP OF BRIX TO VARIETY AND POSITION (INTERNODE) ON STALK (STEM)

| Internode | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mer 59-1 | 12.450 | 8.670 | 9.150 | 8.820 | 9.687 | 9.580 | 9.913 | 10.580 | 11.240 | 9.890 | 10.157 | 9.450 |
| Tracy | 12.710 | 13.913 | 14.420 | 14.520 | 13.837 | 13.137 | 14.893 | 15.160 | 13.853 | 13.420 | 12.710 | 11.710 |

Analysis of Variance Summary

| Source | DF | MS | F ratio |
|---|---|---|---|
| Variety | 1 | 249.7259 | 65.625** |
| Position | 11 | 2.6083 | 0.685 N.S. |
| Error | 11 | 3.8053 | |

| Internode | 12 | 2 | 6 | 11 | 10 | 4 | 5 | 3 | 7 | 9 | 1 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 10.580 | 11.292 | 11.358 | 11.433 | 11.655 | 11.670 | 11.762 | 11.785 | 12.403 | 12.547 | 12,580 | 12.870 |

Statistical significance 0.05 level ______________________________

There was a range in brix reading of 3.780 between the high and low reading of Mer 59-1, and 3.450 for Tracy. Proportionally, the range between the high and low readings for the two varieties was comparatively the same.

## VIII. FREE GLUCOSE

The analysis of variance summary for percent free glucose showed no significant difference for variety or position (Table VIII).

The mean for positions indicates a progressive increase in free glucose in sections 1, 2, 3, and 4, respectively. The average percent free glucose ranged from a high of 5.247 in section 1 to a low of 3.033 in section 4. According to the evaluations, sections 1 and 2 contain 1.5 times the free glucose content as sections 3 and 4, while sections 1, 2, and 3 contained about 4.5 times the free glucose as that produced in section 4. This observation indicates that 82 percent of the free glucose is produced in sections 1, 2, and 3, while section 4 produced only 18 percent.

Table VIII indicates that the free glucose for individual varieties averaged 4.001 percent for Mer 59-1 and 4.272 percent for Tracy. There was no significant difference between these means.

## IX. GLUCOSE FROM SUCROSE

The analysis of variance of glucose derived from inversion of sucrose shows no significant difference between positions on the stalk but a highly significant difference between varieties.

TABLE VIII

RELATIONSHIP OF FREE GLUCOSE TO VARIETY AND POSITION (INTERNODE) ON STALK (STEM)

| Internode | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mer 59-1 | 3.600 | 3.617 | 4.367 | 5.200 | 4.483 | 4.483 | 4.583 | 4.250 | 3.817 | 3.483 | 3.120 | 2.983 |
| Tracy | 6.400 | 6.933 | 6.567 | 5.300 | 5.750 | 3.100 | 3.033 | 2.233 | 3.367 | 2.983 | 2.233 | 3.367 |

Analysis of Variance Summary

| Source | DF | MS | F ratio |
|---|---|---|---|
| Variety | 1 | 1.3206 | 0.279 N.S. |
| Position | 11 | 6.0893 | 1.304 N.S. |
| Error | 11 | 4.6687 | |

| Internode | 11 | 12 | 10 | 8 | 9 | 6 | 7 | 1 | 5 | 4 | 2 | 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 2.692 | 3.175 | 3.233 | 3.242 | 3.592 | 3.792 | 3.808 | 5.000 | 5.117 | 5.250 | 5.275 | 5.467 |
| Statistical significance 0.05 level | | | | | | | | | | | | |

Observing the varieties separately (Table IX) each variety contained the lowest percent sucrose in position 1. The Mer 59-1 variety showed a fairly uniform increase by position from position 1 through position 9 and then a progressive decrease through positions 10, 11, and 12, respectively.

Tracy was very erratic in the percent glucose from sucrose inversion (Table IX). A fairly uniform increase was found from position 1 through 4, with position 5 having twice the amount contained in position 4. Position 6 was considerably lower than position 5 with a difference of 2.933, while position 7 (11.500 percent) showed a two-fold increase over position 6 (5.650 percent). From position 7 through position 10 a slight decrease in percent glucose from sucrose was observed with a sharp decrease in positions 11 and 12.

The two varieties showed the highest percent inversion of glucose from sucrose in positions 7, 8, 9 and 10 (Table IX).

Comparing the average glucose from sucrose for the 12 positions for the individual varieties, the Mer 59-1 variety averaged 2.999 percent, while Tracy was considerably higher with an average of 5.506. This indicates that Tracy contains approximately twice as much sucrose as Mer 59-1.

## X. TOTAL SUGARS

The analysis of variance summary for percent total sugars in the two varieties shows a significant difference in total sugars between positions and between varieties.

TABLE IX

RELATIONSHIP OF GLUCOSE FROM SUCROSE TO VARIETY AND POSITION (INTERNODE) ON STALK (STEM)

| Internode | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mer 59-1 | 1.600 | 1.950 | 1.850 | 2.533 | 2.250 | 3.167 | 3.933 | 4.317 | 4.367 | 4.317 | 3.583 | 2.117 |
| Tracy | 1.683 | 2.517 | 2.983 | 4.183 | 8.583 | 5.650 | 11.500 | 10.567 | 10.167 | 10.217 | 5.717 | 4.300 |

Analysis of Variance Summary

| Source | DF | MS | F ratio |
|---|---|---|---|
| Variety | 1 | 221.3763 | 21.052** |
| Position | 11 | 20.0207 | 2.854 N.S. |
| Error | 11 | 10.5155 | |

| Internode | 1 | 2 | 3 | 12 | 4 | 6 | 11 | 5 | 9 | 10 | 8 | 7 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 1.642 | 2.233 | 2.417 | 3.208 | 3.358 | 4.408 | 4.650 | 5.417 | 7.267 | 7.267 | 7.442 | 7.717 |

Statistical significance 0.05 level ________________________________________

Table X shows that the Mer 59-1 variety had an average total sugars of 9.999 while the Tracy variety averaged 17.282 percent for the 12 positions, or approximately a 4:7 ratio.

The results of Duncan's Multiple Range test shows no significant difference between positions 5 through 11, and that approximately 70 percent of the total sugar was produced in these positions.

The two varieties followed a similar trend as to high and low percent total sugar for positions (Table X). In both varieties, position 1 was lowest in percent total sugar. A progressive increase occurred to approximately the center of the stalk with a progressive decrease to position 12. The Mer 59-1 variety had a low of 6.800 percent at position 1 with a high of 12.883 at position 8, while Tracy exhibited a low of 9.767 at position 1 and a high of 26.033 percent total sugar at position 7.

In comparing sections of the stalk for total sugar, section 3 was highest in total sugar production with an average of 18.497 for the three positions 7, 8, and 9, while section 1 was lowest with an average for positions 1, 2, and 3 of 9.441. Section 3 was followed by section 2 in total sugar production.

## XI. CORRELATION COEFFICIENTS

Significant correlation coefficients were found for several of the variables studied (See Appendix, Table XV).

AIS showed a positive correlation coefficient of 0.508, 0.768, 0.467, 0.679, and 0.594 between total solids, total acidity, brix,

TABLE X

RELATIONSHIP OF TOTAL SUGARS TO VARIETY AND POSITION (INTERNODE) ON STALK (STEM)

| Internode | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mer 59-1 | 6.800 | 7.517 | 8.067 | 10.267 | 8.983 | 10.817 | 12.450 | 12.883 | 12.550 | 12.117 | 10.317 | 7.217 |
| Tracy | 9.767 | 11.967 | 12.533 | 13.667 | 22.917 | 14.400 | 26.033 | 23.367 | 23.700 | 23.400 | 13.667 | 11.967 |

Analysis of Variance Summary

| Source | DF | MS | F ratio |
|---|---|---|---|
| Variety | 1 | 954.8480 | 33.287** |
| Position | 11 | 93.7764 | 3.269* |
| Error | 11 | 28.6849 | |

| Internode | 1 | 12 | 2 | 3 | 4 | 11 | 6 | 5 | 10 | 8 | 9 | 7 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 8.283 | 9.592 | 9.742 | 10.300 | 11.967 | 11.992 | 12.608 | 15.590 | 17.758 | 18.125 | 18.125 | 19.242 |

Statistical significance 0.05 level

glucose from sucrose and total sugars, respectively, and a negative correlation coefficient of -0.611 between free glucose.

Ash showed a negative correlation coefficient of -0.396, -0.399, -0.665, and -0.652 for total solids, brix, glucose from sucrose and total sugars, respectively. It showed a positive correlation coefficient of 0.276 between free glucose and 0.199 between total acidity.

Free glucose gave a negative correlation coefficient of -0.428 and -0.237 for glucose from sucrose and total sugars, respectively.

The most significant positive correlation coefficient were between brix and total solids (0.911) and between total sugar and glucose from sucrose (0.979).

CHAPTER V

DISCUSSION

In order to obtain a high quality syrup, the first prerequisite is to start with high quality juice. According to the literature on syrup making, it can be concluded that several chemical factors in the juice are important in syrup manufacturing.

From the results of this experiment, it is obvious that further discussions of several findings are in order. Three of the factors most often discussed which influence the quality of the finished syrup are AIS, ash and total acidity. These three constituents are classified as impurities when the amounts contained in the juice are detrimental to the manufacture of a high quality syrup.

The analyses of variance (Tables II, III and VI, pages 29, 31, and 35) show that positions comprising section 4 of the stalk contained the highest amount of AIS and total acidity, while section 1 had the highest ash content, followed closely by section 4. In earlier research work on the effects of starch on the finished product, it was found that a high starch content in the juice caused slow boiling and scorching of the syrup, and that starch was the causative agent in jellying (18, 19). Studies by Walton et al. (28) indicated that the top part of the stalk contained more starch than the remainder of the stalk. Their findings were substantiated by this study for the Tracy and Mer 59-1 varieties.

Sorghum juice with a high acid content is considered to be detrimental to a high quality syrup. Much work has been done with lime and various clays for juice neutralization and clarification; but as yet, they have not been solved for the small scale producer. Coleman and Stokes (5) found that most of the additives used to neutralize the juice adversely affected the flavor and quality of syrup. Comparatively, total acid in the juice of this experiment was found to closely parallel the total acid in varieties studied by other workers (29).

The findings of research workers for total acid and starch can be very useful in syrup manufacturing, but until someone defines specifically what is inferred by a high starch content or a high total acid, the syrup manufacturer can never successfully apply these results to his operation. Further work is needed on isolating and identifying the various acids that are reported to be in sorghum juice.

The total solids content closely paralleled the brix values in both varieties. In all positions with a high total solids content, there was a corresponding high brix value and vice versa.

One of the problems that has plagued the syrup producer since the beginning of the syrup industry is sugar crystallization. Walton and Ventre (27) found that crystallization in sorghum syrup results from an excess of either reducing sugars or sucrose. Ventre, Byall and Walton (25) recommended a ratio of 1:1 sucrose to reducing sugars. Comparing the means for the individual varieties (Tables VIII and IX , pages 39 and 41), Mer 59-1 had an average of 4.001 percent glucose and 5.998 percent sucrose, while Tracy averaged 4.272 percent glucose and 13.012 sucrose.

These values provide a ratio of sucrose to glucose for the Mer 59-1 variety of 1.5:1 and for Tracy, 3:1. Considering the recommended ratio of previously cited studies, neither the Mer 59-1 variety or Tracy fit the desired ratio for the production of high quality syrup. However, the possibility of obtaining a syrup that would not crystallize would be much greater in the Mer 59-1 variety than the Tracy. The trend for extraction by sections for glucose and sucrose were exactly opposite. Section 1 was the highest producer of glucose and section 4 was the lowest, while section 3 yielded the highest amount of sucrose with section 1 the lowest. Ventre, Byall and Walton (25) reported that sucrose crystallization occurred most frequently in syrup made from the upper part of the stalk.

Data in Table XI (See Appendix) indicate that the section of the stalk which yielded the lowest volume of juice was section 4. By comparing weights of cane required to produce the juice, section 4 of Mer 59-1 required 164 ounces of raw cane to produce 54 ounces of juice, section 3 required 184 ounces to produce 93 ounces, section 2 required 156 ounces to produce 81 ounces, and section 1 required 262 ounces to produce 128 ounces. The percentage of juice extracted from the four sections was 36, 23, 26, and 15 for sections 1, 2, 3, and 4, respectively. However, the percentage of juice extracted from the Tracy was 25, 36, 21, and 18 for sections 1, 2, 3, and 4, respectively. The low yield of juice from section 4 plus the fact that this part of the stalk is considerably longer and requires more time for extraction indicates a small return for time and labor involved in extracting juice from section 4.

Section 4 contained the highest percentage of alcohol insoluble solids. It also contained relatively high percentages of total acid and ash as compared to other sections. These three factors are generally deemed detrimental to the quality of finished syrup. Considering these factors and the return from labor in harvesting and grinding of section 4, it would seem advisable to utilize this section in another manner.

Two of the factors considered detrimental to a high quality syrup, AIS and total acidity, showed a positive correlation coefficient of 0.768. The most significant positive correlation coefficient was between brix and total solids (0.911) and between total sugars and glucose from sucrose (0.979).

# CHAPTER VI

## SUMMARY

A study was made to determine, by internodes, the amount of certain chemical components contained in juice of two varieties of sorghum cane (Mer 59-1 and Tracy).

Under conditions of this experiment the following findings were made:

1. There was no significant difference in percent of juice extracted between variety or among positions. However, the lowest volume of juice was obtained from section 4, followed by increasing amounts obtained from sections 3, 1, and 2, respectively.

2. There was no significant difference in free glucose between varieties or among positions.

3. The Tracy variety showed a greater inversion of glucose from sucrose than Mer 59-1, however, there was no significant difference between positions of the two varieties.

4. There was a significant difference in percent total sugars by positions and varieties. Tracy variety averaged 17.28 percent and Mer 59-1 variety averaged 9.99 percent of the total sugars for the 12 positions. Positions 5 through 11 produced approximately 70 percent of the total sugars.

5. There were significant differences between varieties and positions for percent ash, total acidity, and alcohol insoluble solids.

High concentrations of these components were found in the upper section of the stalk.

6. There were no significant differences in pH, percent total solids, and brix values between positions but a significant difference was found between Mer 59-1 and Tracy.

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APPENDIX

TABLE XI

WEIGHT OF INTERNODES AND JUICE OBTAINED FROM TWO VARIETIES OF SORGHUM CANE

| | Mer 59-1 | | Tracy | |
|---|---|---|---|---|
| Position | Wt. of internodes ounces | Wt. of juice ounces | Wt. of internodes ounces | Wt. of juice ounces |
| 1 | 90 | 36 | 40 | 16 |
| 2 | 88 | 46 | 88 | 38 |
| 3 | 84 | 46 | 122 | 58 |
| 4 | 66 | 36 | 116 | 57 |
| 5 | 50 | 26 | 104 | 54 |
| 6 | 40 | 19 | 90 | 47 |
| 7 | 35 | 16 | 78 | 40 |
| 8 | 84 | 36 | 64 | 32 |
| 9 | 65 | 41 | 62 | 22 |
| 10 | 50 | 18 | 74 | 32 |
| 11 | 64 | 20 | 48 | 18 |
| 12 | 50 | 16 | 80 | 30 |

TABLE XII

MEANS FOR THE DIFFERENT FACTORS FOR THE TWO VARIETIES OF SORGHUM CANE

| Factors | Varieties | | Probability |
|---|---|---|---|
| | Mer 59-1 | Tracy | |
| Percent extraction | 55.667 | 44.583 | N.S. |
| Alcohol insoluble solids | 0.262 | 0.442 | ** |
| Ash | 0.886 | 0.765 | ** |
| Total solids | 10.024 | 13.825 | ** |
| pH | 5.377 | 5.203 | ** |
| Total acidity | 2.598 | 3.755 | ** |
| Brix | 9.966 | 13.690 | ** |
| Free glucose | 4.001 | 4.272 | N.S. |
| Glucose from sucrose | 2.999 | 6.506 | ** |
| Total sugars | 9.999 | 17.282 | ** |

*Significant at 0.05 level.

**Significant at 0.01 level.

## TABLE XIII

## CHEMICAL COMPOSITION OF RAW SORGHUM CANE JUICE FROM MER 59-1 VARIETY

| Internode | % Extraction | % AIS | % Ash | % Total solids | pH | Total acidity ml | Brix | % Free glucose | % Glucose from sucrose | % Total sugars |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 40.0 | 0.29 | 1.05 | 12.24 | 5.20 | 3.80 | 12.45 | 3.60 | 1.60 | 6.80 |
| | | 0.30 | 1.02 | 12.55 | | 3.74 | 12.45 | 3.60 | 1.60 | 6.80 |
| | | 0.27 | 1.02 | 12.53 | | 3.74 | 12.45 | 3.60 | 1.60 | 6.80 |
| 2 | 52.0 | 0.18 | 1.10 | 8.97 | 5.40 | 3.25 | 8.67 | 4.00 | 1.20 | 6.40 |
| | | 0.19 | 1.11 | 8.93 | | 3.24 | 8.67 | 3.60 | 2.15 | 7.90 |
| | | 0.22 | 1.12 | 8.88 | | 3.24 | 8.67 | 3.25 | 2.50 | 8.25 |
| 3 | 54.0 | 0.16 | 0.94 | 9.02 | 5.50 | 2.61 | 9.15 | 4.60 | 1.15 | 6.90 |
| | | 0.15 | 0.93 | 8.85 | | 2.61 | 9.15 | 4.25 | 2.05 | 8.35 |
| | | 0.18 | 0.95 | 8.88 | | 2.61 | 9.15 | 4.25 | 2.35 | 8.95 |
| 4 | 54.0 | 0.13 | 0.79 | 8.61 | 5.40 | 1.87 | 8.82 | 4.90 | 3.15 | 11.20 |
| | | 0.11 | 0.83 | 8.59 | | 1.93 | 8.82 | 5.20 | 2.85 | 10.90 |
| | | 0.11 | 0.77 | 8.59 | | 1.93 | 8.82 | 5.50 | 1.60 | 8.70 |
| 5 | 52.0 | 0.16 | 0.77 | 9.92 | 5.50 | 1.74 | 9.72 | 4.25 | 2.55 | 9.35 |
| | | 0.14 | 0.77 | 9.53 | | 1.74 | 9.72 | 4.60 | 2.20 | 9.00 |
| | | 0.13 | 0.75 | 9.57 | | 1.74 | 9.62 | 4.60 | 2.00 | 8.60 |
| 6 | 47.0 | 0.21 | 0.90 | 9.71 | 5.50 | 1.74 | 9.38 | 4.60 | 3.20 | 11.00 |
| | | 0.21 | 0.94 | 9.71 | | 1.77 | 9.58 | 4.25 | 3.10 | 10.45 |
| | | 0.22 | 0.86 | 9.69 | | 1.74 | 9.78 | 4.60 | 3.20 | 11.00 |

TABLE XIII (continued)

| Internode | % Extraction | % AIS | % Ash | % Total solids | pH | Total acidity ml | Brix | % Free glucose | % Glucose from sucrose | % Total sugars |
|---|---|---|---|---|---|---|---|---|---|---|
| 7 | 45.0 | 0.26 | 0.73 | 10.19 | 5.40 | 2.05 | 9.98 | 4.60 | 4.05 | 12.70 |
| | | 0.22 | 0.89 | 10.19 | | 2.11 | 9.98 | 4.90 | 3.35 | 11.60 |
| | | 0.24 | 0.73 | 10.18 | | 2.05 | 9.78 | 4.25 | 4.40 | 13.05 |
| 8 | 42.0 | 0.24 | 0.69 | 10.72 | 5.35 | 2.24 | 10.58 | 4.25 | 4.20 | 12.65 |
| | | 0.24 | 0.68 | 10.78 | | 2.24 | 10.58 | 4.25 | 4.75 | 13.75 |
| | | 0.24 | 0.68 | 10.75 | | 2.24 | 10.58 | 4.25 | 4.00 | 12.25 |
| 9 | 63.0 | 0.30 | 0.79 | 11.06 | 5.34 | 2.49 | 11.24 | 3.60 | 4.65 | 12.90 |
| | | 0.35 | 0.80 | 11.04 | | 2.61 | 11.24 | 3.60 | 4.65 | 12.90 |
| | | 0.32 | 0.80 | 11.03 | | 2.55 | 11.24 | 4.25 | 3.80 | 11.85 |
| 10 | 36.0 | 0.37 | 0.83 | 10.58 | 5.30 | 2.86 | 9.89 | 3.25 | 4.55 | 12.35 |
| | | 0.38 | 0.84 | 10.54 | | 2.80 | 9.89 | 3.60 | 4.20 | 12.00 |
| | | 0.40 | 0.85 | 10.53 | | 2.86 | 9.89 | 3.60 | 4.20 | 12.00 |
| 11 | 31.0 | 0.39 | 0.96 | 10.24 | 5.33 | 2.93 | 10.29 | 3.25 | 3.35 | 9.95 |
| | | 0.38 | 0.96 | 10.31 | | 2.99 | 9.89 | 3.10 | 3.70 | 10.50 |
| | | 0.40 | 0.96 | 10.20 | | 2.99 | 10.29 | 3.10 | 3.70 | 10.50 |
| 12 | 32.0 | 0.46 | 1.04 | 9.25 | 5.30 | 3.49 | 9.45 | 3.10 | 2.10 | 7.30 |
| | | 0.42 | 1.04 | 9.25 | | 3.49 | 9.45 | 3.10 | 2.10 | 7.30 |
| | | 0.46 | 1.00 | 9.27 | | 3.49 | 9.45 | 2.75 | 2.15 | 7.05 |

TABLE XIV

CHEMICAL COMPOSITION OF RAW SORGHUM CANE JUICE FROM TRACY VARIETY

| Internode | % Extraction | % AIS | % Ash | % Total solids | pH | Total acidity ml | Brix | % Free glucose | % Glucose from sucrose | % Total sugars |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 40.0 | 0.29 | 1.08 | 12.50 | 5.30 | 3.99 | 12.71 | 6.60 | 2.05 | 10.70 |
| | | 0.26 | 1.12 | 12.53 | | 3.99 | 12.71 | 6.30 | 1.30 | 8.90 |
| | | 0.34 | 1.13 | 12.51 | | 3.99 | 12.71 | 6.30 | 1.70 | 9.70 |
| 2 | 43.0 | 0.27 | 1.03 | 13.82 | 5.25 | 4.06 | 14.08 | 7.35 | 2.00 | 11.35 |
| | | 0.21 | 1.03 | 14.93 | | 4.11 | 13.78 | 7.35 | 2.15 | 11.65 |
| | | 0.23 | 1.06 | 13.87 | | 4.11 | 13.88 | 6.10 | 3.40 | 12.90 |
| 3 | 47.0 | 0.25 | 0.80 | 14.52 | 5.22 | 3.74 | 14.62 | 6.10 | 3.40 | 12.90 |
| | | 0.26 | 0.89 | 14.47 | | 3.74 | 14.32 | 6.80 | 2.85 | 12.50 |
| | | 0.26 | 0.90 | 14.52 | | 3.61 | 14.32 | 6.80 | 2.70 | 12.20 |
| 4 | 49.0 | 0.28 | 0.75 | 14.45 | 5.26 | 3.15 | 14.62 | 5.20 | 3.80 | 12.80 |
| | | 0.29 | 0.74 | 14.57 | | 3.16 | 14.52 | 5.20 | 4.60 | 14.40 |
| | | 0.27 | 0.74 | 14.55 | | 3.14 | 14.42 | 5.50 | 4.15 | 13.80 |
| 5 | 51.0 | 0.29 | 0.60 | 13.50 | 5.30 | 2.68 | 13.87 | 5.75 | 9.85 | 25.45 |
| | | 0.29 | 0.62 | 13.87 | | 2.61 | 13.87 | 5.75 | 7.45 | 20.65 |
| | | 0.26 | 0.60 | 13.44 | | 2.64 | 13.77 | 5.75 | 8.45 | 22.65 |
| 6 | 52.0 | 0.29 | 0.53 | 13.13 | 5.36 | 2.49 | 13.07 | 3.10 | 5.90 | 14.90 |
| | | 0.28 | 0.52 | 13.15 | | 2.49 | 13.27 | 3.10 | 5.90 | 14.90 |
| | | 0.30 | 0.52 | 13.17 | | 2.55 | 13.07 | 3.10 | 5.15 | 13.40 |

TABLE XIV (continued)

| Internode | % Extraction | % AIS | % Ash | % Total solids | pH | Total acidity ml | Brix | % Free glucose | % Glucose from sucrose | % Total sugars |
|---|---|---|---|---|---|---|---|---|---|---|
| 7 | 51.0 | 0.48 | 0.63 | 15.14 | 5.16 | 3.30 | 14.96 | 3.10 | 11.10 | 25.30 |
| | | 0.51 | 0.57 | 15.19 | | 3.30 | 14.86 | 2.75 | 11.95 | 26.65 |
| | | 0.44 | 0.56 | 15.24 | | 3.34 | 14.86 | 3.25 | 11.45 | 26.15 |
| 8 | 50.0 | 0.57 | 0.65 | 15.50 | 5.10 | 3.86 | 15.16 | 2.10 | 10.10 | 22.30 |
| | | 0.56 | 0.67 | 15.52 | | 3.86 | 15.16 | 2.10 | 9.40 | 20.90 |
| | | 0.57 | 0.63 | 15.51 | | 3.86 | 15.16 | 2.50 | 12.20 | 26.90 |
| 9 | 35.0 | 0.69 | 0.77 | 14.28 | 5.14 | 4.55 | 13.92 | 3.25 | 9.95 | 23.15 |
| | | 0.69 | 0.75 | 14.42 | | 4.55 | 13.82 | 3.60 | 9.60 | 22.80 |
| | | 0.68 | 0.76 | 14.45 | | 4.53 | 13.82 | 3.25 | 10.95 | 25.15 |
| 10 | 43.0 | 0.77 | 0.80 | 13.75 | 5.10 | 4.88 | 13.52 | 2.75 | 9.45 | 21.65 |
| | | 0.76 | 0.78 | 13.82 | | 4.86 | 13.32 | 3.10 | 11.10 | 25.30 |
| | | 0.72 | 0.82 | 13.85 | | 4.86 | 13.42 | 3.10 | 10.10 | 23.30 |
| 11 | 37.0 | 0.80 | 0.79 | 12.92 | 5.05 | 4.86 | 12.71 | 2.10 | 5.25 | 12.60 |
| | | 0.79 | 0.79 | 13.08 | | 4.86 | 12.71 | 2.50 | 5.75 | 14.00 |
| | | 0.77 | 0.78 | 13.05 | | 4.86 | 12.71 | 2.10 | 6.15 | 14.40 |
| 12 | 37.0 | 0.38 | 0.71 | 11.47 | 5.20 | 3.56 | 11.71 | 3.25 | 4.10 | 11.45 |
| | | 0.40 | 0.71 | 11.50 | | 3.55 | 11.71 | 3.60 | 4.45 | 12.50 |
| | | 0.40 | 0.71 | 11.51 | | 3.49 | 11.71 | 3.25 | 4.35 | 11.95 |

TABLE XV

CORRELATION COEFFICIENTS FOR DIFFERENT VARIABLES STUDIED

| | % AIS | % Ash | % Total solids | Total acidity ml | Brix | % Free glucose | % Glucose from sucrose | % Total sugars |
|---|---|---|---|---|---|---|---|---|
| % AIS | --- | -0.213 N.S. | 0.508** | 0.768** | 0.467** | -0.611** | 0.679** | 0.591** |
| % Ash | --- | --- | -0.397** | 0.199 N.S. | -0.399** | 0.276** | -0.665** | -0.652** |
| % Total solids | --- | --- | --- | 0.614** | 0.991** | 0.042 N.S. | 0.656** | 0.715** |
| Total acidity ml | --- | --- | --- | --- | 0.592** | -0.197 N.S. | 0.362** | 0.344** |
| Brix | --- | --- | --- | --- | --- | 0.079 N.S. | 0.625** | 0.690** |
| % Free glucose | --- | --- | --- | --- | --- | --- | -0.428** | -0.232* |
| % Glucose from sucrose | --- | --- | --- | --- | --- | --- | --- | 0.979** |
| % Total sugars | --- | --- | --- | --- | --- | --- | --- | --- |

*Significant at 0.05 level.

**Significant at 0.01 level.

## VITA

The author was born April 23, 1922, in Halsell, Alabama. He attended Ward High School, Ward, Alabama, and in 1943 entered the U. S. Army, where he served for three years. In 1946, he enrolled at University of Alabama and later transferred to Auburn University where he received his B. S. degree in Agriculture in 1950. In 1951, he was employed as County Sanitation Officer with the Sumter County Health Department in Livingston, Alabama. On September 1, 1963, he was appointed District Sanitarian with the Alabama State Department of Public Health. In September, 1965, he enrolled at the University of Tennessee and since that time has been working to complete the requirements for the degree, Master of Science.

He was married to Miss Dorothy Lucile Rushing on July 15, 1950, and is the father of two children.