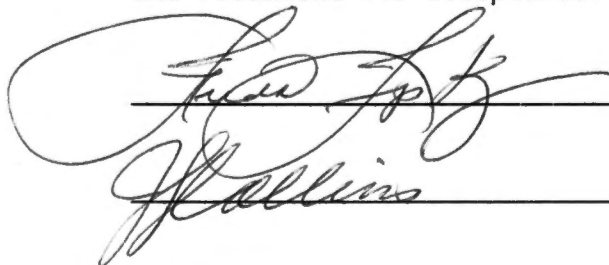


To the Graduate Council:

I am submitting herewith a thesis written by Dennis Wilson Jones entitled "Evaluation of Vacuum Kettle Processing of Sorghum Syrup." I have examined the final 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 Agricultural Mechanization.


Luther R. Wilhelm, Major Professor

We have read this thesis
and recommend its acceptance:


Hallins

Accepted for the Council:


The Graduate School

EVALUATION OF VACUUM KETTLE PROCESSING OF SORGHUM SYRUP

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Dennis Wilson Jones

December 1983

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ABSTRACT

A 19-liter steam-jacketed, stainless steel kettle was modified to simulate a vacuum pan for use in the processing of sweet sorghum (*Sorghum bicolor* (L.) Moench) syrup. The vacuum-processed syrup was compared to syrup processed in a conventional 224-liter, black-iron evaporator pan. The comparison consisted of chemical and physical analyses, as well as a taste preference panel. The experimental design, a randomized complete block design with factorial arrangement of treatment combinations, consisted of five replications with seven treatments per replication. Treatments consisted of combinations of vacuum level and the degrees Brix of the juice or semi-syrup when introduced to the vacuum kettle.

The chemical and physical analyses of the syrup included a determination of degrees Brix, pH, total solids, extraneous materials, percentage ash, and titratable acidity. The taste preference panel compared the conventionally prepared syrup to the vacuum-processed syrup in terms of texture, flavor, and color.

Statistical analyses of the taste preference panel data results indicated that the panel perceived no significant differences in the conventionally processed and the vacuum-processed syrup in terms of texture, flavor, and color. Statistical analyses of the physical and the chemical analyses data indicated a replication effect and a vacuum level, replication interaction effect on pH. There was also a significant replication effect on the extraneous

material. The degrees Brix level to which the syrup was concentrated had a significant effect on total solids. Also, a significant replication effect on total solids was exhibited. A significant vacuum level effect on acidity level was noted. As the vacuum level was increased, the percentage titratable acidity increased.

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CHAPTER I

INTRODUCTION

Tennessee, along with six other southeastern states and Iowa, produce 90 percent of the sweet sorghum (*Sorghum bicolor* (L.) Moench) syrup in the United States (Freeman et al., 1973). As a major producer of sorghum syrup, Tennessee has consistently averaged better than ten percent of the national total in production and sales of syrup (Wilhelm and Morgan, 1973). Statistics are no longer maintained on sweet sorghum due to its overall decline in importance as a cash crop. Tennessee, however, was ranked second in the production and sales of sorghum syrup in the 1964 Census of Agriculture. Tennessee has some sorghum syrup produced in almost every county (Wilhelm and Morgan, 1973).

The decline of sorghum syrup production can be attributed to several factors. Other sugar sources, such as sugar cane, sugar beets, and corn sweeteners, have filled a need once filled by sorghum syrup. Other syrups can be produced more easily at a lower production cost than sorghum syrup.

Most sorghum syrup is produced by small volume operators. The average producer grows less than one acre for syrup production (Freeman et al., 1973). Often the cane is milled and processed at a community plant. Beyond the question of economies of scale, there lies the problem of finding operable equipment to support a viable sorghum syrup operation. Many of the mills used by the small volume

operators were manufactured in the early 1900's. The evaporator pans used to concentrate the syrup present other problems to the producer.

Conventional evaporator pans are either batch or continuous flow in design. In the past, and in some instances the present, these evaporators were heated by a wood fire. Today, most evaporator pans are of the continuous flow type and are heated by propane fuel. The ideal heat source in either batch or continuous flow pans is steam. Steam allows more operator control and removes the product scorching danger that is possible when other heat sources are used. When steam is used as a heat source, less operator skill is required.

Only a fixed amount of syrup can be produced in a batch evaporator pan. Raw juice is introduced to the pan and heated to a boil with the colloidal matter being removed by manual skimming. The syrup is produced by the evaporation of the water from the juice, thus increasing the percentage sugar content. No new raw juice is added to the pan once the evaporation process has begun.

In a continuous flow evaporator pan (Figure 1), the raw juice enters one end of the pan. The juice is heated to a boil as it follows a long winding course through the baffled pan from the input end to the output end. Skimming to remove the colloidal matter is performed as the product progresses from input to output end of the pan. Flow is generally continuous if the heat input and the flow rate are correct for proper concentration.

Skilled labor and high energy input are fundamental to conventional systems. A market for high quality syrup apparently exists if a cost-effective production system can be developed. As the old



Figure 1. Continuous flow evaporator pan of typical baffled design.

Note: Generally, evaporator pans are constructed of metal, rather than wood.

equipment fails and is replaced, producers are seeking new methods of producing sorghum syrup.

Vacuum processing is considered a potential alternative to conventional methods while increasing control and reducing labor requirements. Continuous flow vacuum evaporator systems are currently in existence. These systems are used in producing condensed milk and other products. A major consideration in designing or choosing equipment for sorghum syrup processing is how to remove the impurities. Another consideration would be the effect of vacuum processing on the quality of the finished syrup. Thus, a study was initiated to compare vacuum kettle processing of sorghum syrup to open pan processing.

Objectives

The specific objectives of this study were:

1. To determine if the quality of sorghum syrup processed in vacuum conditions equaled or exceeded the quality of syrup produced by a conventional, open pan system. The quality factors of flavor, texture, and color were evaluated by a taste preference panel.
2. A determination of causal effects of differences, if they exist, between the syrup produced by vacuum and open pan processes.

CHAPTER II

REVIEW OF LITERATURE

Tennessee was ranked second in production and sales of sweet sorghum (*Sorghum bicolor* (L.) Moench) syrup according to the 1964 Census of Agriculture (U.S. Census of Agriculture, 1964). Due to the decline of sweet sorghum as a cash crop, statistics are no longer maintained on its production. Wilhelm et al. (1973) indicated that sweet sorghum syrup was produced in almost every county in Tennessee.

Collins et al. (1977), in a study of the quality of syrup produced in Tennessee, found that a number of varieties of cane are grown for syrup production and that the methods of harvesting and milling varied. In the same study, they also determined that unstripped cane produced syrup with 0.4 percent to 3.6 percent extraneous material while syrup produced from stripped cane had 0.2 percent to 3.2 percent extraneous material. They further determined that the sorghum consumer in Tennessee preferred syrup concentrated to 76 degrees Brix with a viscosity of 3,140 centipoise.

Samples of sorghum syrup concentrated to the same degrees Brix level may exhibit variation in viscosity. Walton et al. (1938) attributed the variation in viscosity to the presence of starch. The starch gelatinizes as the juice is being concentrated to syrup. The starch content of syrup is related to the variety of cane used and the cultural practices employed. Generally, mature cane has a higher starch content than less mature cane (Walton et al., 1938). Coleman

et al. (1964) and Walton et al. (1938) noted that the top three or four internodes of the cane have a higher percentage of starch and relatively high acidity as compared to the rest of the cane parts. These higher percentages adversely affect the syrup quality. Collins et al. (1977) indicated that generally there is an inverse relationship between the pH and the percentage acidity of a product. However, they were unable to verify this relationship.

Freeman et al. (1973) noted that a high quality syrup had a light-amber color that was almost free of opaqueness. Coleman et al. (1964) observed that in general, syrup produced from unstripped cane was darker than syrup produced from stripped cane.

Wall et al. (1970) suggested that after the milling of the cane, the juice should be stored in large shallow tanks to allow the heavy particles of trash, bagasse, and starch to settle to the bottom before the juice was clarified. Webster et al. (1953) clarified sorghum syrup by the use of clay added to the hot juice prior to concentration. This treatment reduced the amount of skimming required, under normal conditions, to clarify the syrup as it was being concentrated. Walton et al. (1938) and Clark et al. (1981) recommended the use of carbonated lime to settle out the solids present in the juice without affecting flavor. Excessive use of lime will remove the aconitic acid which, to a great extent, gives sorghum syrup its characteristic flavor.

Mechanical filters are also used in the clarification of the juice and syrup. Cheese cloth was traditionally used to filter the raw juice and the finished syrup. Webster et al. (1953) completed

clarification by the use of a cream separator. This treatment did not prove to be wholly satisfactory. A filter press was determined to be adequate but not cost-effective on a small farm scale. Clark et al. (1981) suggested that the filtering could be satisfactorily completed using a plate, frame, rotary vacuum, or pressure filter.

Open-type evaporator pans are used for clarification, evaporation, and the final finishing of sorghum syrup (Wall et al., 1970). Wall et al. (1970) noted that evaporator pans are generally constructed to allow cold juice to enter one end with the syrup being drawn off continuously at the other end. A specific exception to this type design is the "Stubbs" evaporator. With this design, the juice enters on the cool end of the pan and travels lengthwise along a high longitudinal partition, around the end of the partition, and back to the syrup finishing compartment (Freeman et al., 1973). Somewhat less operator skill is required when this type pan is used.

Of the two basic types of evaporators used in Tennessee, batch and continuous flow, most are the shallow baffle-type continuous flow evaporator pans (Wilhelm et al., 1973).

Fuel sources for heating evaporator pans include wood, oil, propane, fuel oil, liquid petroleum gas, and coal (Freeman et al., 1973). These heat sources are used directly and indirectly via steam.

A review of literature discussing vacuum processing of sweet sorghum cane juice reveals that little research has been conducted on this specific method of processing syrup. Freeman et al. (1970) briefly discussed vacuum processing, indicating this method of

processing reduced scorching and excessive darkening of the syrup.

It was also stated that because steam heat was used, the systems were prohibitively expensive. Another problem addressed was that of clarification of the syrup once it was in the vacuum processor. Freeman also indicated that because the syrup was processed at a lower temperature in vacuum conditions, it was necessary to cook the syrup at high temperature for a short period after vacuum processing in order to obtain the characteristic sorghum syrup flavor. The temperature range for this characteristic flavor development is reported to be 106°C to 110°C (Freeman et al., 1970).

Clark et al. (1981) constructed a pilot community-sized syrup plant using a continuous flow, steam-heated, stainless steel vacuum evaporator. The equipment was originally designed for the processing of maple syrup. In the sorghum configuration, the juice flowed through a concentric tube preheater, mixed with recycled hot syrup and then passed through a shell and tube exchanger into a vapor-liquid separator. The vapor was condensed in a plate condenser. Clark reported that ten gallons of syrup per hour could be produced in continuous operation.

Clark et al. (1981) recommended that fresh sorghum juice be held in a refrigerated tank until it was processed. For clarification, Clark recommended the use of phosphoric acid and lime, and the use of settling tanks prior to concentration. The evaluation of the pilot plant indicated a need to rearrange the exchanger to a vertical position. The rearrangement would reduce foaming and overheating of the product (Clark et al., 1981).

CHAPTER III

PROCEDURES AND EXPERIMENTAL METHODS

The experimental design, a randomized complete block design with factorial arrangement of treatment combinations, consisted of five replications, with seven treatments per replication, as outlined below.

- A. Cook to 76° Brix in open pan; filter; 0 kPa vacuum.
- B. Preheat in open pan; filter; cook to 76° Brix in vacuum kettle with 23.7 kPa vacuum.
- C. Preheat in open pan; filter; cook to 76° Brix in vacuum kettle with 47.4 kPa vacuum.
- D. Cook in open pan to 21° Brix; filter; cook to 76° Brix in vacuum kettle with 23.7 kPa vacuum.
- E. Cook in open pan to 21° Brix; filter; cook to 76° Brix in vacuum kettle with 47.4 kPa vacuum.
- F. Cook in open pan to 42° Brix; filter; cook to 76° Brix in vacuum kettle with 23.7 kPa vacuum.
- G. Cook in open pan to 42° Brix; filter; cook to 76° Brix in vacuum kettle with 47.4 kPa vacuum.

Sweet sorghum cane (*Sorghum bicolor* (L.) Moench), of the Williams variety, was processed in this experiment. The raw juice was obtained from two local syrup producers in Eastern Tennessee.

The cane used in replications one and two was cut, stripped, and milled approximately 18 hours prior to processing, and the juice was placed in a milk chiller. This allowed for the sedimentation of much of the extraneous matter. The cane used in replications three, four, and five was cut, stripped, and milled immediately prior to processing. Sedimentation was minimal. The cane used in replications one and two was grown at a different location than the cane used in replications three, four, and five.

The raw juice was initially introduced to a 224-liter, black-iron evaporator pan (Figure 2) fabricated by Tranter Manufacturing, Incorporated of Lansing, Michigan. The usable capacity of the evaporator pan was approximately 152 liters due to foaming during the evaporation process. Heat was supplied through three sets of individually controlled steam coils that permitted temperature control of each third of the pan bottom.

All of the juice or syrup was filtered during processing. A 22.9-centimeter diameter disk type, stainless steel, double element milk filter was used (Figures 3 and 4).

In treatment "A," filtration was performed after the syrup was concentrated to the 76° Brix level. The syrup used in treatments "B" and "C" was filtered after initial preheating in the open pan but prior to processing in the vacuum kettle. Filtration of the syrup used in treatments "D" and "E" occurred after the juice was concentrated to the 21° Brix semi-syrup level in the open pan, but prior to vacuum processing. In treatments "F" and "G," the juice was

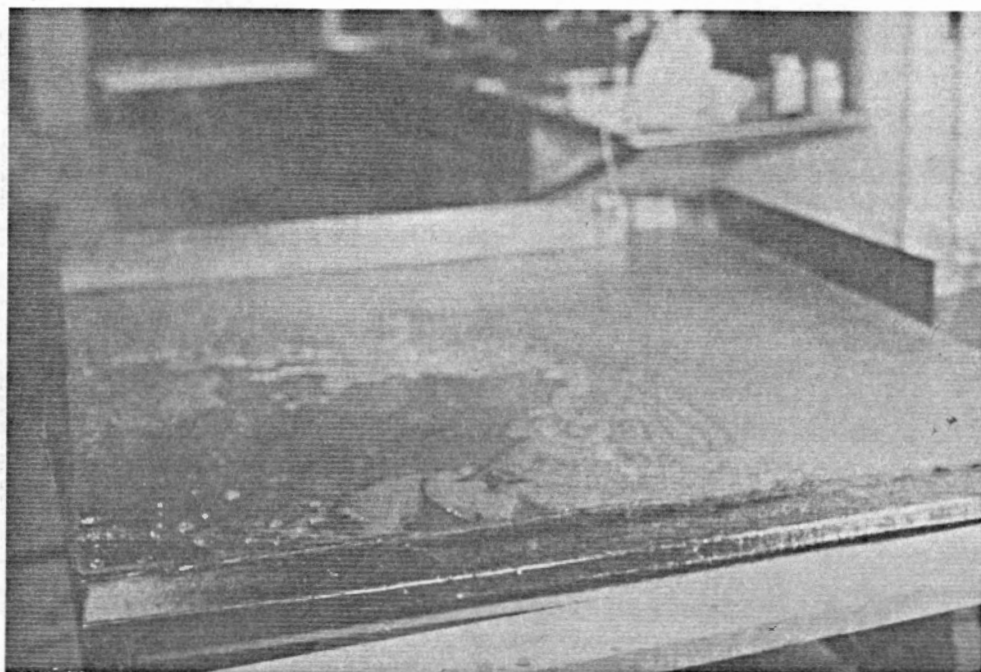


Figure 2. Batch evaporator pan with sorghum juice.

Note: Coagulated matter is visible on the surface of the juice.

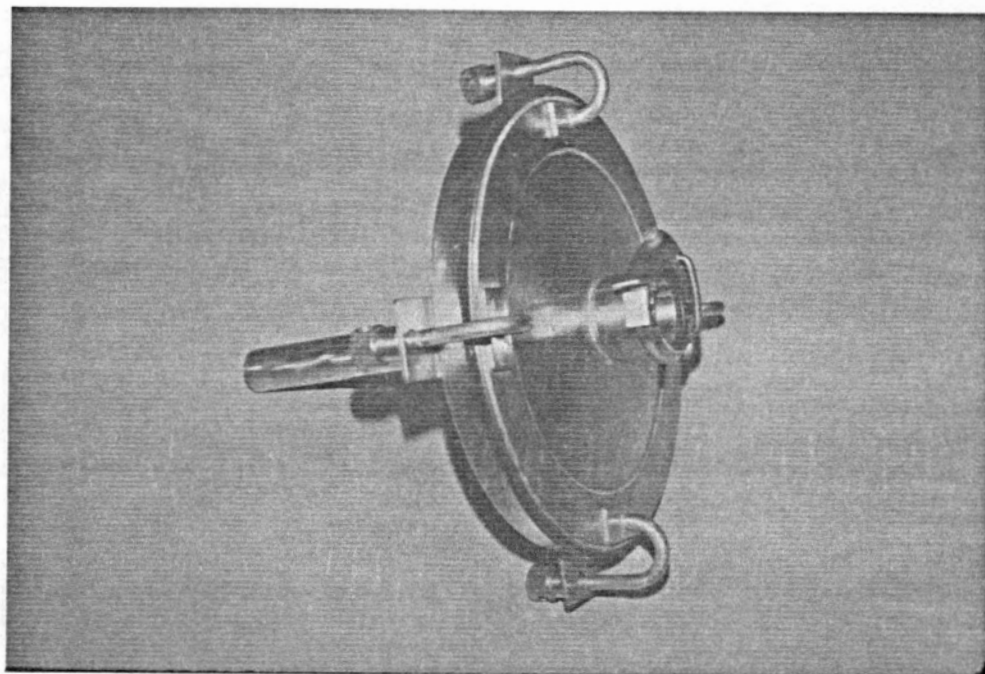


Figure 3. Assembled milk filter used to remove foreign matter from raw juice.

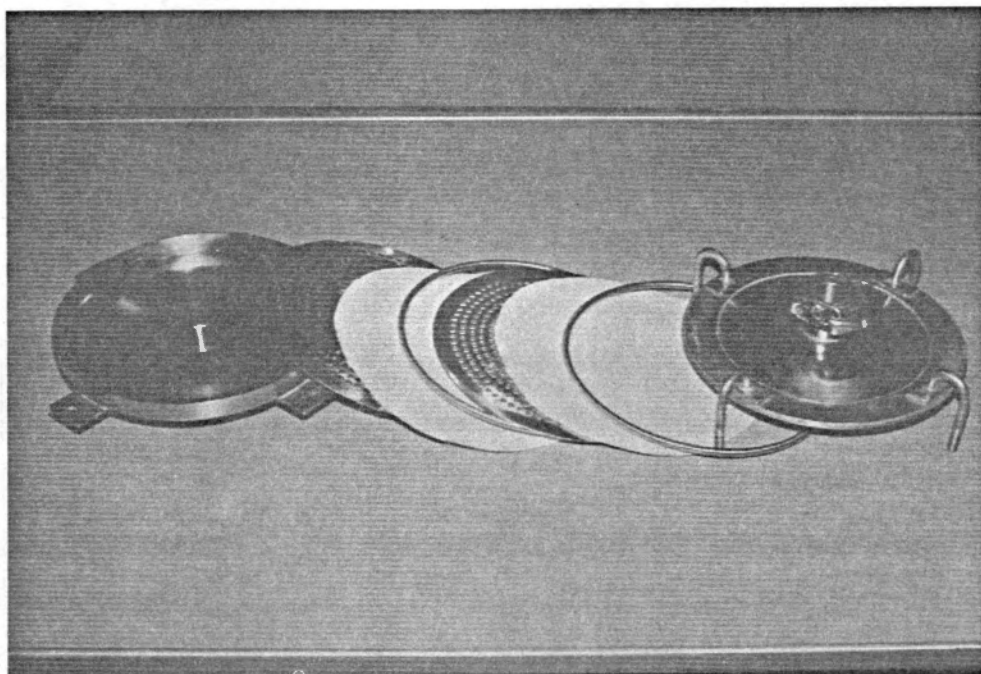


Figure 4. Disassembled milk filter. Two sheets of filter paper were used for all filter operations.

concentrated to the 42° Brix semi-syrup level in the open pan, filtered, and then processed in the vacuum bottle.

The amount of sugar in the raw juice, the semi-syrup, and syrup was determined by the use of an Abbe' Refractometer. This instrument provided an indication of degrees Brix which is a measurement of all soluble substances. The predominate substances in the cane juice are sugars; therefore, degrees Brix is an indication of the percentage of sugars.

The vacuum portion of the processing was accomplished by using a modified Groen, 19-liter, steam-jacketed, stainless steel kettle (Figures 5 and 6). The modification to accomplish a vacuum was via the use of a 1.91-centimeter-thick, plexiglass cover fitted with a vacuum port. The seal between the cover and the kettle was provided by a 3.175-millimeter-thick neoprene gasket. A bleed-air valve and vacuum gauge were also incorporated in the top.

The treatments in the experiment were the different combinations of vacuum used in processing and the syrup concentration prior to vacuum processing. In treatment "A," the raw juice was introduced to the open evaporator pan and brought to a boil. As the juice was heated, the suspended matter in the juice coagulated and formed a layer on the surface of the juice. This coagulated matter was skimmed off manually (Figure 7). This process continued throughout the processing until the syrup was concentrated to approximately 76° Brix. When this level of concentration was reached, the syrup was pumped through the filter, using a low pressure centrifugal pump, placed in 3.8-liter plastic jugs, and cooled in a water bath.

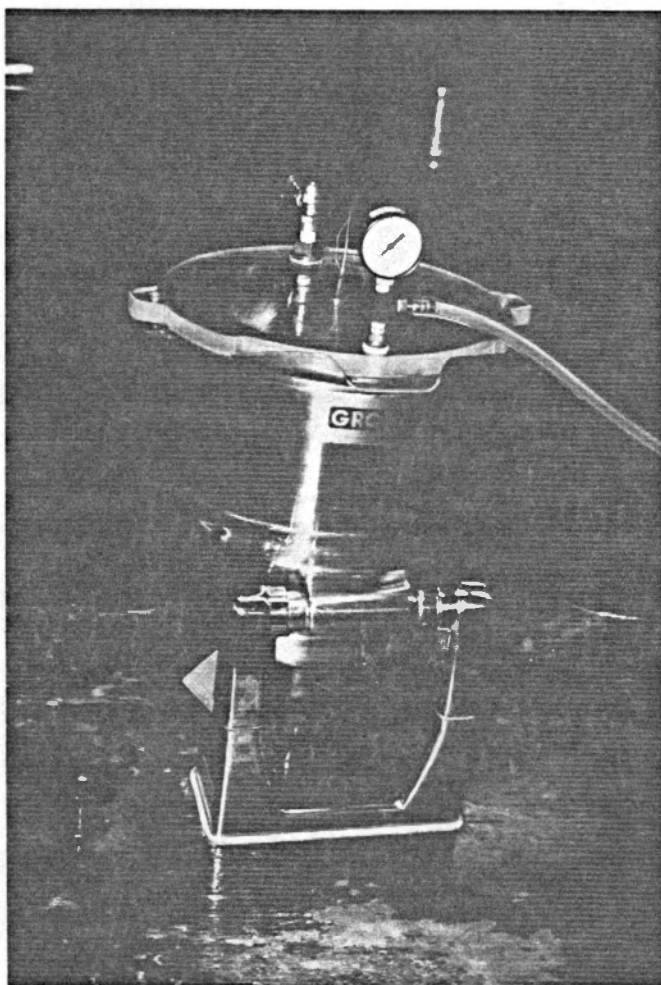


Figure 5. Vacuum kettle with cover in place.

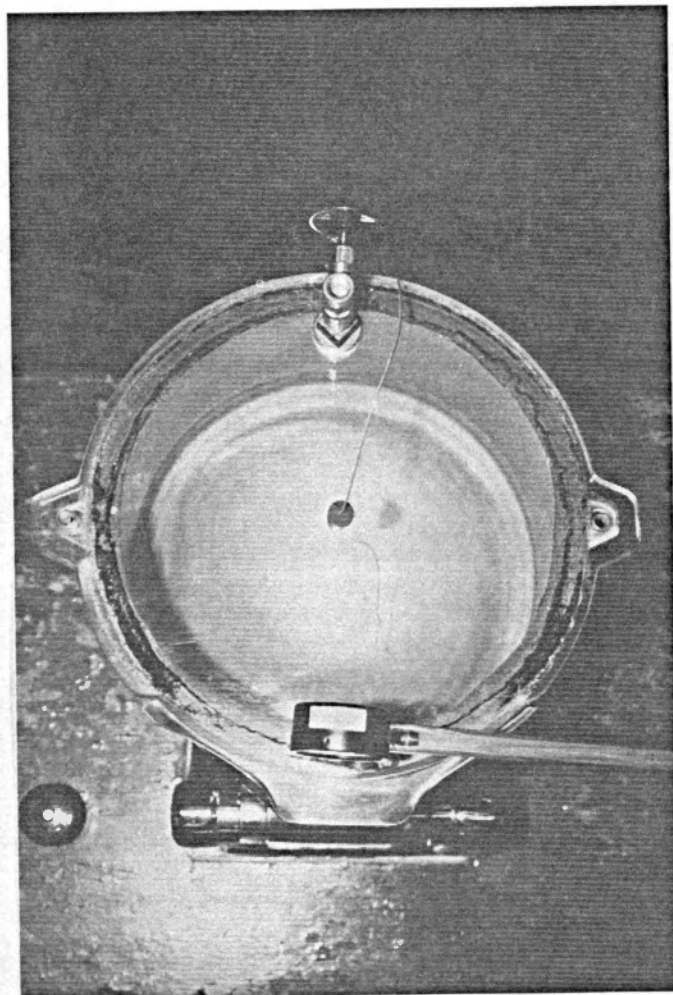


Figure 6. Vacuum kettle, top view. The thermocouple entering near the center of the cover was used to sense boiling point change during tests.

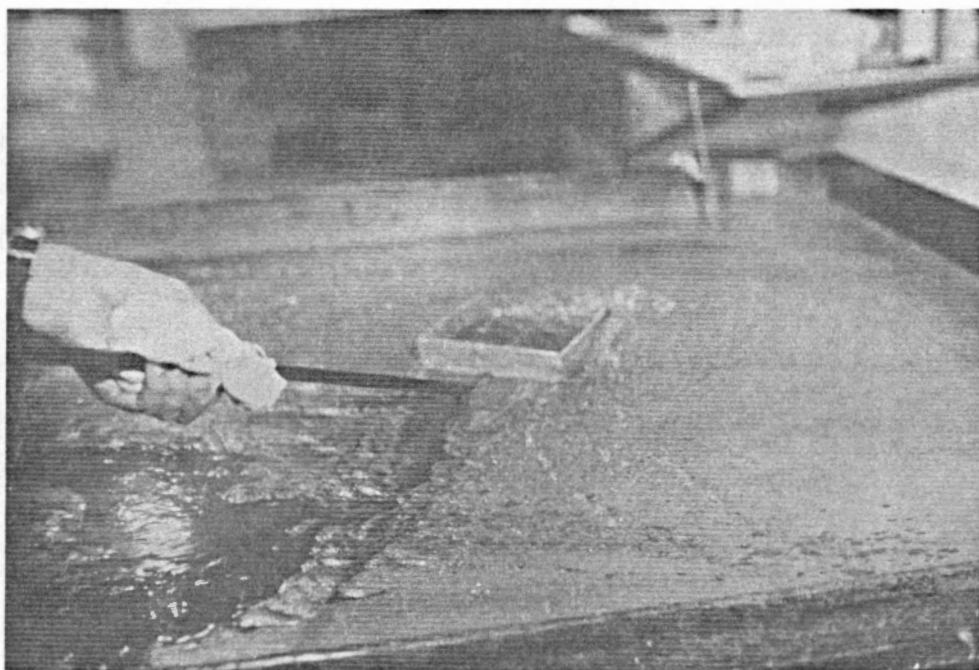


Figure 7. Manual skimming of juice in batch evaporator pan.

In treatments "B" and "C," the raw juice was heated, but not boiled, in the open evaporator pan. As the coagulated matter formed a surface layer on the juice, it was removed. When the surface was free of coagulated matter, the juice was removed from the evaporator pan, pumped through the filter, and placed in plastic 3.8-liter jugs. The jugs were placed in a water bath to cool and then placed in a freezer. At the time of vacuum processing, the samples were thawed and the juice placed in the vacuum kettle. The evaporation process was accomplished under 23.7 kPa vacuum in treatment "B" and 47.4 kPa vacuum in treatment "C." No removal of the coagulated matter, that might have formed, was possible in the vacuum system. When the syrup reached a Brix concentration of approximately 76°, it was removed from the kettle, placed in the plastic jugs, and cooled.

In treatments "D" and "E," the raw juice was concentrated to a 21° Brix semi-syrup level in the open evaporator pan before filtering and freezing. The coagulated matter was removed during the open pan evaporation. No additional removal of the coagulated matter was possible in the vacuum kettle processing. The vacuum processing procedure was the same as in previously mentioned treatments. Samples of "D" treatment were processed under 23.7 kPa vacuum, while "E" treatment samples were processed under 47.4 kPa vacuum.

In treatments "F" and "G," the raw juice was concentrated to a 42° Brix semi-syrup level in the open evaporator pan before filtering and freezing. The remainder of the processing was as noted for treatments "D" and "E." Processing was accomplished under 23.7 kPa vacuum in treatment "F" and 47.4 kPa vacuum in treatment "G."

Chemical and physical analyses of the "finished" syrup included a determination of degrees Brix, pH, total solids, percentage ash, percentage extraneous material, and percentage titratable acidity. In addition, a multiple comparison taste preference test was conducted. The subject variables for the taste panels were syrup texture, flavor, and color.

The degrees Brix was determined by the use of an Abbe' Refractometer. The pH was determined with a Sargent Model LS pH meter using a mixture of ten milliliters of syrup and 20 milliliters of boiled deionized water. Total solids were determined using adaptations of methods defined by the National Canners Association and AOAC official methods. Porcelain dishes were pretreated by heating for two hours at 525°C, then cooled and weighed. The dishes were weighed to the nearest milligram. These dishes were then weighed after the addition of approximately ten grams sample syrup and a small amount of acid-rinsed sand. The sand was added to prevent foaming during the ashing of the samples. The dishes containing the samples were placed in a vacuum oven that maintained 37.2 kPa vacuum at 70°C, for 48 hours. The dishes were then removed and weighed. The percentage of total solids was calculated as follows:

$$TS\% = \frac{(\text{dried sample wt.} + \text{dish wt.}) - (\text{dish wt.})}{(\text{wet sample wt.} + \text{dish wt.}) - (\text{dish wt.})} \times 100$$

To determine percentage ash, these samples were then placed in a cold muffle furnace, brought to 525°C, and held at that temperature until a white ash was obtained. All carbon was destroyed after

heating in the muffle furnace for approximately 12 hours. The dishes were then removed from the furnace and placed in a desiccator to cool. The samples were weighed and the percentage ash was calculated as follows:

$$\text{ASH\%} = \frac{(\text{ash wt.} + \text{dish wt.}) - (\text{dish wt.})}{(\text{wt. of sample before ashing} + \text{dish wt.}) - (\text{dish wt.})} \times 100$$

The amount of extraneous material in the syrup was determined, as discussed by Collins et al. (1977), by mixing ten milliliters of syrup with 20 milliliters of deionized water and filtering through number one Whatman filter paper. The mixture was poured through the filter paper and rinsed with 25 milliliters of deionized water. The filter paper which held the extraneous material was then vacuum dried to constant weight at 70°C. An expression of extraneous material on a percentage basis was made through calculation. Acid present in the syrup was measured by titrating a mixture of ten milliliters of syrup, 20 milliliters of deionized water, with 0.1N sodium hydroxide (NaOH). The percentage of acid was expressed as aconitic acid. Duplicate titrations were conducted on all the samples. The calculation was made as follows:

$$\text{TA\%} = \frac{\text{milliequivalent wt. aconitic acid} \times \text{ml NaOH} \times \text{normality of NaOH}}{\text{wt. of sample}} \times 100$$

A multiple comparison taste preference test was conducted to provide subjective evaluation of syrup quality. Ten panelists were used for each replication. The panelists were asked to compare two

samples to a reference sample. The reference sample was the syrup processed in the conventional open pan. The other samples were comprised of syrup processed in the vacuum kettle under various treatments. The panelists were asked to compare texture, flavor, and color. An example of the comparison sheet is shown in Figure 8.

Compare samples _____ and _____ with the reference sample (R) for texture, flavor, and color. Taste the samples on the tray and evaluate for texture and flavor, using the scale below. Place the score which best reflects your reaction in the table. Color comparison will be conducted on the samples located in the outer area of the testing room.

Extremely preferred 9
 Strongly preferred 8
 Moderately preferred 7
 Slightly preferred 6
 Equal to R 5
 Slightly disliked 4
 Moderately disliked 3
 Strongly disliked 2
 Extremely disliked 1

Table 1.

Characteristic	Reference	Sample _____	Sample _____
Texture	5	_____	_____
Flavor	5	_____	_____
Color (sample in outer area)	5	_____	_____

Age Group:

18-24 _____ 25-30 _____ 31-36 _____ Over 36 _____

Background: Farm _____ Non-Farm _____

What regional area of the United States are you from originally:

North _____ South _____ East _____ West _____ Outside USA _____

How often do you consume sorghum syrup:

Once a week _____ 2 or 3 times/month _____ 2 or 3 times/year _____

Once a month _____ Once a year _____ Never _____

Figure 8. Taste panel comparison sheet.

CHAPTER IV

RESULTS AND DISCUSSION

The analyses of results were divided into two phases to compare open evaporator pan processing and vacuum kettle processing of sorghum syrup. The first phase of analyses was performed on the results of the taste preference panel. The taste panel evaluated the color, texture, and flavor of the syrup samples. Physical and chemical analyses of the sorghum syrup samples were performed in the second phase of the analyses.

Taste Preference Panel

The taste preference panel evaluation was designed to have each panelist compare vacuum-processed syrup to syrup processed in an open evaporator pan. The properties evaluated were color, texture, and flavor. The panelists were not aware of how the different samples were processed. The reference sample in each case was the syrup processed in the open evaporator pan and was given a predetermined score of five on a scale of one to nine. The score of one corresponded to "extremely disliked," and the score of nine corresponded to "extremely preferred" as related to the reference sample.

In the experiment, there were five replications with seven treatments per replication. The experimental design called for all samples to be evaluated by the taste preference panel. After processing, it was determined by visual inspection that only samples

from three of the treatments could be used in the taste preference panel evaluation. The samples used represented syrup processed in the open evaporator pan and syrup that was concentrated to the 42° Brix level of semi-syrup prior to vacuum processing with either 23.7 or 47.4 kPa vacuum. The rejection of the samples from the other four treatments was based on the presence of extreme amounts of visible coagulated matter and the resulting dark green color of the syrup. Thus, only the syrup processed in the open evaporator pan and the syrup processed to the 42° Brix semi-syrup level prior to vacuum processing were evaluated by the taste preference panel.

Prior to the taste preference panel test, it was determined that samples from two of the five replications were contaminated and could not be used. The presence of mold growth on the samples from replications four and five prohibited human consumption. Ten panelists evaluated the samples from each of the three remaining replications tested, resulting in a total of 30 panelists.

Statistical analyses of the results of the taste preference panel data (Appendices A through C) indicated that the panel perceived no significant differences in the conventionally processed and the vacuum processed syrup in terms of color, texture, and flavor. Of note, however, is the closeness to a significant effect on flavor by treatment at the 90 percent probability level (Appendix C).

Freeman et al. (1970) noted an absence of the characteristic sorghum syrup flavor when the syrup was vacuum processed with no post vacuum heating to the 106°C to 110°C range. This phenomenon was not noted in this limited study.

Over 50 percent of the individuals who comprised the taste preference panel were in the 18- to 24-year-old age group. Sixty percent of the individuals on the panel had a non-farm background. The southern region of the United States had the largest representation on the panel, comprising 76 percent. Possibly the most significant demographic data noted is that over 36 percent of the panel members had never consumed sorghum syrup prior to the preference evaluation. Another 23 percent consume sorghum syrup only two or three times a year.

Chemical and Physical Analyses

The significance of the effects in the statistical analyses was based on the Type IV sum of squares test at a 90 percent level of confidence. The Type IV, partial sum of squares test was considered more desirable than the Type I, sequential sum of squares test. Statistical evaluation of the physical and chemical analyses data indicated a replication effect and a vacuum level, replication interaction effect on pH (Appendix D). No significant effects on extraneous material were noted using the Type IV test. A significant replication effect was noted using the Type I test (Appendix E). The final degrees Brix level to which the syrup was concentrated and a vacuum level, Brix, Brix interaction effect on total solids was noted (Appendix F). A replication effect on total solids was exhibited (Appendix F). A significant vacuum level effect on acidity was also noted (Appendix G). No significant effects on ash were noted (Appendix H).

The replication effect in this study was quite pronounced. It can be explained to some extent by examining the materials used. The sorghum juice obtained was from the same variety of cane and the same lot of seed but was produced at two different locations. The same general cultural practices were employed; however, the variation in location and environment probably affected juice composition. There was a differentiation in the cane maturity of up to two weeks.

The pH level and the amount of starch present in the syrup varied among replications. The variation can be attributed to the maturity of the cane, the environment, and the cultural practices employed (Walton et al., 1938).

The variation, among replications, in the level of extraneous material present may be attributed partially to the time interval between milling and processing. The juice used in replications one and two was held in a milk chiller for approximately 18 hours prior to processing. This allowed sufficient time for a great deal of sedimentation. The juice used in replications three, four, and five was processed immediately after milling. No significant sedimentation occurred prior to processing.

There was a significant effect on titratable acidity by the vacuum level used in processing. The percentage titratable acidity increased as the vacuum level increased (Figure 9). The explanation of this phenomenon is not apparent. The reduced availability of oxygen might have affected some chemical reaction.

The level of heating and skimming or cleaning of the juice prior to introduction to the vacuum kettle was important. Preheating

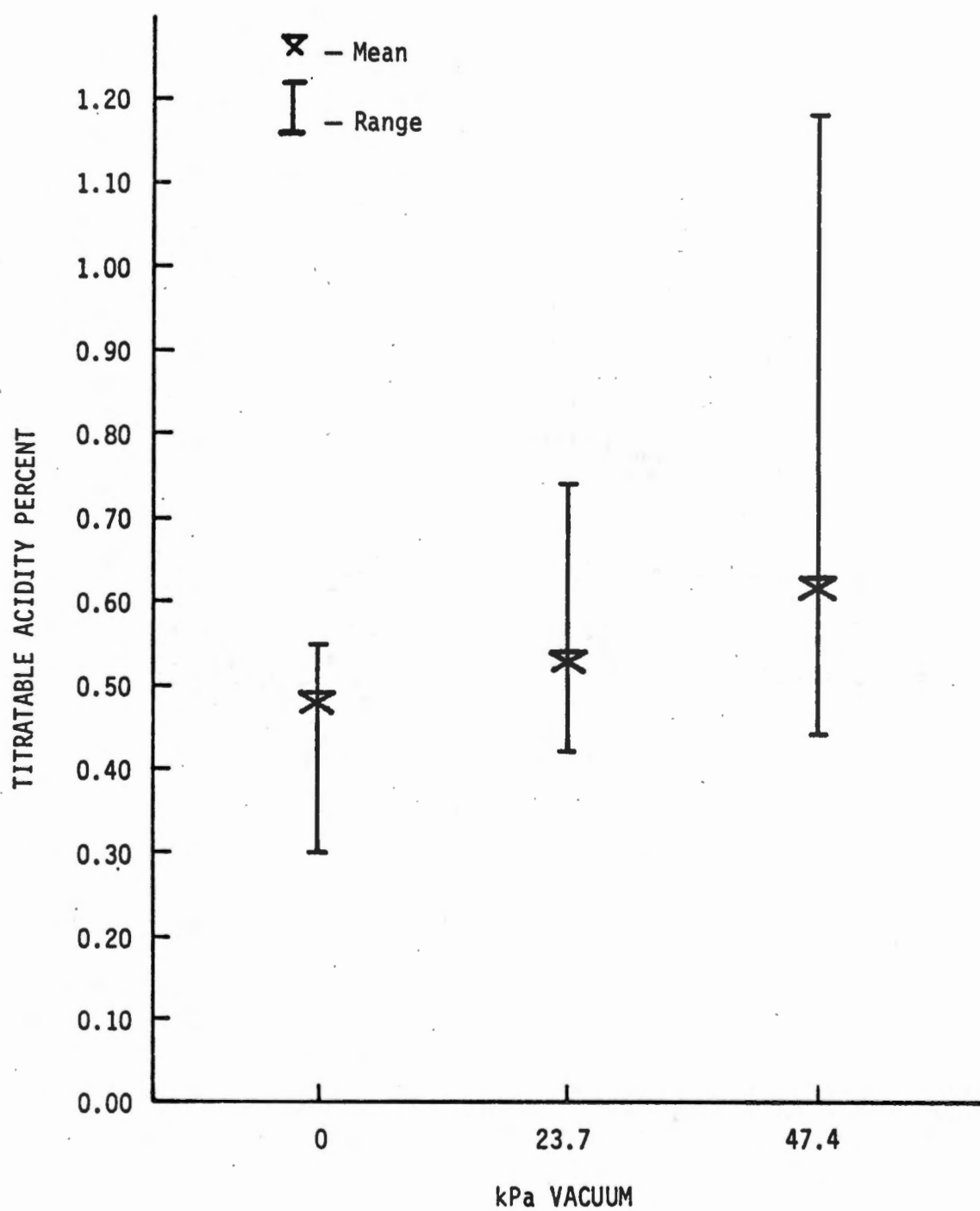


Figure 9. Titratable acidity as a function of vacuum used during final concentration of sorghum syrup.

or concentrating the juice to the 21° Brix level did not allow for the total coagulation of the suspended matter in the juice. The filter used was clogged in some instances due to the extreme amounts of extraneous matter present (Figure 10). The holding of the juice in sedimentation tanks prior to filtering and vacuum processing would possibly remedy this problem.

The extreme levels of starch present in the samples from three of the replications made filtering almost impossible due to clogging. A modification of cultural practices and harvesting techniques might prevent much of this problem. The juice could be treated with the enzyme amylase to remedy this problem.

Raw data from the taste preference panel and the syrup analyses are shown in Tables 1 and 2.

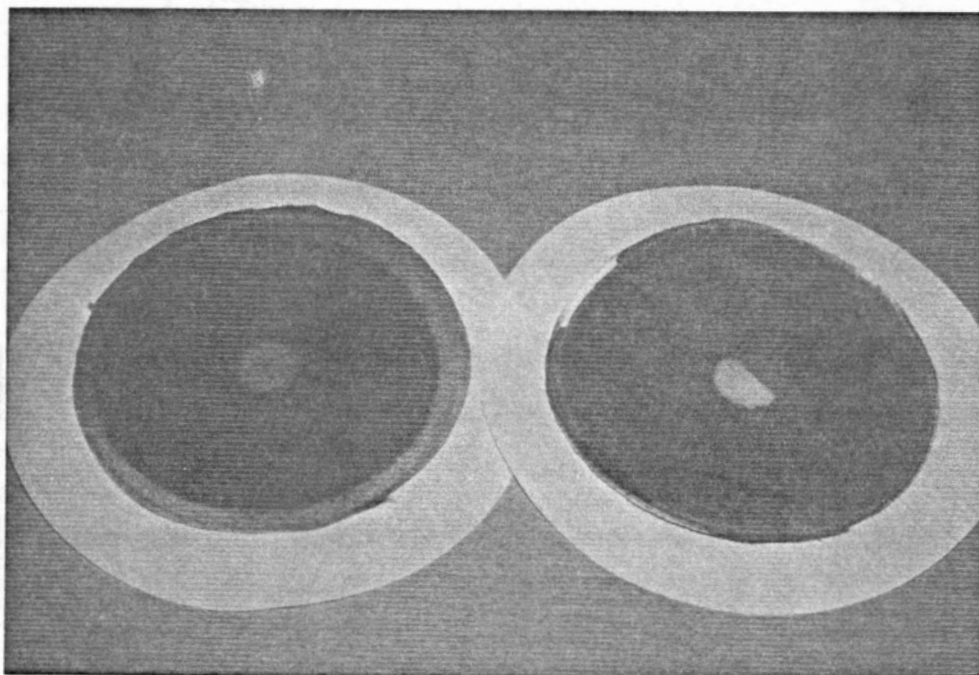


Figure 10. Clogged filter material from milk filter after processing 21° Brix sorghum juice.

Table 1. Taste Preference Panel Raw Data.

Sample	Panelist																													
	Texture										Flavor										Color									
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
1	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
6	4	3	7	3	7	8	7	7	4	6	6	4	4	6	8	4	3	6	4	6	6	5	4	6	7	4	7	7	6	6
7	4	6	6	5	2	6	7	8	4	5	6	7	7	5	2	7	6	6	5	5	5	5	6	5	4	7	6	6	5	5
8	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
13	3	4	6	5	3	2	4	4	5	7	6	4	3	5	3	2	6	7	9	6	6	5	7	6	4	3	7	3	4	4
14	7	7	9	8	7	6	7	7	5	4	7	8	8	8	6	5	7	5	6	4	4	8	7	8	5	8	4	7	6	7
15	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
20	5	4	5	6	5	8	4	8	9	5	4	5	7	6	5	8	4	8	9	4	5	5	4	5	5	6	5	5	5	4
21	5	7	5	8	6	7	4	6	8	5	6	7	5	8	7	7	4	6	8	4	6	6	8	4	5	4	5	5	5	4

Table 2. Syrup Analyses Raw Data.*

Sample	Source	VAC	DEGBS	REP	pH	TOTSOL	Ash	EXTMAT	TITACD	BRIX
1	A	0	0	1	5.20	76.2	1.36	17.7	0.55	74.8
2	A	7	0	1	5.15	73.0	2.16	22.6	0.56	69.3
3	A	14	0	1	5.20	84.1	2.75	17.5	0.54	80.0
4	A	7	21	1	5.15	67.6	1.78	9.9	0.49	65.8
5	A	14	21	1	5.20	78.4	2.34	19.1	0.56	74.5
6	A	7	42	1	5.20	70.9	2.35	4.9	0.46	67.5
7	A	14	42	1	5.20	73.6	2.21	9.4	0.54	70.3
8	A	0	0	2	5.15	85.9	2.89	11.7	0.49	77.5
9	A	7	0	2	5.20	76.9	1.94	11.1	0.42	67.7
10	A	14	0	2	5.20	87.2	3.11	9.0	0.94	74.0
11	A	7	21	2	5.20	79.2	2.62	10.2	0.48	67.5
12	A	14	21	2	5.35	71.0	2.52	6.0	0.44	69.3
13	A	7	42	2	5.15	77.2	2.72	5.3	0.45	71.0
14	A	14	42	2	5.20	87.1	2.94	21.1	0.52	77.0
15	B	0	0	3	5.05	90.2	3.71	16.7	0.52	73.5
16	B	7	0	3	5.05	77.2	2.07	25.8	0.50	69.0
17	B	14	0	3	5.00	84.7	2.37	17.7	0.54	73.0
18	B	7	21	3	5.05	80.6	2.35	15.3	0.54	74.0
19	B	14	21	3	5.05	77.4	2.21	11.1	0.51	72.5
20	B	7	42	3	5.05	73.0	2.09	26.8	0.50	72.0
21	B	14	42	3	4.85	81.7	1.82	12.0	0.50	72.0
22	B	0	0	4	4.85	79.7	2.33	12.2	0.54	74.5
23	B	7	0	4	4.95	78.9	2.39	33.1	0.49	76.5
24	B	14	0	4	4.90	82.0	2.55	30.2	0.56	80.0
25	B	7	21	4	4.95	82.5	2.60	43.1	0.51	79.0
26	B	14	21	4	4.95	82.0	4.76	13.8	0.52	71.5
27	B	7	42	4	4.95	76.4	2.21	18.5	0.56	68.0

Table 2. (Continued)

Sample	Source	VAC	DEGBS	REP	pH	TOTSOL	Ash	EXTMAT	TITACD	BRIX
28	B	14	42	4	5.05	79.0	2.28	13.5	1.18	72.5
29	B	0	0	5	5.05	77.9	2.60	23.1	0.30	75.0
30	B	7	0	5	5.05	80.9	3.17	41.3	0.74	72.0
31	B	14	0	5	5.00	82.2	3.19	25.1	0.73	80.0
32	B	7	21	5	5.05	78.1	2.85	12.2	0.70	75.0
33	B	14	21	5	5.00	69.6	0.52	15.1	0.64	70.0
34	B	7	42	5	5.00	64.3	2.86	33.4	0.52	62.0
35	B	14	42	5	5.05	84.7	4.67	20.7	0.57	70.5

*VAC = vacuum level; DEGBS = degrees Brix semi-syrup; REP = replication, TOTSOL = total solids; EXTMAT = extraneous material, TITACD = titratable acidity; BRIX = final degrees Brix.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

A steam-jacketed, stainless steel kettle was modified to simulate a vacuum pan for use in the processing of sweet sorghum syrup. The syrup processed in the vacuum kettle was compared to syrup processed in an open evaporator pan. The experimental design, a randomized complete block design with factorial arrangement of treatment combinations, consisted of five replications with seven treatments in each replication. The treatments differed by the combination of the degrees Brix level to which the semi-syrup was concentrated prior to vacuum processing and the vacuum level used during the process of final concentration.

The primary evaluation in determining the feasibility of the vacuum system was that of the taste preference panel. Physical and chemical analyses were conducted in order to determine specific quantifiable differences and to explain subjective differences as perceived by the taste panel.

After processing, four treatments were removed from the taste panel evaluation due to the obvious unsuitability of the product quality. Two of the five replications were also removed from the taste panel review due to product contamination.

The taste preference panel perceived no significant differences between the syrup processed in the vacuum kettle and that processed in the conventional open evaporator pan.

The differences quantified by the physical and chemical analyses were generally related to replication effect. The replication effect was expected. An unexpected and unexplained phenomenon did occur in this experiment. A correlation was exhibited between the vacuum level used in the processing and the titratable acidity in the finished syrup. As the vacuum level was increased, the titratable acidity increased.

Conclusions

The following conclusions were drawn from the results:

1. Vacuum-processed sorghum syrup can equal conventionally processed syrup in the quality terms of color, texture, and flavor.
2. Attention to cultural practices, harvesting techniques, and juice clarification could improve syrup quality.
3. Sedimentation tanks should be used prior to the filtering and processing of sorghum juice.

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APPENDICES

APPENDIX A

STATISTICAL ANALYSES OF TASTE PREFERENCE PANEL DATA FOR THE DEPENDENT VARIABLE COLOR

<u>Source</u>	<u>DF</u>	<u>Sum of Squares</u>	<u>Mean Square</u>	<u>F Value</u>	<u>PR > F</u>	<u>R-Square</u>	<u>C.V.</u>
Model	30	33.00000000	1.10000000	0.52	0.9614	0.348346	336.6966
Error	29	61.73333333	2.12873563		STD DEV		Color Mean
Corrected Total	59	94.73333333			1.45901872		0.43333333

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<u>Source</u>	<u>Type I</u>				<u>Type IV</u>			
	<u>DF</u>	<u>Sum of Squares</u>	<u>F Value</u>	<u>PR > F</u>	<u>DF</u>	<u>Sum of Squares</u>	<u>F Value</u>	<u>PR > F</u>
Treatment	1	4.26666667	2.00	0.1675	1	4.26666667	2.00	0.1675
Replication	2	4.43333333	1.04	0.3658	2	4.43333333	1.04	0.3658
Panelist (Replication)	27	24.30000000	0.42	0.9864	27	24.30000000	0.42	0.9864

Note: Factors tested were treatment, replication, and panelist within replication.

APPENDIX B

STATISTICAL ANALYSES OF TASTE PREFERENCE PANEL DATA FOR THE DEPENDENT VARIABLE TEXTURE

Source	DF	Sum of Squares	Mean Square	F Value	PR > F	R-Square	C.V.
Model	30	98.16666667	3.27222222	1.22	0.2936	0.558877	251.4732
Error	29	77.48333333	2.67183908		STD DEV		Texture Mean
Corrected Total	59	175.65000000			1.63457612		0.65000000

Source	Type I				Type IV			
	DF	Sum of Squares	F Value	PR > F	DF	Sum of Squares	F Value	PR > F
Treatment	1	6.01666667	2.25	0.1443	1	6.01666667	2.25	0.1443
Replication	2	3.70000000	0.69	0.5085	2	3.70000000	0.69	0.5085
Panelist (Replication)	27	88.45000000	1.23	0.2950	27	88.45000000	1.23	0.2950

Note: Factors tested were treatment, replication, and panelist within replication.

APPENDIX C

STATISTICAL ANALYSES OF TASTE PREFERENCE PANEL DATA FOR THE DEPENDENT VARIABLE FLAVOR

Source	DF	Sum of Squares	Mean Square	F Value	PR > F	R-Square	C.V.
Model	30	81.80000000	2.72666667	0.92	0.5894	0.487679	234.7364
Error	29	85.93333333	2.96321839		STD DEV		Flavor Mean
Corrected Total	59	167.73333333			1.72140013		0.73333333

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Source	Type I				Type IV			
	DF	Sum of Squares	F Value	PR > F	DF	Sum of Squares	F Value	PR > F
Treatment	1	8.06666667	2.72	0.1097	1	8.06666667	2.72	0.1097
Replication	2	5.63333333	0.95	0.3982	2	5.63333333	0.95	0.3982
Panelist (Replication)	27	68.10000000	0.85	0.6617	27	68.10000000	0.85	0.6617

Note: Factors tested were treatment, replication, and panelist within replication.

APPENDIX D

STATISTICAL EVALUATION OF CHEMICAL AND PHYSICAL ANALYSES DATA FOR THE DEPENDENT VARIABLE pH

Source	DF	Sum of Squares	Mean Square	F Value	PR > F	R-Square	C.V.
Model	11	0.40072845	0.03642986	13.71	0.0001	0.867646	1.0157
Error	23	0.06112870	0.00265777		STD DEV		pH Mean
Corrected Total	34	0.46185714			0.05155356		5.07571429

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Source*	Type I				Type IV			
	DF	Sum of Squares	F Value	PR > F	DF	Sum of Squares	F Value	PR > F
Final Brix Level	1	0.01610540	6.06	0.0217	1	0.00092872	0.35	0.5602
Vac	1	0.00187733	0.71	0.4093	1	0.00179521	0.68	0.4196
Brix S-S	1	0.00991821	3.73	0.0658	1	0.00071920	0.27	0.6079
Replication	4	0.34557972	32.51	0.0001	4	0.07645243	7.19	0.0007
Vac*Replication	4	0.02724779	2.56	0.0655	4	0.02724779	2.56	0.0655

*Vac = vacuum level; Brix S-S = degrees Brix of the semi-syrup.

Note: Factors tested were final degrees Brix, vacuum level, degrees Brix of the semi-syrup, replication, and vacuum level, replication interaction.

APPENDIX E

STATISTICAL EVALUATION OF CHEMICAL AND PHYSICAL ANALYSES DATA FOR THE DEPENDENT VARIABLE EXTRANEOUS MATERIAL

Source	DF	Sum of Squares	Mean Square	F Value	PR > F	R-Square	C.V.
Model	11	1159.93273346	105.44843031	1.25	0.3093	0.375037	50.4309
Error	23	1932.91562654	84.03980985		STD DEV		EXTMAT Mean
Corrected Total	34	3092.84836000			9.16732294		18.17800000

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Source*	Type I				Type IV			
	DF	Sum of Squares	F Value	PR > F	DF	Sum of Squares	F Value	PR > F
Final Brix Level	1	172.54530405	2.05	0.1653	1	59.63579172	0.71	0.4082
Vac	1	38.40495544	0.46	0.5058	1	21.90758728	0.26	0.6145
Brix S-S	1	0.39321419	0.00	0.9461	1	11.52639505	0.14	0.7145
Replication	4	896.46248706	2.67	0.0581	4	368.40834367	1.10	0.3821
Vac*Replication	4	52.12677272	0.16	0.9587	4	52.12677272	0.16	0.9587

*Vac = vacuum level; Brix S-S = degrees Brix of the semi-syrup.

Note: Factors tested were final degrees Brix, vacuum level, degrees Brix of the semi-syrup, replication, and vacuum level, replication interaction.

APPENDIX F

STATISTICAL EVALUATION OF CHEMICAL AND PHYSICAL ANALYSES DATA FOR THE DEPENDENT VARIABLE TOTAL SOLIDS

Source	DF	Sum of Squares	Mean Square	F Value	PR > F	R-Square	C.V.
Model	10	801.08457432	80.10845743	5.41	0.0003	0.692864	4.8917
Error	24	355.10849997	14.79618750		STD DEV		TOTSOL Mean
Corrected Total	34	1156.19307429			3.84658127		78.63485714

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Source*	Type I				Type IV			
	DF	Sum of Squares	F Value	PR > F	DF	Sum of Squares	F Value	PR > F
Final Brix Level	1	528.96587958	35.75	0.0001	1	178.41192854	12.06	0.0020
Vac	1	0.48157276	0.03	0.8583	1	29.56253267	2.00	0.1703
Brix S-S	1	0.65709499	0.04	0.8349	1	1.52189476	0.10	0.7512
Replication	4	154.33552289	2.61	0.0610	4	153.80156032	2.60	0.0616
Vac*Brix S-S	1	51.76693813	3.50	0.0737	1	37.01988486	2.50	0.1268
Vac*Vac*Brix S-S	1	4.65370154	0.31	0.5801	1	6.73382491	0.46	0.5064
Vac*Brix S-S*Brix S-S	1	60.22386443	4.07	0.0550	1	60.22386443	4.07	0.0550

*Vac = vacuum level; Brix S-S = degrees Brix of the semi-syrup.

Note: Factors tested were final degrees Brix, vacuum level, degrees Brix of the semi-syrup, replication, and vacuum, degrees Brix of the semi-syrup interaction.

APPENDIX G

STATISTICAL EVALUATION OF CHEMICAL AND PHYSICAL ANALYSES DATA FOR THE DEPENDENT VARIABLE TITRATABLE ACIDITY

Source	DF	Sum of Squares	Mean Square	F Value	PR > F	R-Square	C.V.
Model	11	0.22477272	0.02043388	0.84	0.6062	0.286226	27.8627
Error	23	0.56052442	0.02437063		STD DEV		TITACD Mean
Corrected Total	34	0.78529714			0.15611095		0.56028571

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Source*	Type I				Type IV			
	DF	Sum of Squares	F Value	PR > F	DF	Sum of Squares	F Value	PR > F
Final Brix Level	1	0.01295529	0.53	0.4733	1	0.00330942	0.14	0.7159
Vac	1	0.09227611	3.79	0.0640	1	0.08527191	3.50	0.0742
Brix S-S	1	0.00013893	0.01	0.9405	1	0.00001119	0.00	0.9831
Replication	4	0.05821588	0.60	0.6683	4	0.01738605	0.18	0.9473
Vac*Replication	4	0.06118651	0.63	0.6476	4	0.06118651	0.63	0.6476

*Vac = vacuum level; Brix S-S = degrees Brix of the semi-syrup.

Note: Factors tested were final degrees Brix, vacuum level, degrees Brix of the semi-syrup, replication, and vacuum level, replication interaction.

APPENDIX H

STATISTICAL EVALUATION OF CHEMICAL AND PHYSICAL ANALYSES DATA FOR THE DEPENDENT VARIABLE ASH

Source	DF	Sum of Squares	Mean Square	F Value	PR > F	R-Square	C.V.
Model	11	5.60751895	0.50977445	0.78	0.6568	0.271625	31.6942
Error	23	15.03683534	0.65377545		STD DEV		Ash Mean
Corrected Total	34	20.64435429			0.80856382		2.55114286

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Source*	Type I				Type IV			
	DF	Sum of Squares	F Value	PR > F	DF	Sum of Squares	F Value	PR > F
Final Brix Level	1	0.44780693	0.68	0.4164	1	0.23918812	0.37	0.5512
Vac	1	0.15920664	0.24	0.6264	1	0.09600239	0.15	0.7051
Brix S-S	1	0.13949831	0.21	0.6485	1	0.07689710	0.12	0.7347
Replication	4	2.18590824	0.84	0.5164	4	2.50316893	0.96	0.4495
Vac*Replication	4	2.67509884	1.02	0.4164	4	2.67509884	1.02	0.4164

*Vac = vacuum level; Brix S-S = degrees Brix of the semi-syrup.

Note: Factors tested were final degrees Brix, vacuum level, degrees Brix of the semi-syrup, replication, and vacuum level, replication interaction.

VITA

Dennis Wilson Jones was born in Knoxville, Tennessee on January 31, 1953. He was reared in Hialeah, Florida until 1971, when he returned to Knoxville, Tennessee. In June of that year, he graduated from West High School. The author graduated from The University of Tennessee, Knoxville in June 1977, where he received a Bachelor of Science degree in Business Administration. During his years as an undergraduate student, the author worked as a laboratory assistant in the Agricultural Engineering Department. He entered the Graduate School at The University of Tennessee, Knoxville in June 1977 and served as a graduate research assistant in the Agricultural Engineering Department. In July 1978, the author entered military service in the United States Navy via Officer Candidate School. Discharged a Lieutenant, he had served four years and continued his service as an active reservist in the United States Naval Reserve. Returning to Graduate School at The University of Tennessee, Knoxville, the author received a Master of Science degree with a major in Agricultural Mechanization in December 1983.

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