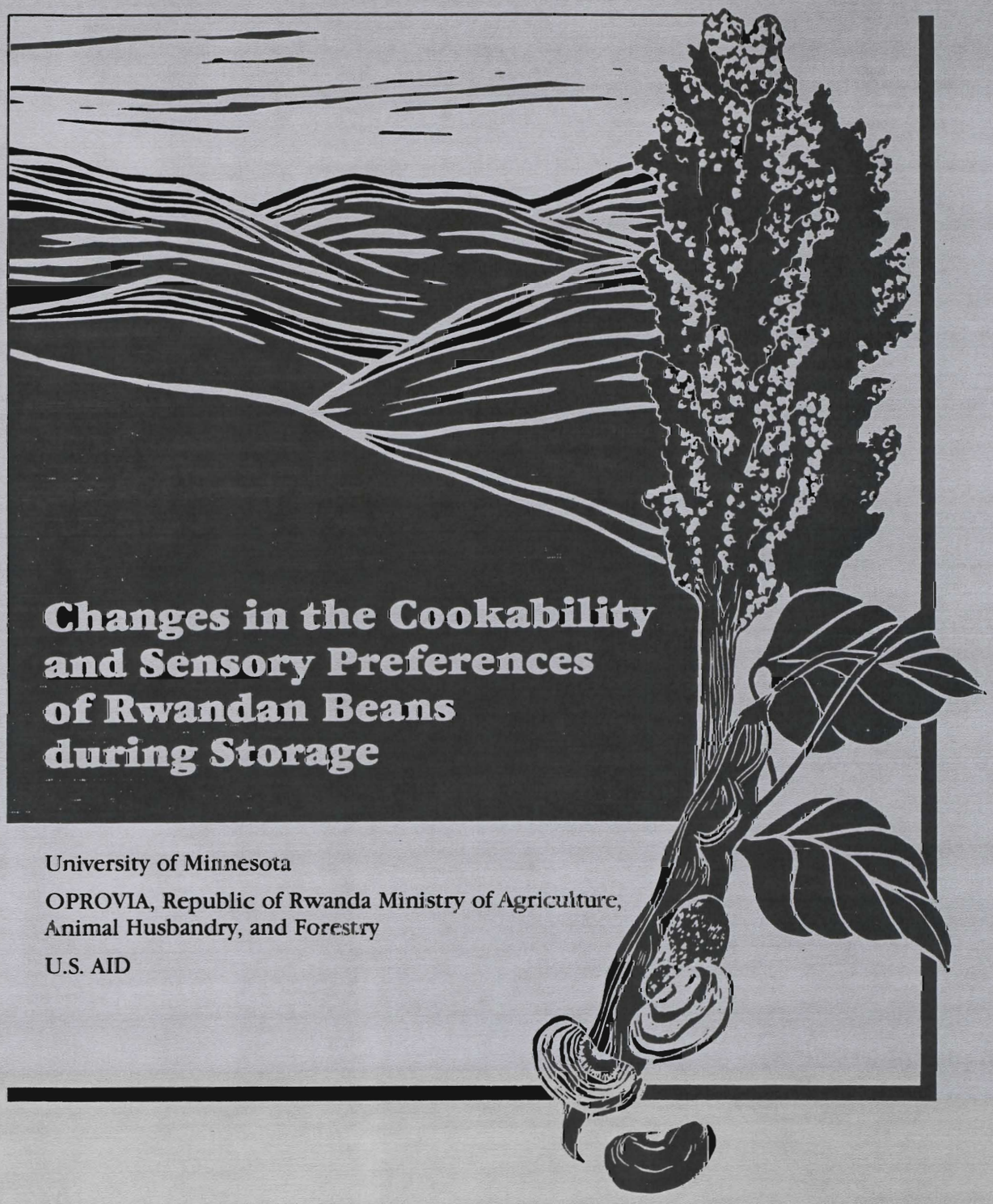


Changes in the Cookability and Sensory Preferences of Rwandan Beans during Storage

University of Minnesota

OPROVIA, Republic of Rwanda Ministry of Agriculture, Animal Husbandry, and Forestry

U.S. AID

Miscellaneous Publication 47—1986
Minnesota Agricultural Experiment Station, University of Minnesota

As a miscellaneous publication of the Minnesota Agricultural Experiment Station, this title is intended for a very limited audience. Initial distribution was made by the University of Minnesota's Office of International Agricultural Programs, 299 Coffey Hall, University of Minnesota, 1420 Eckles Ave., St. Paul, MN 55108.

Changes in the Cookability and Sensory Preferences of Rwandan Beans during Storage

J. A. Edmister
Research Assistant

W. M. Breene
Food Scientist
Technical Advisor

Z. M. Vickers
Food Scientist
Technical Advisor

A. Serugendo
Research Assistant

Miscellaneous Publication 47--1986
Minnesota Agricultural Experiment Station, University of Minnesota

SUMMARY

The research reported here is grouped into nine separate studies, each a research project in its own right. The central study of this group is the Large Scale Bagged Study, Section IV, in which beans at different moisture contents are stored at different agroclimatic regions of the country. Sensory measures of hardness, preference, and acceptability, instrumental measurements of hardness and color, and measurements of other physical qualities are made on the stored bean mixture at two-month intervals for 24 months. Although this study has yet to be completed, it will provide a large data base from which a wide variety of knowledge (i.e. which storage location and moisture produce the best quality beans, the relationships between storage conditions, sensory quality and instrumental hardness) can be gleaned. Other studies support or extend the results of this large scale bagged study.

In Section I, Development of Standard Laboratory Sensory and Cookability Tests, we outline the preliminary studies conducted to determine the feasibility of the different sensory testing procedures and instrumental hardness procedures. The testing methods specified in this section are used in all the other studies of this report.

In Section II, Moisture Meter Calibration, we detail the procedures used to calibrate several different moisture meters for both single bean varieties and typical Rwandan bean mixtures. All the moisture meters used were reasonably accurate, but there was considerable variability among meters and within a single meter. Some of this variability is likely due to the variety of beans present in a mixture and can be partly counteracted by making several replicate measurements.

In Section III, Moisture Sorption Isotherms, desorption and adsorption isotherms were obtained experimentally for both mixtures and single varieties of Rwandan beans. These isotherms can be used to predict the moisture content of stored Rwandan beans when storage temperature and relative humidity are known. The isotherms obtained for Rwandan beans were then compared with published isotherms of other bean varieties.

In Section V, Laboratory Storage Studies, bean mixtures were stored in the laboratory at controlled temperatures and moisture contents (or relative humidities) for a two year period. At four-month intervals instrumental hardness and color were measured. Beans stored at the higher temperatures and the higher relative humidities were harder and showed greater color changes. One of these studies is currently in progress and parallels the large scale bag storage study.

Section VI, Alternative Preservation of Green and Dry Beans, examines the following technologies as alternatives to the normal Rwandan method of storing beans: controlled atmosphere storage of dry beans, canning dry beans, canning green beans, precooking and drying beans, and preparing a bean flour that can be used to thicken soup. The canned green beans and the soup thickened with bean flour were both new products to Rwandans, and both were very acceptable. The precooked dried beans and beans of relatively higher moisture content (14-16%) were not acceptable after twelve months storage. The controlled atmosphere beans at lower moisture levels (10-12%) and the canned dry beans were both acceptable after twelve months storage. This study is still in progress.

In Section VII, Effect of Drying on Cookability, Color, Viability and Germinability of Beans, beans were dried to several different final moisture contents at several different drier air temperatures. Beans having the highest moisture contents after drying were harder after cooking and showed increased color changes.

In Section VIII, Thin Layer Drying Curves, drying data were collected for a bean mixture over a temperature range of 28-45°C. The data were fit to a drying model which was generalized to determine drying constants K and N as a function of drying air temperature. The data fit the model well and can be used to design appropriate drying systems for Rwandan beans.

Finally, the Bean Variety Study, Section IX, examined the sensory preferences and instrumental hardness and color for six varieties of beans stored for zero, six and twelve months. Subjects participating in the sensory tests were from three different regions of Rwanda. During the twelve months of testing neither the sensory scores or the instrumental hardness values decreased. The specific likes and dislikes for the different bean varieties were to some extent generalizable to subjects from all regions and to some extent region specific. There was no apparent relationship between the instrumental hardness of the beans and the sensory preference scores.

As indicated above, the studies designated as the Large Scale Bagged Study (Section IV) and Laboratory Storage Studies (Section V) could not be completed within the time limitations of the project. We have updated the data tables as the report has been undergoing revision. We will publish the full results of these two sections when all of the data has been collected, analyzed and interpreted. Copies of these publications will be presented to the interested parties when they become available.

ACKNOWLEDGEMENTS

This research was supported by the United States Agency for International Development (USAID) through the Local Crop Storage/Food Storage and Marketing II Project under Contract No. AFR-0107-C-4001-00.

The authors are grateful for the help of the following people in conducting the research reported here:

Ms. Chantal Umugwaneza, former counterpart of Judith Edmister;

Mrs. Vénéranda Murebwayire, Miss Julienne Mukankunze and Mr. Augustin Bizimana, laboratory technicians;

Drs. Vance Morey, Dave Thompson and Paul Hanegreefs for help in the design and analysis of experiments, construction and troubleshooting of equipment, and review of parts of this report;

Mr. Steve Clarke and Mr. Phocas Kayinamura for making the necessary arrangements; and

Mrs. Dorothy Brent for typing the manuscript.

TABLE OF CONTENTS

SECTION IV

LARGE SCALE BAGGED STUDY

SECTION V

LAB STORAGE STUDIES

SECTION VI

ALTERNATIVE PRESERVATION OF GREEN AND DRY BEANS (*Phaseolus vulgaris*) IN RWANDA

SECTION VII

INFLUENCE OF DRYING ON COOKABILITY, COLOR, VIABILITY AND GERMINABILITY OF RWANDAN BEANS (*Phaseolus vulgaris*)

SECTION VIII

THIN-LAYER DRYING OF RWANDAN BEANS (*Phaseolus vulgaris*)

SECTION IX

BEAN VARIETY STUDY

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

BACKGROUND INFORMATION ON RWANDA**

Geographical Aspects

Rwanda is located 1 to 3° south of the equator in east central Africa and is bordered by Uganda, Zaire, Burundi, and Tanzania. Rwanda covers an area of 26,388 km^2. The topography is hilly with elevations of 950 masl* in the southern region to 4,500 masl in the volcanic region of the northwest. The native vegetation ranges from savannah to highland tropical forest which has now been largely cleared for farmland. Ninety percent of the soils are basic pre-Cambrian. Five percent are alluvial and are found in the marshy areas between the hills. Areas with rich volcanic soils (5%) are characterized by high population densities. Streams, rivers and lakes are well distributed throughout the country. The rainfall is bimodal, with rainy seasons occurring between February and May and October and December. Total annual precipitation is 800 to 2,000 mm. Average temperatures range from 16 to 24°C, varying with altitude.

Demographic Aspects

The population was 5.5 million in 1982 with an annual growth rate of 3.5 percent, one of the highest in Africa. The population density of the whole country is 200 inhabitants per square kilometer but rises to 400 inhabitants per square kilometer when it is calculated on the basis of arable land area. The population is still largely rural, with only 5 percent of the people living in cities. The rural organization is one of scattered homesteads rather than organized villages.

Political Division

The capitol of Rwanda is Kigali. The country is divided into 10 prefectures, each with a center of government. Prefectures are divided into communes, of which there are 143. Communes are divided into sectors which are divided into cellules which are further divided into collines. These individual hillsides constitute the smallest political unit.

Agriculture in Rwanda

A total of 1,229,600 ha of arable land is available (1980 data). Subsistance farming makes up the greatest part of agricultural effort in the country with each family having about one hectare of disjointed small plots to cultivate. Agriculture is characterized by a lack of mechanization, intercropping, mixed crop and livestock culture and the production of multiple food crops. The cropping seasons reflect the rainfall pattern although a third season is possible in the marshy areas.

---

*Meters above sea level.
**This section is primarily from Lamb and Hardman, 1986.

The most important crops, by harvested area (1978-1980), are beans (Phaseolus vulgaris), banana, sorghum, sweet potato, maize, pea, cassava and Irish potato. Maize, pea and Irish potato are most important at the higher elevations. Soybean, peanut, millet, wheat, rice, taro, and yams are also grown, as well as various vegetable crops including tomato, eggplant, cabbage, leek, and onion. Fruits grown include papaya, pineapple, avocado and custard apple. The principal industrial crops are coffee, tea and pyrethrum. Cattle, goats, sheep, pigs, chickens and rabbits are produced. The country has been divided into 12 agroclimatic zones, based on elevation, rainfall, soils and types of agricultural production (Appendix I).

Agricultural Research

ISAR (Institut des Sciences Agronomiques du Rwanda) has primary responsibility for all agricultural research done in Rwanda. Seven branch stations are distributed in various regions of the country. Research is carried out on food and industrial crops, farming systems, forestry, and livestock production. Seldom are postharvest topics selected for research projects. At the headquarters in Rubona, laboratory and field space is available for plant breeding, plant protection, soil and plant chemistry and microbiology. Some research is carried out by the Faculty of Agronomy of the National University of Rwanda (UNR), generally in relation to the training of students.

Bean Production, Storage and Marketing

Beans (Phaseolus vulgaris) are the major source of vegetable protein in the Rwandan diet. The estimated consumption of dry beans is 40 kg per person per year. In 1984, 98 percent of 2,100 sampled farms grew some beans during the year. Yields ranged from 417 kg/ha to 975 kg/ha with a nationwide average of 662 kg/ha. The mean yield for the first and most important season, harvested in January, was 760 kg/ha dropping to 475 kg/ha for the second season. Based on national averages, each family plants 0.35 ha to beans, either as a pure crop or the primary component in a mixed crop. Only 10.4 percent of the area used for bean cultivation is devoted to pure crops. On 71 percent of the area, beans are the primary crop and on 18 percent of the area, the secondary crop. The total harvested area of beans is approximately 240,000 ha and the total production in 1984 was 256,306 metric tons.

Beans are stored for seed and food by farmers between harvests. Generally, they are stored in large baskets in the house. Storage cooperatives are organized where farmers may sell their beans with the possibility of purchasing beans at a later time. These cooperatives use hangar or silo-type storage structures. GRENARWA (Grenier National du Rwanda) has a storage capacity of 16,000 metric tons of grain, mostly beans and sorghum. The most commonly encountered storage problems of beans are molds, insects, physical changes resulting in cookability problems, and rats.

Marketing is usually done at the local level. An estimated 30 percent of total production is marketed. Excess produce may be sold at harvest or at various times during the year when money is needed. Local merchants also buy and resell beans, generally buying when the prices are low and selling when beans are more scarce and more expensive. OPROVIA (Office National Pour le Développement et la Commercialisation des Produits Vivriers et des Productions Animales) also buys beans from farmers and merchants and markets them through the OPROVIA stores.

MODIFICATIONS TO ORIGINAL WORK PLAN

The contract signed on November 5, 1983 by the University of Minnesota and AID gave two objectives for research conducted by this component:

A. To find ways acceptable to consumers of reducing cooking time for beans.

B. To obtain a better understanding of producer and consumer preferences of beans to facilitate orderly marketing of the crop.

The work plan, developed by the authors of this report and Dr. David Thompson, presented a vastly more detailed proposal broken into twelve separate studies. This report is organized based on those twelve studies, however this report contains only nine separate sections. One of the original twelve studies, Bulk Storage Monitoring, was moved to the alternative storage component. Another two, explaining our data in terms of mechanisms which have been identified in the literature and modeling and developing other tools for effective presentation of results, are not reported here as separate sections. Instead information from them can be found throughout the report as an integral part of the other studies.

Numerous small changes have been made in the original work plan since the time it was prepared. Most of the authors had not been to Rwanda when that work plan was developed and knew little about the facilities and personnel that would eventually be available to help conduct the research. Even so the majority of the studies have been conducted as planned with only minor variations. At the time this report was prepared three of the studies had not been completed. These were: Laboratory exploration of alternative preservation techniques, Laboratory storage study, and the Large scale bag study. The Laboratory exploration of alternative preservation techniques was started in July 1985 and should be completed in January 1988. The Laboratory storage study and Large scale bag study were started in February 1986 and should be completed in February 1988.

SECTION I

DEVELOPMENT OF STANDARD LABORATORY SENSORY AND COOKABILITY TESTS

ABSTRACT

Sensory test procedures and test locations for determining the desirability and the hardness of Rwandan beans were established for use in the FSM II GRENARWA/RECHERCHES Project. Standardized procedures for cooking the beans and measuring their hardness instrumentally were also established. The sensory testing procedure for bean preferences includes questions on subjects' willingness to eat the beans, the degree to which they like the beans and their perception of the current market value of those beans. The sensory test locations were selected to provide a suitably large number of potential consumers of Rwandan beans who would be available when needed. The instrumental hardness test to be used in all portions of this research is a puncture test on a sample of 100 beans that have been cooked in boiling salted water for three hours. The sensory hardness tests will be done using a group of ten trained subjects using a 9 point structured category scale.

INTRODUCTION

The Bean Cookability and Sensory Preference component of the FSM II GRENARWA/RECHERCHES Project includes several studies in which both instrumental and sensory testing of Rwandan bean mixtures and varieties are necessary. The studies involved are: the Large Scale Bagged Storage study; the Bean Varietal study; the Laboratory Storage study; the Alternative Conservation study; and

the Influence of Drying on Cookability. The objectives of this first study were to: 1) identify appropriate laboratory cookability tests; 2) establish appropriate consumer preference testing procedures and locations; and 3) identify and train a sensory panel for bean hardness evaluation at the OPROVIA laboratory. This paper summarizes the results of the study, and describes in detail the sensory and instrumental testing procedures to be used throughout the project.

MATERIALS AND METHODS

I. Identification of Appropriate Laboratory Cookability Tests: Instrumental Hardness

A. Cooking Procedure

In preparation for cooking, obviously cracked, split, shriveled, dented, or otherwise damaged beans are removed. One-third cup beans (approximately 150 beans) and ½ tsp. salt are added to excess tap water in a 2 or 3 quart Farberware saucepan. The beans are brought to a boil over high heat, on either electric Thermolyne hotplates (model HPA2230M, Thermolyne Corp., 2555 Kerper Blvd., Dubuque Iowa 52001), or on a Seppelfricke 2-burner kitchen model hotplate (Metallwerke Gebr. Seppelfricke GmbH and Co., 4650 Gelsebkirchenschalke Amstahthafen 16). When the beans begin to boil (at approximately 96°C), the heat is reduced to maintain a moderate boil with the saucepan covered. The cooking time is measured three hours from the start of boiling (Benchtop sensory tests of beans stored 1-2 months after harvest and cooked for different lengths of time indicated that a cooking

time of three hours was adequate to cook the beans to a sensory acceptable level of doneness.) Hot water was added slowly as necessary during cooking to maintain a liquid condition and in such a way that the boiling rate did not change appreciably.

At the end of the cooking time the beans were drained and transferred to small enamel dishes for cooling. An inverted plate was placed over the beans to avoid changes in hardness due to drying. The beans were cooled for three hours, or to room temperature, before instrumental hardness testing.

B. Instrumental Hardness Testing

Bean hardness was tested with a Chatillon dial push/pull gauge (model DPP-500G) mounted on a test stand (model LTS; John Chatillon and Sons, Inc., 83-30 Kew Gardens Rd., Kew Gardens, NY 11415). The system was modeled after the simple texture test system described by DeMan and Kamel (1982). The gauge has several advantages over the methods of texture measurement such as the Instron Universal Testing Machine (Bourne et al., 1966) or the Ottawa Texture Measuring System (Voisey, 1977): it is relatively low in cost, easy to operate, small in size, and requires no electricity.

The push/pull gauge is equipped with a 1/8 in diameter stainless steel probe mounted on the test stand. As the test stand arm is raised, the probe pierces the bean. The gauge dial registers the grams force necessary to completely pierce the bean on a scale from 0 to 500 g. Readings are to the nearest 5 g. One hundred randomly chosen beans from each sample were tested in this manner.

C. Analysis of Data

Mean grams force, percent hard-to-cook beans, standard deviation, standard error of the estimate, and coefficients of skewness and kurtosis (descriptors of the shape of the sample distribution) are determined for each bean sample.

Hard-to-cook beans are those registering $\geq$ 450 g force on the Chatillon tester. The cut off point of 450 g was determined subjectively by squeezing individual cooked beans between the thumb and forefinger and comparing tactile sensations with the grams force registered by these beans using the Chatillon tester. At about 450 g, bean cotyledons cease to mush together; instead, they separate into identifiable pieces. The number of beans $\geq$ 450 g is the percent hard-to-cook beans, since each sample consists of 100 beans.

To determine if there is a difference in mean hardness (MGF) between samples an Analysis of Variance or T test can be used, and if so, multiple comparisons tests can be conducted to determine which samples are significantly different from each other. If 100 beans are tested the 95% confidence interval is about 24 grams force. This value is based on an observed variance of 15,000 and calculated according to the formula.

$$1.96\,\sigma/\sqrt{n} = L \quad \text{(Snedecor and Cochran, 1967)}$$

where σ is the square root of the variance,

n = the number of beans tested and

$\pm$ L is the 95% confidence interval

For this equation to be valid the bean hardness values must be normally distributed. Observations of some histograms of our hardness data indicate

that this assumption probably does not hold for Rwandan bean mixtures.

The percent hard-to-cook beans can be analyzed using a X^2 test to determine if there is a difference in percent hard-to-cook beans between samples, and if so, what the difference is. At a given test time, the samples can also be arranged in order of percent hard-to-cook beans and any statistically significant differences noted. Both mean grams force and percent hard-to-cook beans can be used to determine relationships between sensory and instrumental judgments of hardness.

II. Establishment of Appropriate Consumer Preference Testing Procedures and Locations (Large Scale Bagged study, Alternative Conservation study, Bean Varietal study)

A. Selection of Test Locations

A number of potential testing sites were visited throughout the country (Table 1). These sites were evaluated based on the objectives of the studies in question and on the availability of appropriate subjects and facilities. The Large Scale Bagged study and the Alternative Conservation study require subjects who are representative of OPROVIA/GRENARWA consumers.

The Bean Varietal study requires subjects from three agroclimatic regions of the country (represented by Ruhengeri, Butare, and Kibungo prefectures) who are current or potential consumers of GRENARWA beans. The following information was assembled for each site:

1. Relating to Subjects:

   a. the number of subjects available (at least 50/site);

   b. age range of subjects (20-50 yrs);

Table 1. List of places visited as potential sensory testing sites, the person contacted and their address.

Place	Person Met	Address	Title
1. Camp Militaire de Kanombe	Luitenant-Colonel MAYUYA Stanislas	B.P. 85 KIGALI RWANDA Central Africa	Mon Colonel
2. Camp Militaire de Kacyiru	Commandant NTIWIRAGABO Aloys	B.P. 85 KIGALI RWANDA Central Africa	Mon Major
3. Camp Militaire de Kigali	Capitaine KAYIBANDA	B.P. 85 KIGALI RWANDA Central Africa	Mon Capitaine
4. Ecole des Infirmières accoucheuses de RWAMAGANA	Révérende Soeur Directrice	B.P. 2 RWAMAGANA RWANDA Central Africa	Révérende Soeur
5. Groupe Scolaire de Rwaza	Révérende Soeur Directrice	B.P. 62 RUHENGERI RWANDA Central Africa	Révérende Soeur
6. C F N R (Centre de Formation Nutritionnelle de Ruhengeri)	Madame Fébronie, Directrice du C F N R	C/O Préfet de RUHENGERI RUHENGERI RWANDA Central Africa	Madame la Directrice
7. Préfecture de Ruhengeri	Le Préfet de la Préfecture ZIGIRANYIRAZO Protais	RUHENGERI RWANDA Central Africa	Monsieur le Préfet
8. Centre Nutritionnel de GAHANGA	Révérende Soeur la Directrice du Centre	C/O KAYINAMURA Phocas B.P. 953 KIGALI RWANDA Central Africa	Révérende Soeur la Directrice
9. Centre d'Etudes des Techniques Modernes à l'Université Nationale du Rwanda	Madame NDOREYAHO Directrice du CETM	C/O MUHIRE André B.P. 953 KIGALI RWANDA Central Africa	Madame la Directrice

c. ratio of males to females (approx. equal numbers);

d. availability of subjects at different times of the year, week, and day;

e. literacy;

f. region of origin in Rwanda;

g. representation of OPROVIA/GRENARWA consumers;

h. decision-making regarding selection or cooking of beans.

2. Relating to Facilities:

a. adequate cooking facilities (their stoves or availability of electrical outlets for hotplates, or other arrangements);

b. cleanliness and working environment; and

c. a room accommodating at least ten subjects at one time for testing.

3. Other:

a. willingness of head to cooperate;

b. availability of people to recruit subjects and to help administer the tests.

B. Consumer Preference Testing

1. Cooking Procedure

The cooking procedure for sensory preference testing is basically the same as that for instrumental testing, with the following changes/additions:

a. Sensory tests should be held within a 7-day period of instrumental tests. Bean samples are kept in tightly sealed plastic containers at room temperature (approx. 23°C) until testing.

b. Four cups of dried beans and 2 tsp. salt are brought to a boil in excess tap water. Samples are cooked in metal saucepans on small metal charcoal-fueled cookstoves (braseros).

c. At the end of the cooking time, bean samples are drained and served to judges.

2. Test Format (sample response form, Figure 1)

A set of simple questions was developed to give information on how well subjects like a sample of beans and whether or not these beans would be acceptable. For each sample tested, the subjects indicate their level of preference for that sample by marking a point anywhere along a line of known length (hedonic scale). The subjects also indicate whether or not they would eat the beans on a normal basis; the current market price of beans; and how much they would be willing to pay for the same measure of the bean sample tested. These questions can be posed in either a written or oral form, and are in Kinyarwanda. Written response forms will be used at OPROVIA and possibly at the military camp; at nutritional centers, nutritionists and research staff will administer the tests orally. This basic response form can be modified according to each study and product being tested.

All samples are presented to subjects at the same time, each in a separate coded enamel bowl. The order in which samples are tasted is randomized for each judge. Subjects are instructed to taste each sample and then answer the questions.

Figure 1. Sample Response Form. Sensory Preference Testing

Name: ____________________ Date: ____________________

Taste each bean sample and answer the following questions:

____

1. Would you eat these beans on a normal basis? Yes ______ No ______
2. Show your level of preference for these beans by marking a point along the line

I don't like these beans at all ______________________________ I like these beans very much

3. How much do a kilo of beans cost that you usually eat? __________
4. How much would you pay for a kilo of these beans? __________

____

1. Would you eat these beans on a normal basis? Yes ______ No ______
2. Show your level of preference for these beans by marking a point along the line

I don't like these beans at all ______________________________ I like these beans very much

3. How much do a kilo of beans cost that you usually eat? __________
4. How much would you pay for a kilo of these beans? __________

____

1. Would you eat these beans on a normal basis? Yes ______ No ______
2. Show your level of preference for these beans by marking a point along the line

I don't like these beans at all ______________________________ I like these beans very much

3. How much do a kilo of beans cost that you usually eat? __________
4. How much would you pay for a kilo of these beans? __________

____

1. Would you eat these beans on a normal basis? Yes ______ No ______
2. Show your level of preference for these beans by marking a point along the line

I don't like these beans at all ______________________________ I like these beans very much

3. How much do a kilo of beans cost that you usually eat? __________
4. How much would you pay for a kilo of these beans? __________

3. Analysis of Results

From the hedonic scale, scores can be tabulated from each sample (identified by initial moisture content and location of storage) and analyzed using Analysis of Variance to determine if differences in preference exist by location and/or initial moisture content. At each test time, the samples can be arranged in order of desirability and by using a multiple comparisons test any statistically significant differences noted.

The price subjects would be willing to pay for a measure of each sample will be recorded as a proportion of the price they think is the current market price. These percentage scores will be analyzed in the same manner as the hedonic scale data.

C. Location-Distance from OPROVIA

The secondary schools (4 and 5. Table 1) and the university (9) were rejected as testing sites; the ages and regional distribution of subjects were not appropriate. Also, students would not be available for testing during vacations several times during the year.

For the Large Scale Bagged study, the following sites were chosen: OPROVIA Headquarters, Kicukiro; the military camp at Kanombe; and the Gahanga nutritional center. Subjects at these sites represent three major groups of OPROVIA/GRENARWA consumers -- a parastatal organization, the military, and an organized consumer group. Sensory tests for the Alternative Conservtion study will be at OPROVIA as well. For the Bean Varietal study, the tests will be at a nutritional center in each of the prefectures identified above.

III. Identification and Training of Subjects for Bean Hardness Evaluation

The Large Scale Bagged study requires approximately ten trained judges to judge the hardness of bean samples over time. These subjects have been trained at OPROVIA headquarters.

A. Training of Judges and Test Format (sample response form, Figure 2)

Ten OPROVIA staff members were asked to participate based on their availability and interest in the project. The subjects met with a member of the research staff weekly over a 6-week period. At the first meeting the researcher explained the project goals and objectives, and discussed the definition of bean hardness and the sensory techniques for judging it. The definition of hardness to be used for the purpose of sensory testing is: "The force required to compress a substance between the molar teeth" (Szczesniak et al., 1963). To evaluate hardness, the subject places the food between the molar teeth and bites down evenly, evaluating the force required to compress the food (Szczesniak et al., 1963).

Over the following six weeks, the subjects judged a number of bean samples representing a wide range of hardnesses. Sample hardness was manipulated by varying cooking time, age and additions to the cooking water (such as salt or baking soda). The panelists used a nine-point category scale to judge hardness (Figure 2). The scale is labeled at 5 points: not hard at all; a little hard; fairly hard; very hard; and extremely hard. Panelists can circle any one of these points, or one of the points in between, to indicate their impression of hardness. All the bean samples are

Figure 2. Sample Response Form. Sensory Hardness Testing.

Name: ______________________ Date: ______________________

Taste the first bean sample. Then indicate your impression of the hardness of the sample by circling a point on the line below which corresponds to your impression. Continue with the rest of the samples.

Sample No. ________

not hard at all	a little hard	fairly hard	very hard	extremely hard

Sample No. ________

not hard at all	a little hard	fairly hard	very hard	extremely hard

Sample No. ________

not hard at all	a little hard	fairly hard	very hard	extremely hard

Sample No. ________

not hard at all	a little hard	fairly hard	very hard	extremely hard

Sample No. ________

not hard at all	a little hard	fairly hard	very hard	extremely hard

Sample No. ________

not hard at all	a little hard	fairly hard	very hard	extremely hard

represented at the same time, each in a separate coded enamel bowl. The order in which they are tasted is randomized. Panelists are instructed to taste the first sample, circle the point which corresponds to their impression of its hardness, and then go on to the next sample.

The samples tested in the first sessions differed greatly in hardness and were used to test subjects' ability to distinguish large differences in hardness between samples. Any subject who was not able to put these samples in order from least to most hard was replaced at this point. Later samples tested subjects' ability to distinguish small differences in hardness between samples. Subjects whose responses for the same samples were generally inconsistent over time were replaced. A major problem in testing the consistency of responses over time was in getting the same subjects weekly for the test sessions; often several subjects were unavailable. Subjects were considered to be "trained" after six weeks if they were able to put samples differing greatly in hardness in the correct order and if their responses for the same samples were generally consistent over time.

B. Cooking Procedures

The same changes/additions to the basic cooking procedure in sensory preference testing apply to sensory hardness testing. The sample size for cooking is 1/3 cup beans. Samples are cooked in 2 quart Farberware saucepans on electric hotplates.

C. Correlation Between Sensory and Instrumental Hardness

The instrumental and sensory hardness scores of a number of bean samples were compared to assure adequate correlation between the two methods. The data was fit to four different curves:

1. straight line: $y = mx + b$;
2. exponential curve: $y = be^{mx}$
3. logarithmic curve: $y = m\ln x + b$; and
4. power curve: $y = bx^{m}$, where

   x = instrumental hardness (g);

   y = sensory hardness (rank sums);

   m = slope of the curve; and

   b = y intercept.

Values for the slope, y intercept, R^2, and r (coefficient of determination and correlation, respectively) were calculated for each curve. Sensory hardness scores from three different test sessions and the corresponding instrumental scores were correlated separately. The results of the comparisons are summarized in Table 2.

All of the correlation coefficients were in the range of 0.84 to 0.94. The highest correlation was obtained by fitting the data to a logarithmic curve ($r = 0.94$); however, logarithmic curves did not consistently result in the best correlations. At present, there is insufficient data to conclude that any one of the four curves best describes the relationship between sensory and instrumental bean hardness. During the course of our studies, further analysis of this relationship may reveal that one of the curves is most appropriate for describing the data.

Table 2. Comparisons of Sensory and Instrumental Hardness Scores of Selected Bean Samples

Date of Sensory Test Session	Curve	m	b	R^2	r
	Straight line				
3/17/84		0.18	-45.79	0.85	0.92
3/24/84		0.27	-83.32	0.86	0.93
3/31/84		0.37	-110.09	0.78	0.88
	Exponential				
3/17/84		0.01	0.61	0.72	0.85
3/24/84		0.01	0.13	0.78	0.88
3/31/84		0.01	0.25	0.71	0.84
	Logarithmic				
3/17/84		66.32	-371.55	0.83	0.91
3/24/84		110.08	-632.78	0.88	0.94
3/31/84		147.49	-846.11	0.80	0.89
	Power				
3/17/84		3.39	3.56E-8	0.73	0.85
3/24/84		5.23	5.92E-13	0.80	0.89
3/31/84		4.93	5.06E-13	0.73	0.85

m = slope
b = y intercept
R^2 = coefficient of determination
r = coefficient of correlation

LITERATURE CITED

Bourne, M.C., Moyer, J.C., and Hand, D.B. 1966. Measurement of food texture by a universal testing machine. Food Technol. 20:170.

DeMan, J.M., and Kamel, B.S. 1982. A simple texture test system. J. Texture Studies. 13:241.

Snedecor, G.W., and Cochran, W.G. 1967. Statistical Methods, 6th Ed. Iowa State University Press.

Szczesniak, A.S., Brandt, M.A., and Friedman H. 1963. Development of standard rating scales for mechanical parameters of texture and correlation between the objective and the sensory methods of texture evaluation. J. Food Sci. 28:397.

Voisey, P.W. 1971. The Ottawa texture measuring system. Can. Inst. Food Sci. Technol. J. 4:91.

SECTION II

MOISTURE METER CALIBRATION

Electronic Moisture Meter Calibration for Pure Varieties and Mixtures of Dry Beans (*Phaseolus vulgaris*) in Rwanda

ABSTRACT

A single electronic moisture meter (Motomco 919) was calibrated for measuring the moisture contents of two different bean mixtures and two pure varieties, and the calibration curves for five different moisture meters were determined for a single bean mixture. The calibration curves for the Motomco meter differed for the different mixtures and varieties tested. The differences between these curves may be due to seed size, electrical properties, or different amounts of damage. All five moisture meters were reasonably accurate as evidenced by very high correlation coefficients between the oven-dry moisture measurements and the meter readings. However there was considerable variability among the different meters and within a single meter. The variability within a single meter may be largely due to the different bean varieties present in the mixture and therefore could be counteracted by making several replicate measurements.

INTRODUCTION

There is a well-established need in grain commerce for a rapid and reliable means of determining moisture content. Moisture content is obviously important economically because grain is traded on the basis of weight; nutritional value

per unit weight decreases as moisture content increases (Hurburgh et al., 1985). The moisture content of grain is also an indicator of its keeping quality. Storage of dry beans at elevated moisture contents may favor fungal growth, insect infestation, and undesirable changes in cooking quality. Thus knowledge of moisture contents at time of purchase and during storage can help to prevent/reduce postharvest losses due to moisture-related damage.

Electronic moisture meters are currently used to measure the moisture contents of many grains including dry beans. They have been found to provide acceptably reliable results in the range of moisture contents normally encountered. Okwelogu (1971) has reviewed several types of moisture meters available on the market and their principles of operation.

One type of moisture meter currently available measures the dielectric constant of grain since this constant is a function of moisture content within a given range. Brand names of moisture meters which measure the dielectric constant of grains include: Motomco Model 919; Dickey-John Model DJ GMT; and Dole Model 400B. The manufacturers of these meters furnish calibration tables for a variety of grains along with the meters. The tables relate moisture meter readings to oven-dry moisture contents over the range of moisture contents typically encountered, depending on the type of grain.

Certain studies have found, however, that the reliability of the calibration tables varies depending on 1) the particular moisture meter being used , 2) the condition of the grain being tested, and 3) the oven-dry method used to determine the "real" moisture content of the grain. Error may be introduced from any or all of these sources. A review of the research conducted on the possible sources of error in the measurement of grain moisture content is presented here.

I. Moisture meter-dependent sources of error

A. Electrical properties of the grain

A major problem exists in measuring the electrical properties of grain and relating these measurements to moisture content, because the electrical properties of a given type of grain are subject to daily variation as well as to variation by region and growing season (Hunt and Neustadt, 1966). Grain characteristics influencing the relationship between dielectric properties and moisture content include electrical frequency, temperature, bulk density and chemical composition (Nelson, 1977). However, the most important source of electrical variations in grain appears to be the distribution of water within the grain, i.e. the ratio of "free" to "bound" water.

Hunt and Neustadt (1966) defined "bound" water as the water tightly linked within the molecular structure of starch, protein, and other components of the grain. Since bound water cannot dissolve mineral salts, it does not conduct electricity and thus cannot be measured by conductance type meters (such as Weston, Marconi, or Universal meters). A correction factor is added to the obtained values in order to account for bound water in grain when these meters are used. However, dielectric moisture meters (such as Motomco or Steinlite meters) do measure bound water. "Free" water in the interstitial spaces between larger molecules acts as a solvent and therefore contains dissolved mineral salts and conducts electricity. It can be measured by all types of electronic moisture meters. The correction factors for bound water in grain remains constant. According to Hunt and Neustadt (1966) this is probably not the case, so some error may occur in

these moisture measurement methods due to the changing ratio of free to bound water in grain. Even with dielectric meters, the large difference in dielectric constants between free and bound water may cause error in measurement when the ratios between the two are available. Hunt and Neustadt (1966), found that Motomco moisture meters were less influenced by daily, regional, or seasonal variations than Steinlite or Weston moisture meters.

Hurburgh et al. (1985) studied the accuracy of Steinlite, Burrows, Motomco and Dickey-John moisture meters in measuring the moisture content of six varieties of corn. They determined the calibration bias of the meters by regressing meter-determined moisture content (taken from calibration tables) minus oven moisture content versus oven moisture content. All four meters gave biased readings with respect to the oven-dry moisture contents. Three sources of random error in moisture measurement were identified: the electrical properties of samples, the repeatability of a meter reading on a given sample and the repeatability of an oven-dry test on a given sample. Variations in the electrical properties of samples were found to contribute 85 - 90% of the total variability in moisture measurement values. The authors suggested that fundamental research of the dielectric properties of grain should help to improve accuracy of electronic moisture meters.

Paulsen et al. (1984) tested the bias of six moisture meters (Motomco 919; Dickey-John AC-II, Burrows 700, and Steinlite Models 55-250, DM and RCT) on corn samples from Illinois, Indiana and Ohio. Meter bias was determined by regressing meter moisture content minus oven moisture content versus oven moisture content. It differed significantly in the Motomco, Burrows, and Dickey-John meters among the three states. Differences in

meter bias were attributed to differences in corn electrical properties arising from differences in varieties and growing seasons.

B. Repeatability of moisture meter readings on a given sample

Hurburgh et al. (1985) found that moisture meter repeatability was a source of error contributing about 10% of the random error. Variation in meter readings between sample replicates increased as moisture content increased.

Gutheil et al. (1984) determined the percent moisture in six different field corn varieties using three different moisture meters (Steinlite RCT, Motomco 919 and Dickey-John GAC-II) and the official USDA air oven method. They also used these methods to assess the variation in results within a single field corn variety as influenced by moisture content (18.44 to 27.83% by the USDA air oven method) and sampling and subsampling. They concluded that most of the inaccuracy in meters can be attributed to differences among individual moisture content readings (duplicates or other replicates). In other words, variation in readings can still be expected within properly obtained representative samples of corn.

II. Sources of error dependent on the condition of the grain being tested

A. Grain moisture content

Results of several studies indicate that moisture meter accuracy decreases as grain moisture content increases above a certain range. Gutheil et al. (1984) found that meter inaccuracy increased with moisture content, particularly above 25% moisture. At high moisture levels, moisture

contents determined by meters were significantly lower (by approximately 0.9 to 3.3% moisture) than those determined by the USDA air oven method. At low moisture levels, moisture contents determined by the meters were significantly higher (by approximately 0.9 to 1.6% moisture) than those determined by the USDA air oven method. The Motomco 919 meter gave lower readings overall than the Steinlite or the Dickey-John meters indicating that it was more accurate in the low moisture range, but less accurate in the higher moisture range than the other meters.

Paulsen et al. (1984) studied the calibration bias of six moisture meters using 690 corn samples from different regions of the country (see I A. above). They found that meter bias increased with oven-dry moisture contents at elevated moisture levels. Variability in moisture meter bias also increased as oven moisture increased. The 95% confidence limits for moisture meter tolerances generally ranged from ± 0.8 percentage points in the 12% to 16% moisture content range to ± 3.2 percentage points in the 28% to 32% moisture content range, also indicating greater inaccuracy of meter determinations at elevated moisture contents.

Hurburgh et al. (1985) found that the variability in percent moisture as determined by electronic meters as compared with that determined by the oven method increased as moisture content decreased from the optimum range of 15% to 20%. Thus meter accuracy decreased as moisture content moved in either direction away from this range. Calibration bias errors typically ranged from +1.5% to -3.5% over the range of moisture contents tested (11% to 38%). The moisture meter values tended to be lower than the oven values at high moisture levels ($\geq$ 30%) and higher than the oven values at low moisture levels. Their results are in agreement with those of Gutheil et al. (1984).

B. Level of damage and foreign material

The amount of damaged seeds and foreign material in a grain sample is a generally accepted source of error in moisture meter readings. In the studies conducted by Paulsen et al. (1984), Gutheil et al. (1984) and Hurburgh et al. (1985) on corn, foreign material and broken kernels were removed from samples before moisture determinations were made. In the Gutheil et al. (1984) study, the corn samples used were harvested and shelled by hand in order to limit the amount of cracked and broken grain. Paulsen et al. (1984) examined the differences in meter calibration bias between hand-shelled and combine-shelled corn samples. They found that the meters tended to give lower values than the oven method and that the extent of these differences increased with moisture content particularly when the samples were hand-shelled rather than combine-shelled. These results indicate that the increased levels of damage normally occurring in mechanically harvested samples might influence moisture meter readings.

C. Temperature of the grain sample

Sample temperature is known to affect moisture meter readings. This is dealt with by means of temperature correction charts for each type of grain or by automatic temperature correction built into the instrument circuitry. The Motomco 919 operator's manual, for example, contains temperature correction charts for each of several types of grain commodities commonly tested by the instrument. A specified percentage of moisture is usually subtracted from the determined moisture content of the sample for each °F above 77°F and added to it for each °F below 77°F. The Dickey-John DJ GMT

meter corrects moisture content for temperature automatically as the grain is being tested. The Dole 400B meter is supplied with a thermometer which when inserted into the sample indicates the appropriate moisture content correction.

Gough (1983) recommended the following temperature corrections in the absence of appropriate data from the manufacturer:

1. For commodities not containing oil, add 0.1% moisture content for each 1°C of sample temperature above 27°C (80°F). For each 1°C of sample temperature above or below 27°C, a specified moisture content (in %) is subtracted or added to the moisture meter value, respectively. Dry edible beans contain about 1.5% lipid compared to about 20% for soybeans and therefore would be included in this first category.

2. For commodities of relatively low oil content, e.g. soybeans, add 0.08% moisture content per 1°C above 27°C.

3. For commodities of intermediate oil content, e.g. hulled peanuts, add 0.05% moisture content per 1°C above 27°C.

4. For commodities of relatively high oil content, e.g. copra, add 0.3% moisture content per 1°C above 27°C.

For each 1°C below 27°C, these correction factors would be subtracted from the respective moisture meter values. It is interesting to note that the corrections suggested by Gough are opposite those suggested by the manufacturers of the Motomco and Dole meters, that is, they are added rather than subtracted at higher sample temperatures and subtracted rather than added at lower sample temperatures.

III. Sources of error in oven-dry moisture content determinations

Paulsen et al. (1984), Gutheil et al. (1984) and Hurburgh et al. (1985) showed that a part of the inaccuracy in meter moisture content determinations could be attributed to error or variability in oven-dry moisture content determinations. Warner and Browne (1963), Matthews (1962) and Hunt and Neustadt (1966) have reviewed possible sources of error in oven moisture content determinations and have suggested various means of reducing this error. The major sources of error in oven moisture determinations are discussed below.

A. Milling grain samples before drying

Several standard oven-dry procedures (AACC, 1975; USDA, 1971) for the determination of grain moisture contents require that samples be ground before drying. The fineness of the ground product may influence the final moisture content determination. If the grind is too coarse, the sample may not give up all of its moisture during the drying period (according to the method used, ground samples are generally dried for 1-2 hours at 130° ± 1°C). If the grind is too fine, the moisture content of the sample may change during grinding if the sample is either at a low or an elevated moisture content. At low moisture contents, finely ground samples that are hygroscopic may pick up moisture from the environment. At high moisture levels, heat generated by the mill during grinding may cause the sample to lose moisture by evaporation.

Bowden (1984) compared the effects of three different oven methods on moisture content determinations of barley and wheat. In the first method, samples were ground and then dried for two hours at 130 - 133°C. The other

two methods used whole grain methods which were dried for either 16 or 20 hrs at 129 - 131°C. The whole grain methods gave significantly lower moisture contents than the milled method over the entire range of moisture contents tested (9.1% to 28.6% wet basis). Deviations in moisture contents of the whole grain methods from the milled method decreased as moisture contents increased. The author attributed decreases in deviations with increases in moisture content to increases in the amount of moisture lost during milling at higher moisture contents in the milled method. Increased moisture loss during grinding at high moisture levels would result in reduction in indicated moisture contents. Higher indicated moisture contents at lower moisture levels using the milled as opposed to the whole grain method may indicate that samples at low moisture contents were subject to moisture uptake during grinding.

Matthews (1962) compared the effects of two oven methods on moisture content determinations on wheat and barley. In one method, milled samples were dried for 1 hour at 130°C. In the other method, whole grain samples were dried for 16 hours at 130°C. The milled sample method gave proportionately higher results at low moisture contents (indicating moisture gain during milling) and lower results at high moisture contents (indicating moisture loss during milling) when compared to the whole grain method.

Warner and Browne (1963) examined the effects of milling fineness on moisture content determinations of wheat over a moisture range of 5% to 30%. Milled samples were dried for 1 hour at 130°C. Whole grain samples were dried for 16 hours at 130°C. At 15% moisture, the whole and milled grain moisture contents were the same at the finest mill setting, provided that the mill did not heat up very much. At the coarsest setting, there was

incomplete moisture loss compared to the unmilled sample - a difference of 0.7% moisture. Lower moisture grain samples apparently gained moisture when ground at the finest setting and dried incompletely at the coarsest setting. At intermediate settings, absorption and incomplete drying appeared to compensate for each other, and moisture contents were similar to those obtained by the whole grain method. High moisture grain samples consistently lost moisture during milling, and the moisture loss increased with the fineness of milling and the running time of the mill.

One way in which moisture loss may be limited during milling of high moisture content samples is to dry them in two stages. During the first stage, samples are dried for a period at room temperature, or slightly above, to reduce the moisture content to a level where moisture loss during grinding is considered to be less significant (usually < 16% moisture).

Hunt and Neustadt (1966) compared the effects of direct and two stage oven methods on moisture content determinations of a variety of grains (not specified) up to moisture contents of 16%. There were no differences in moisture contents determined by the two methods, with the exception of soybeans and rough rice. Between moisture contents of 16 - 18%, the direct method gave moisture contents averaging 0.09% lower than the two stage method, indicating that additional moisture may have been lost during direct milling without predrying. For moisture contents above 18%, differences between the two methods were erratic. The two stage method was recommended for soybean samples having moisture contents greater than 10% and for rough rice samples having moisture contents greater than 13%. One possible disadvantage to the two stage drying method is that while error due to moisture loss during milling may be reduced, additional error may be

introduced by two additional weighing operations and subsequent handling of samples. The two stage method also requires additional technician time, which must be taken into consideration.

B. Moisture content of samples

There is evidence to suggest that the moisture content of samples may influence the repeatability of oven-dry moisture content determinations. In Bowden's (1984) comparison study of three oven methods on moisture content determinations of wheat and barley, the variability of moisture determinations between 20 replicates of the same samples were examined for each method. Regardless of the oven method used, the variation between replicate moisture content determinations increased as moisture contents increased. No attempt was made to explain these results, but they may indicate that with wetter grain samples, some parts of the sample may contain more moisture than other parts of the sample which results in appreciable differences in moisture contents between replicates.

C. Sources of error - oven

1. Non uniformity of heating

Hunt and Neustadt (1966), Warner and Browne (1963) and Matthews (1962) determined that the placement of samples in the oven may influence moisture content determinations. All three studies showed differences in moisture contents between and within shelves for samples having the same nominal moisture content. Hunt and Neustadt recommend individual testing of ovens, and the placement of all samples on the shelf closest to the thermometer unless other shelves have been tested and found to give the same results.

2. Oven timing and temperature

Small differences in the drying time and temperatures from standard oven methods may influence moisture content determinations. Warner and Browne (1963) examined the effect of differences in drying time and temperature on moisture content determinations of milled wheat samples. In the first experiment, four wheat samples rewetted to 27% m.c. were milled and dried for a total of two hours at 130°C. The samples were removed from the oven every 15 minutes, weighed hot, and returned to the oven. They determined that an error of five minutes in drying time after 60 minutes could lead to a moisture content error of 0.02%. In the second experiment, six replicate moisture content determinations were made on wheat samples at 12.5% and 24.5% m.c. at each of three oven temperatures: 125°C, 130°C and 135°C. The magnitude of error in moisture content was determined to be about 0.02% for each °C that the oven temperature differed from 130°C. Thus, it is important to regulate both drying time and temperature to avoid small but measurable changes in moisture content.

Error in moisture measurement using electronic meters may be compounded when these meters are used with grain mixtures containing numerous varieties. In Rwanda, dry beans (Phaseolus vulgaris) are commonly grown, stored and consumed as mixtures. These mixtures may contain as many as 30 different types, the average mixture containing approximately 10 - 15 types (Lamb and Hardman, 1986). There is no literature available on the calibration of a moisture meter for determining the moisture content of bean mixtures. Moisture measurement of these mixtures using electronic meters will depend on a recalibration

of the meters using mixtures commonly found in Rwanda.

The objectives of this study were: 1) to calibrate a single electronic meter (Motomco 919) for measuring the moisture contents of two different bean mixtures and two pure varieties and to identify differences between these curves; and 2) to determine the calibration curves for a single bean mixture on five different moisture meters (three Motomco 919s, a Dickey-John DJ GMT, and a Dole Model 400B).

METHODOLOGY

The study was repeated twice - once between November 1984 and June 1985 by Chantal Umugwaneza, and again in October 1985 by Assuman Serugendo. There were several differences between the methodology used each time. The following paragraph briefly summarizes these differences; the more detailed methodology follows.

The first study calibrated a single moisture meter (Motomco Model 919) for two bean mixtures and two single varieties. In the second study five different moisture meters were calibrated for one bean mixture. Some samples in the first study were rewetted to provide moisture contents in the upper range (18 - 23% moisture) whereas the beans for the second study were at an initially high moisture content and therefore not rewetted. Oven-dry moisture determinations also differed between the two studies. In the first study samples were ground before drying, necessitating a two stage process for beans having moisture contents in excess of 16%. In the second study the beans were not ground.

I. Study I. Moisture meter calibration using two mixtures and two pure varieties: November 1984 - May 1985

A. Beans

Calibration curves were determined for two Rwandan bean mixtures and for two pure varieties. Three kg of each mixture/variety were used. Mixture no. 1 was purchased at the Nyarugenge market in Kigali, mixture no. 2 from GRENARWA, and the two pure varieties (Ikinimba and Mutiki 2) from a seed selection service (Semences Selectionées) in Kigali. Approximate initial moisture contents of the beans were determined using a Motomco calibration curve for a Rwandan bean mixture which had been constructed in preliminary tests. Varietal analyses were not performed on the two mixtures; however, mixture 1 contained predominantly large-seeded varieties, while mixture 2 contained predominantly small-seeded varieties. Table 3 lists the approximate harvest dates, lengths of storage and initial moisture contents of the mixtures and varieties used.

B. Preparation of samples for moisture content determination

The beans were screened to remove large foreign objects (stones, leaves, grass, and other grains such as corn and peas), divided into six subsamples of 375 g each, and kept in tightly closed glass jars at room temperature (23°C) until further use. The subsamples were either dried or rewetted to give a range of moisture contents from approximately 9% to 23%. Subsamples were dried in thin layers at 40°C in a mechanical convection oven (Blue M Stabil-Therm model OV-500C-2Y, Blue M Co., Blue Island, IL 60406) until the desired moisture contents (determined by measured weight loss) were reached

Table 3. Bean mixtures and varieties used, harvest date, length of storage before testing, and the initial moisture contents of beans used in Study I.

Mixture/Variety	Harvest Date	Length of Storage (months)	% Initial Moisture contents
Mixture 1	June 1984	5	21.0
Mixture 2	June 1985	1	15.4
Ikinimba (small round black)	Jan. 1985	3	15.4
Mutiki 2 (long oval red speckled with white)	Jan. 1985	4	13.1

and then returned to glass jars for storage before oven-dry moisture content determinations. Subsamples were rewetted by adding calculated amounts of distilled water to the samples in the glass jars and allowing them to equilibrate for 72 hours at room temperature. The jars were rotated and shaken gently several times daily to promote uniform water absorption.

C. Moisture content determination

1. Moisture meter readings

A Motomco moisture meter (model 919; Motomco Inc., Box 300, 267 Vreeland Ave., Paterson, NJ 07543) was used. 250 g of each 375 g subsample were weighed to the nearest 0.1 g on a triple beam balance (Ohaus 800 series, 2610 g capacity; Ohaus Co., Florham Pk, NJ 07932). Triplicate Motomco readings were made on each 250 g sample. All readings were done on room temperature (23°C) samples. The mean of the three readings was taken to be the final Motomco reading for a given sample. After testing, the 250 g samples were placed in glass jars. Oven-dry moisture contents were subsequently determined on portions of these 250 g samples.

2. Oven-dry moisture content determinations

Oven-dry moisture contents of samples were determined as follows based on the standard method published by the USDA (1971):

a) Two stage method for beans containing 16% or greater moisture

Approximately 30 grams of each sample were first weighed, then air dried for at least 24 hours on top of the convection oven to

reduce their moisture content to less than 16%, and then reweighed. These dried samples were then ground for 90 sec. in a micromill (Belart 500; Technilab Cat. No. 37250; Belart Products, 61 Industrial Road, Pequannock, NJ 07440). Five 2 - 3 g portions of each ground sample were first weighed then dried in the convection oven at 130°C $\pm$ 1°C for one hour and finally reweighed.

b) One stage method for beans containing less than 16% moisture

Samples were ground and oven-dried in a single stage. The weights of samples were determined to the nearest 0.1 mg on an analytical balance (Sauter model 424; August Sauter Strasse, Postfach 250, D-7470 Albstadt 1-Ebingen, West Germany).

The percentage moisture content of samples dried in 2 stages was calculated as:

$$\% \text{ m.c.} = \frac{\frac{EB}{D} + C}{A} \times 100; \quad \text{where}$$

A = weight of the original portion used for the test;

B = weight of the portion after air-drying;

C = moisture loss due to air-drying;

D = weight of the ground subportion used for the 130°C air-oven drying; and

E = loss of moisture due to oven-drying.

The percentage moisture content of samples dried in a single stage was calculated as:

$$\% \text{ m.c.} = \frac{\text{wet weight of sample} - \text{dry weight of sample}}{\text{wet weight of sample}}$$

D. Determination of calibration curves

The formulas for the lines relating moisture meter readings to oven-dry moisture contents were determined using linear regression. Mean moisture meter readings were considered to be the independent (X) variables, and the oven-dry moisture content determinations were considered to be the dependent (Y) variables.

II. Study II. Moisture meter calibration using five moisture meters and a single bean mixture: October 1985.

A. Bean mixture

The mixture used in this study was purchased in the Bugesera region of Rwanda in October 1985. The beans had been freshly harvested from the low-lying areas in the region and were to be used primarily for studies conducted in the alternative storage methods component. The initial oven-dry moisture content of the mixture was 23.8%. A varietal analysis of the mixture according to the method developed by Lamb and Hardman (1986) is found in Table 4. (The mixtures were not analyzed for seed size or shininess.) The beans were stored in sealed plastic bags at 4°C until further use.

Table 4. Varietal analysis of bean mixture used in moisture meter calibration. Study II. October 1985

Form[a]	Color description[b]	Hilum[c]	Base color[c]	Color of lines/spots[c]	Number
lo	mc	-	pr	-	30
lo	tl	br	cr	pr	11
lo	mc	n	pr	-	17
ro	mc	-	rs	-	7
ro	mc	br	jbr	-	14
lo	zb	n	cr	n	5
ro	mc	n	j	-	4
lo	mc	-	br	-	2
ro	tp	n	cr	n	1
lo	mc	-	n	-	2
ro	mc	-	rg	-	1
ro	tt	-	cr	n	1
					100

[a] lo = long oval
ro = round oval

[b] mc = monochromatic
tl = spotted with lines
zb = zebra-striped
tp = spotted with small spots
tt = spotted with spots

[c] br = brown
n = black
pr = purple
cr = cream
rs = pink
jbr = yellow-brown
bl = white
j = yellow
rg = red

B. Preparation of beans for moisture content determinations

Beans were screened to remove foreign material and divided into 14 subsamples of 375 g each. To provide a wide range of moisture contents for the calibration curves, these subsamples were dried to final weights approximately 5 g apart, from 370 to 305 g. The subsamples were dried in thin layers in the convection oven at 40°C until the desired moisture losses were obtained. After drying, the subsamples were cooled to room temperature and stored in sealed plastic bags at 4°C until moisture meter readings and oven-dry moisture contents were determined.

C. Moisture content determinations

1. Moisture meter readings

The moisture meters used are shown in Table 5. All the moisture meters were battery operated except Motomcos # G6418 and G6419, which had been specially modified to run off of 220 v current.

The 14 subsamples were allowed to come to room temperature before the meter readings were taken. Three replicate readings were taken on each meter for each sample. Since the Motomco and the Dickey-John meters required the largest sample size (250 g), the readings on these meters were taken first. Subsamples of the 250 g sample were then used for the Dole readings and for the oven-dry moisture content determinations.

Table 5. Moisture meters calibrated: October 1985

1. Motomco no. 919, Serial No.s G6347, G6418, G6419
   (Motomco, Inc., 267 Vreeland Ave., Box 300, Paterson, NJ 07453)

2. Dickey-John, model No. DJ GMT, serial No. 0528-3829C
   (Dickey-John Corp., Auburn, IL 62615)

3. Dole, model No. 400B, PB-70-21, serial No. 8412010
   (Eaton Corp., Controls Division, 191 East North Ave., Carol Stream, IL 60187)

2. Oven-dry moisture content determinations

Oven-dry moisture contents of the 14 subsamples were determined according to AACC method no. 44-15A. Five 10 g replicates of whole beans from each sample were dried for 72 hours at 103°C. The final moisture content was calculated according to the formula:

$$\% \text{ moisture} = \frac{\text{moisture loss during drying}}{\text{wet weight of beans}} \times 100$$

D. Determination of calibration curve

See I. D. above.

STUDY I: RESULTS AND DISCUSSION

RESULTS

The calibration curves and equations relating oven-dry moisture contents to Motomco readings are shown in Figs. 3-6. The slopes of the calibration curves vary between 0.17 and 0.24; the Y intercepts, moisture content corresponding to a meter reading of zero, vary from almost 0 to nearly 8. The correlation coefficients for these plots were high ($r = 0.98-0.99$) indicating reasonably good - although not perfect - predictability. Table 6 shows moisture contents predicted by the calibration curves across the 10-100 range of Motomco readings. For a given Motomco reading, there were obvious differences between the moisture contents predicted by each calibration curve. For a reading of 10, predicted moisture contents varied from approximately 2.3% to 9.1%; for a reading of 50, from approximately 11.2% to 15.9%; and for a reading of 100, from 20.7% to 25.4%.

Moisture contents predicted by the calibration curves for the two pure varieties, Mutiki 2, and Ikinimba, were dissimilar across the entire range of Motomco readings, although dissimilarity decreased somewhat as moisture contents increased. Moisture contents predicted by by calibration curves for mixtures 1 and 2 were somewhat similar at low moisture contents, but became less so as moisture contents increased.

Table 7 compares predicted and oven-dry moisture contents for each mixture and variety. The differences in moisture content between the predicted and oven-dry values (Y-oven) indicate meter accuracy. Differences between predicted and oven-dry moisture contents were as large as 1.8%.

Figure 3. Motomco moisture meter calibration curve for mixture 1, Study I. Solid black line is the regression line.

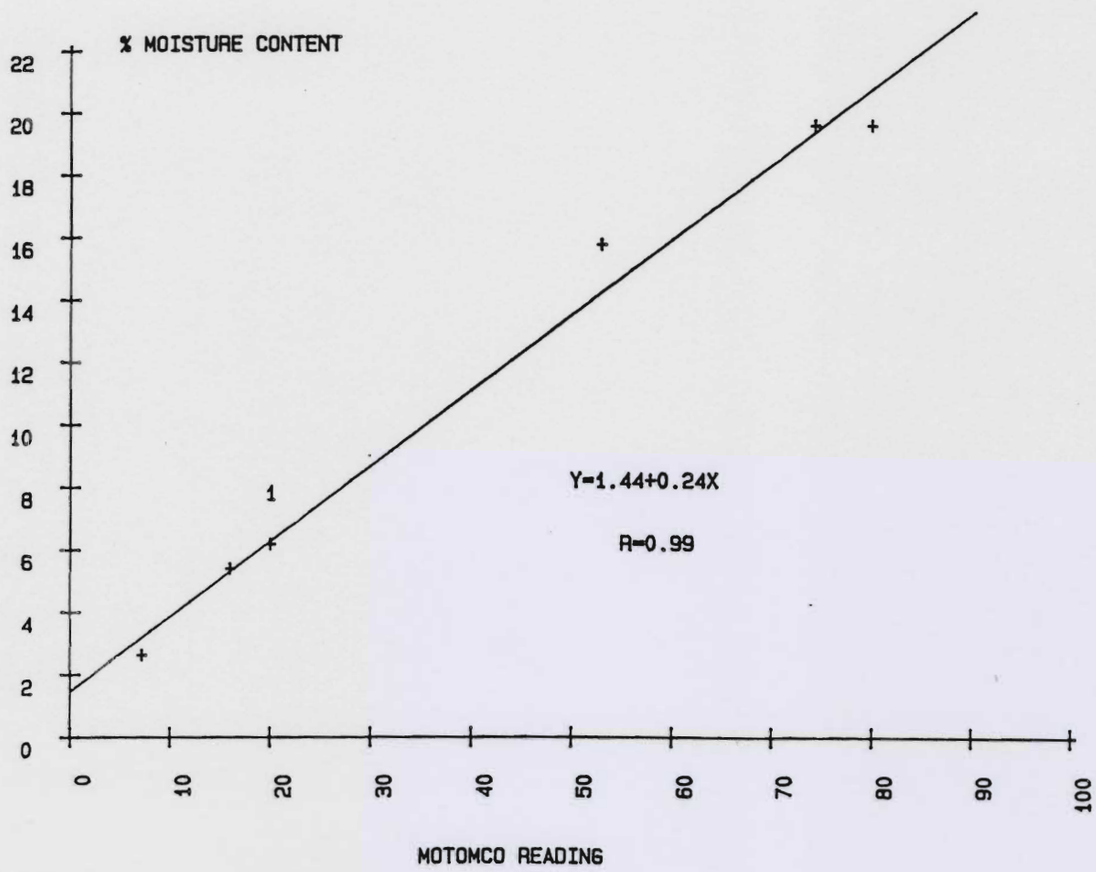


Figure 4. Motomco moisture meter calibration curve for mixture 2, Study I. Solid black line is the regression line.

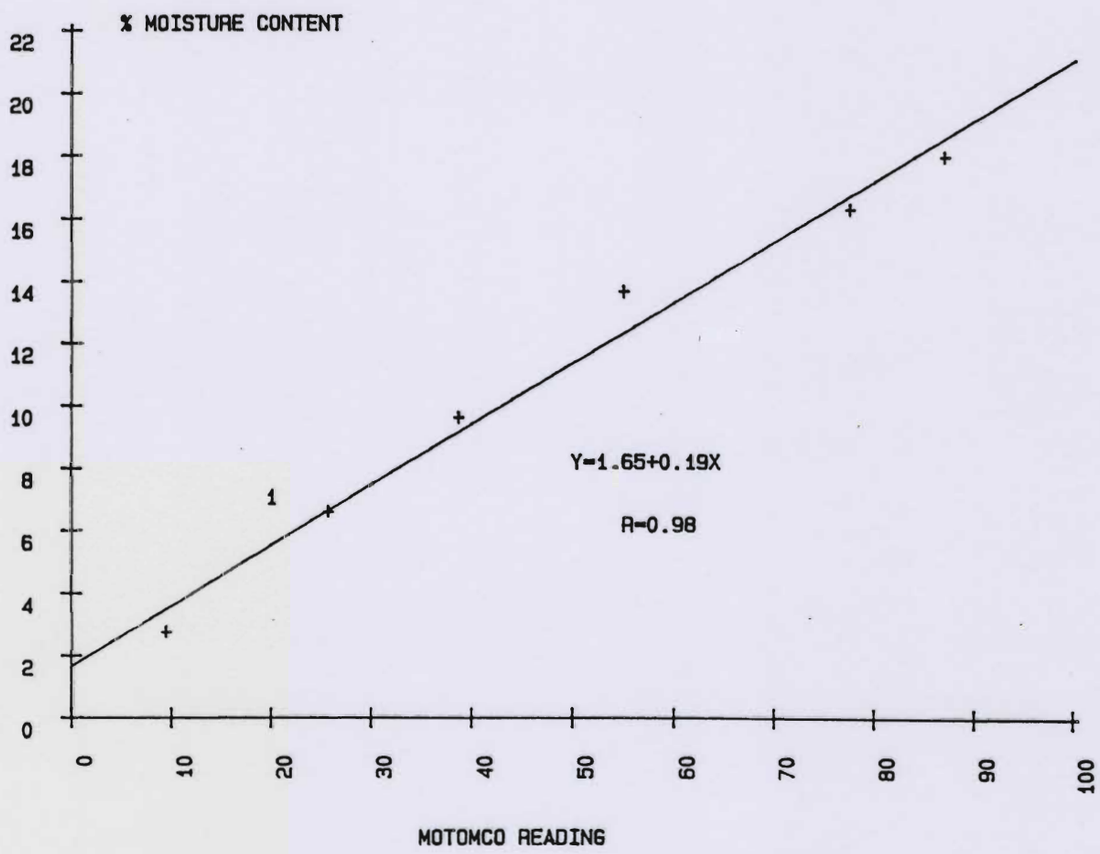


Figure 5. Motomco moisture meter calibration curve for Mutiki 2 beans, Study I. Solid black line is regression line.

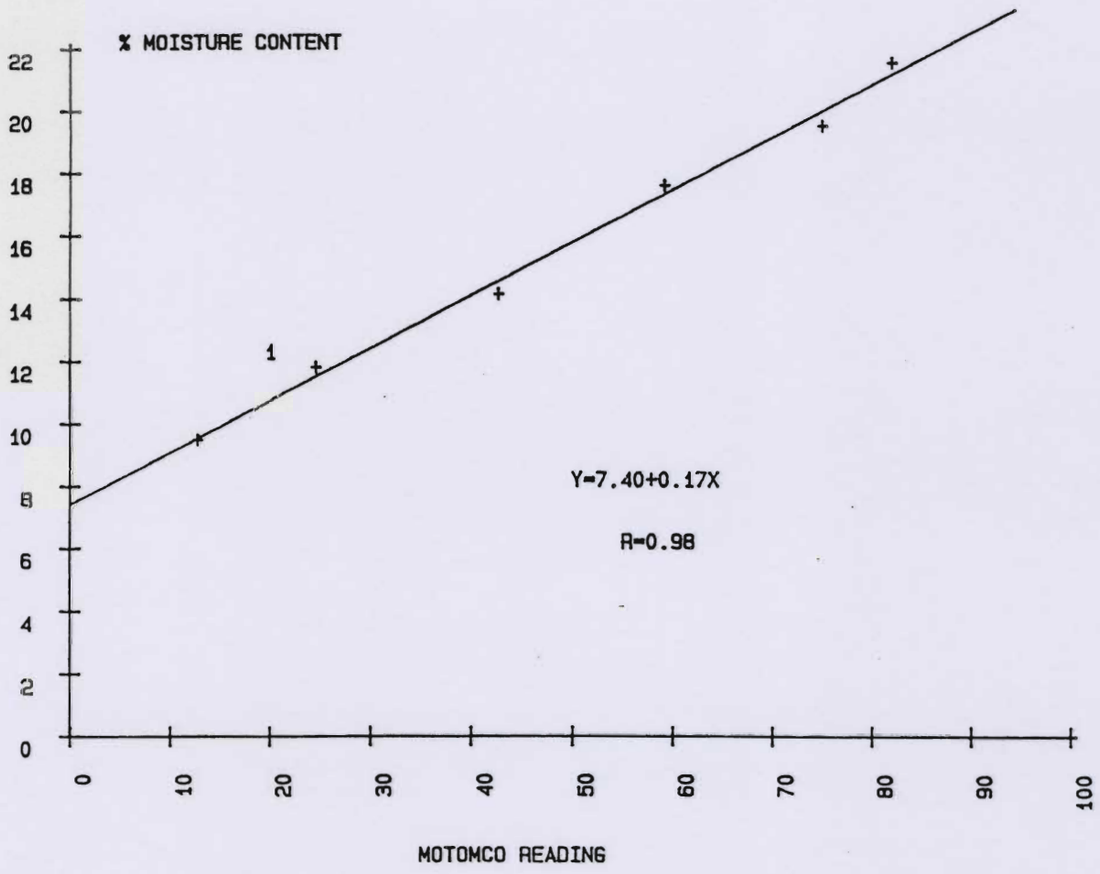


Figure 6. Motomco moisture meter calibration curve for Ikinimba beans, Study I. Solid black line is regression line.

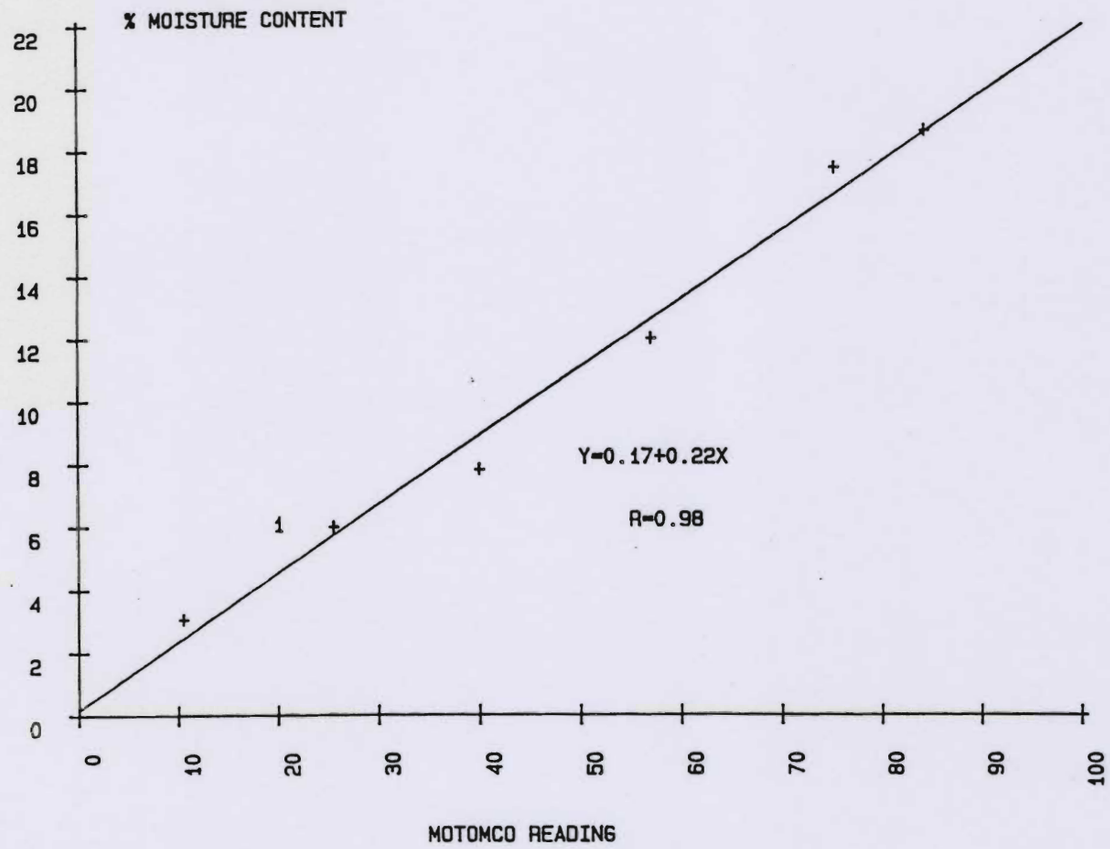


Table 6. Moisture contents predicted by calibration curves for Motomco readings 10-100

	Motomco Readings									
Mixture/Variety	10	20	30	40	50	60	70	80	90	100
Mixture 1	3.8	6.2	8.6	11.0	13.4	15.8	18.2	20.6	23.0	25.4
Mixture 2	3.6	5.5	7.4	9.3	11.2	13.1	15.0	16.9	18.8	20.7
Mutiki 2	9.1	10.8	12.5	14.2	15.9	17.6	19.3	21.0	22.7	24.4
Ikinimba	2.3	4.6	6.8	9.0	11.2	13.4	15.6	17.8	20.0	22.2

Table 7. Comparison of moisture contents predicted by calibration curves (Y) with oven-dry moisture contents

Mixture I			Mixture 2			Mutiki 2			Ikinimba		
Oven-Dry	Y*	Y-Oven**	Oven-Dry	Y	Y-Oven	Oven-Dry	Y	Y-Oven	Oven-Dry	Y	Y-Oven
2.62	3.17	+ 0.55	2.75	4.56	+ 1.81	9.49	9.56	+ 0.07	3.06	2.48	- 0.58
5.40	5.28	- 0.12	6.60	6.53	+ 0.07	11.82	11.57	- 0.25	5.99	5.78	0.21
6.18	6.24	+ 0.06	9.62	9.00	- 0.62	14.16	14.66	+ 0.50	7.81	8.97	1.16
15.76	14.16	- 1.60	13.67	12.10	- 1.57	17.61	17.46	- 0.15	12.00	12.71	+ 0.71
19.59	19.27	- 0.32	16.30	16.38	+ 0.08	19.51	20.15	+ 0.64	17.46	16.71	- 0.75
19.59	20.64	+ 1.05	17.98	18.18	+ 0.20	21.55	21.34	- 0.21	18.64	18.72	+ 0.08

*Y = moisture content predicted by regression line

**Y_{-oven} = difference in moisture content between predicted and oven-dry determination

DISCUSSION

I. Factors contributing to differences between calibration curves

The calibration curves of samples containing seeds of approximately the same sizes were more similar than those in which seed sizes were very different. For example, the predicted moisture contents for mixture 2 (which contains predominantly small seeded varieties) and Ikinimba (a small seeded variety) were similar over the entire range of Motomco readings. Predicted moisture contents for mixture 1 (predominantly medium to large seeds) and Mutiki 2 (large seeds) were similar in the high moisture content range but differed consistently at low moisture levels. Predicted moisture contents for Mutiki 2 and Ikinimba were dissimilar across the entire range of Motomco readings.

Differences in electrical properties between beans likely contribute to differences between calibration curves. These differences may arise from the different varieties, regional and seasonal variations, differences in growing conditions, and other factors affecting the distribution of free and bound water within the seeds. The growing conditions of the samples tested were not known; it is likely that they were grown under fairly different soil and climate conditions. Only two of the four samples were grown during the same season. Thus differences in electrical properties are likely to be responsible for some of the differences between calibration curves.

Differences in damage levels between samples may also have contributed to differences between the calibration curves. Paulsen et al. (1984) found that samples containing low levels of broken kernels gave lower moisture meter contents as oven moisture contents increased compared to samples with higher levels of broken kernels. In the present study, large foreign objects such as

stones, grass, and other grain types were removed from samples before the moisture determinations were made, but no effort was made to remove broken seeds or to otherwise assess damage level.

II. Factors affecting the accuracy of predicted moisture contents

A. Sample size

Due to constraints of time, laboratory personnel and equipment available to process the samples, a very limited number of moisture levels (6) was chosen to represent a moisture range from approximately 2% to 24%, one sample for approximately every 3% change in moisture content. This relatively small number of levels limits predicted moisture content accuracy (indicated by the size of the correlation coefficient) by limiting the number of data points used to determine the calibration curve.

For mixture 1, difficulty experienced in controlling drying times to give samples with moisture contents evenly dispersed over the moisture range caused samples to be grouped at the low and high ends of the range (Fig. 3). Thus there were no data in the middle range of moisture contents. This may have diminished the validity of the correlation coefficient without affecting its size. A large sample size would have made precise control of drying times less necessary and would have resulted in more complete information concerning the oven moisture/meter reading relationship.

B. Sample temperature

Moisture meter determinations are dependent on sample temperature. In this study, all meter readings were done on samples at room temperature, about 23°C. Thus the calibration curves are only appropriate for use with samples at approximately this temperature.

C. Variability between replicate moisture determinations

Variability between replicate oven-dry moisture content determinations and between meter readings may also influence predicted moisture content accuracy (Gutheil et al., 1984; Hurburgh et al., 1985). Table 8 shows the replicate oven-dry moisture content determinations and Motomco readings for the samples tested. Variability between replicate oven-dry determinations was frequently greater than the maximum 0.2% moisture allowed by standard oven-dry methods (AACC, 1975; USDA, 1971). Weighing errors and sample loss during the oven-dry moisture determinations may have also contributed to this variability.

Replicate determinations on samples from pure varieties were just as variable as samples from mixtures. Variability did not appear to increase with moisture content, as found in Bowden's 1984 comparison study of three standard oven-dry methods, but remained fairly constant over the entire moisture range.

Table 8. Motomco readings and oven-dry moisture determinations by mixture/variety. X's and Y's represent mean values and are plotted separately for each mixture or variety in Figures 1-4.

Mixture 1				Mixture 2				Mutiki 2				Ikinimba			
Motomco	X	Oven-Dry	Y	Motomco	X	Oven-Dry	Y	Motomco	X	Oven-Dry	Y	Motomco	X	Oven-Dry	Y
7		2.35		9.5		2.48		12.5		9.62		10.5		2.18	
7.5	7.2	2.20	2.62	10.0	9.5	2.28	2.75	13.0	12.7	9.64	9.49	10.5	10.5	4.24	3.06
7		3.65		9.0		2.43		12.5		9.17		10.5		2.26	
		2.73				4.02				9.88				4.35	
		2.19				2.52				9.16				2.29	
15.5		6.27		25.5		6.26		24.5		12.10		25.5		6.11	
16.0	16.0	5.46	5.40	26.0	25.7	6.04	6.60	23.5	24.5	11.73	11.82	25.0	25.5	5.51	5.99
16.5		6.00		25.5		8.37		25.5		11.49		26.0		5.70	
		4.40				6.14				12.09				6.86	
		4.89				6.21				11.67				5.76	
20		6.16		38.5		9.46		44		14.11		41		8.71	
20.5	20.0	6.58	6.18	39.5	38.7	8.85	9.62	41.5	42.7	14.10	14.16	40	40	8.40	7.81
19.5		5.25		38.0		11.17		42.5		14.14		39		8.11	
		5.77				9.63				14.47				9.23	
		7.16				9.01				13.99				4.60	
53.5		15.85		54.5		13.54		58		17.72		56		12.14	
52	53	15.85	15.76	55.0	55	13.83	13.67	60	59.2	17.04	17.61	58	57	11.25	12.00
53.5		15.56		55.5		13.81		59.5		17.42		57		12.70	
		15.79				13.75				17.70				11.66	
		-				13.40				18.19				12.23	
72		19.31		78		15.32		76		20.24		76.5		17.40	
74.5	74.3	19.78	19.59	78	77.5	15.83	16.30	75	75	20.08	19.51	73.5	75.2	17.45	17.46
76.5		19.77		76.5		15.39		74		20.26		75.5		18.01	
		19.46				17.46				16.58				17.59	
		19.65				17.51				20.39				16.83	
78.5		19.71		87		18.79		82.5		21.54		85		18.58	
80	80	19.58	19.59	86	87	18.57	17.98	80.5	82	21.95	21.55	83	84.3	18.55	18.64
81.5		19.35		88		16.86		83.0		21.83		85		18.88	
		19.66				17.92				22.02				18.50	
		19.63				17.77				20.39				18.69	

STUDY II: RESULTS AND DISCUSSION

RESULTS

The calibration curves and regression equations relating oven-dry moisture contents to Motomco readings are shown in Figures 7-9; the calibration curves and regression equations for the Dickey-John and Dole meters are shown in Figures 10 and 11.

II. Comparison of moisture meter performance

A. Agreement between Motomco meters

The three Motomco calibration curves differed slightly in Y-intercept and negligibly in slope. The differences between predicted moisture contents and meter readings are shown in Table 9. At moisture contents $\leq$ 13.74%, the predicted moisture contents from all three meters agreed fairly well. The difference in predicted moisture contents was always less than 0.4%. None of the meters gave consistently lower or higher determinations than the others in this range. At moisture contents $\geq$ 15.64%, differences in predicted moisture contents between meters increased. (The G6418 meter consistently gave readings from 0.4 to 1.2% moisture higher than the other two meters in this range.)

Figure 7. Calibration curve for Motomco G6347 moisture meter. Study II.

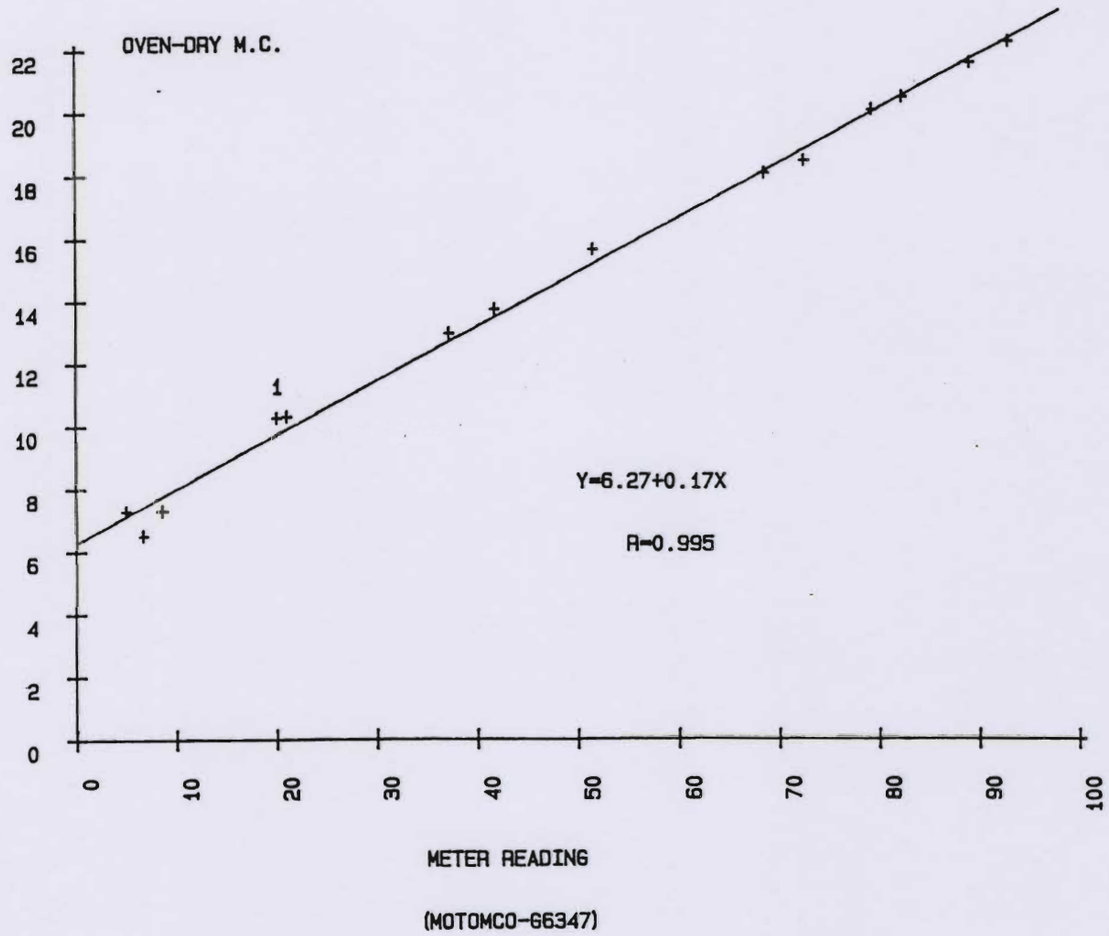


Figure 8. Calibration curve for Motomco G6418 moisture meter. Study II.

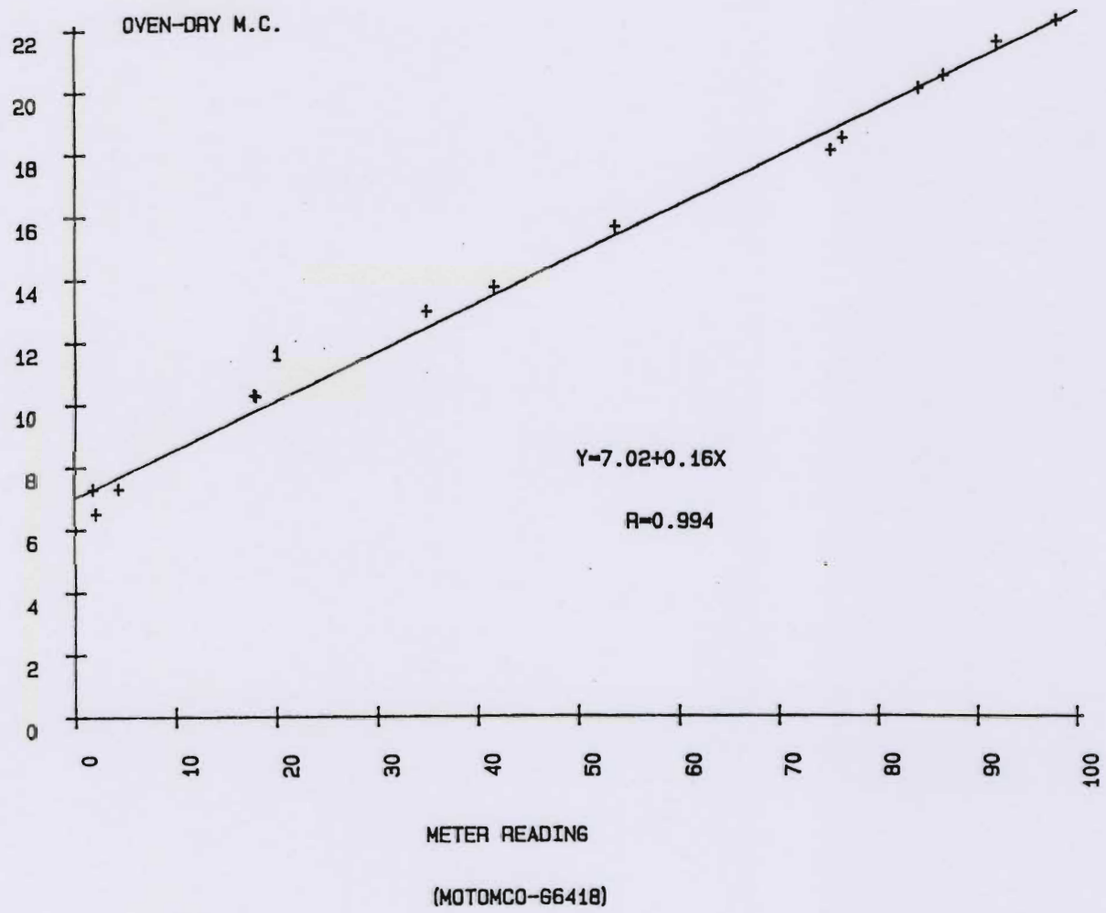


Figure 9. Calibration curve for Motomco G6419 moisture meter. Study II.

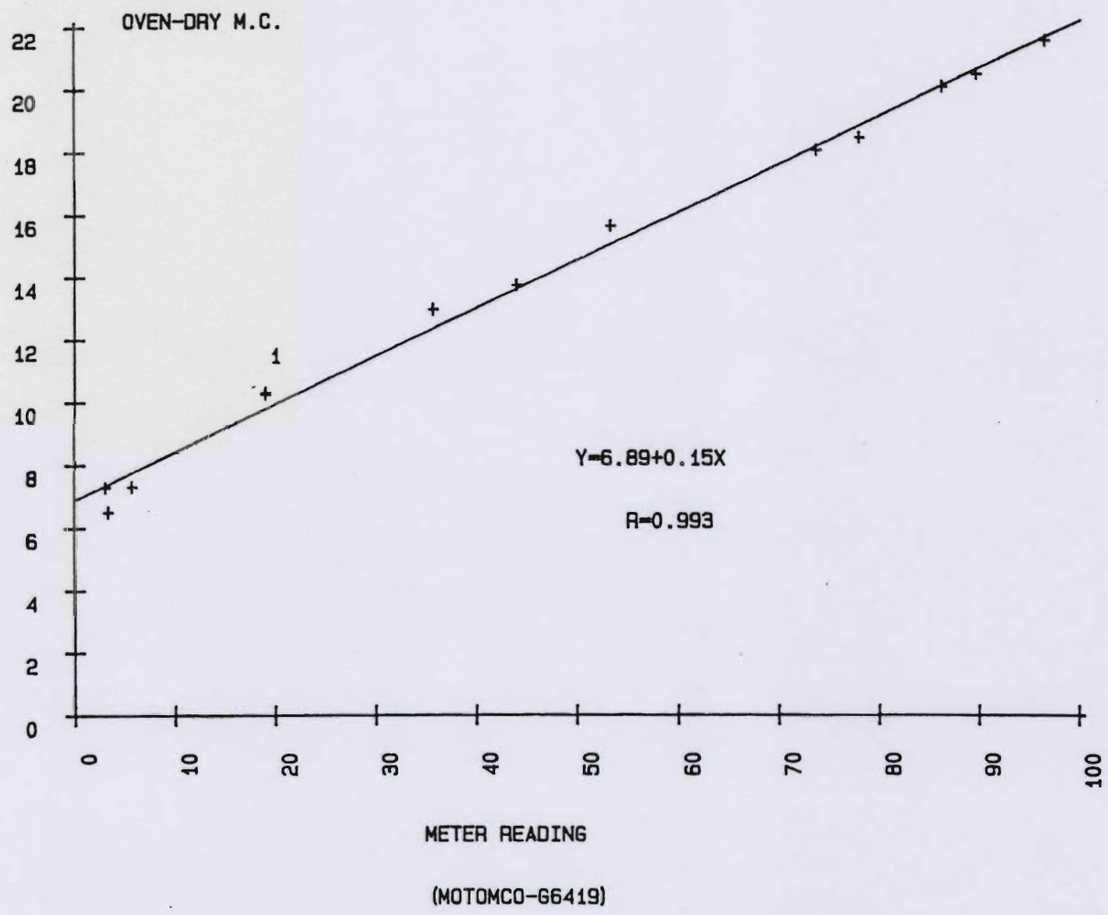


Figure 10. Calibration curve for Dickey-John moisture meter. Study II.

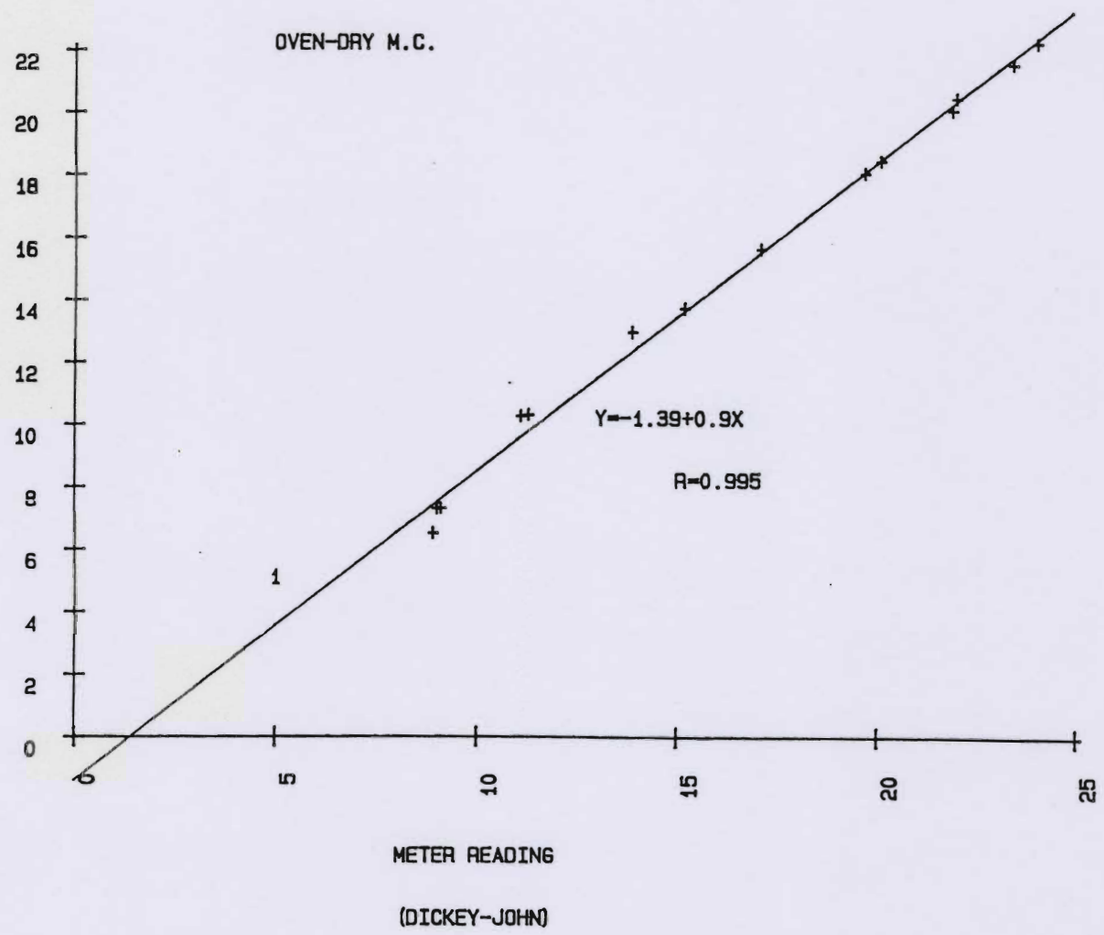


Figure 11. Calibration curve for Dole moisture meter. Study II.

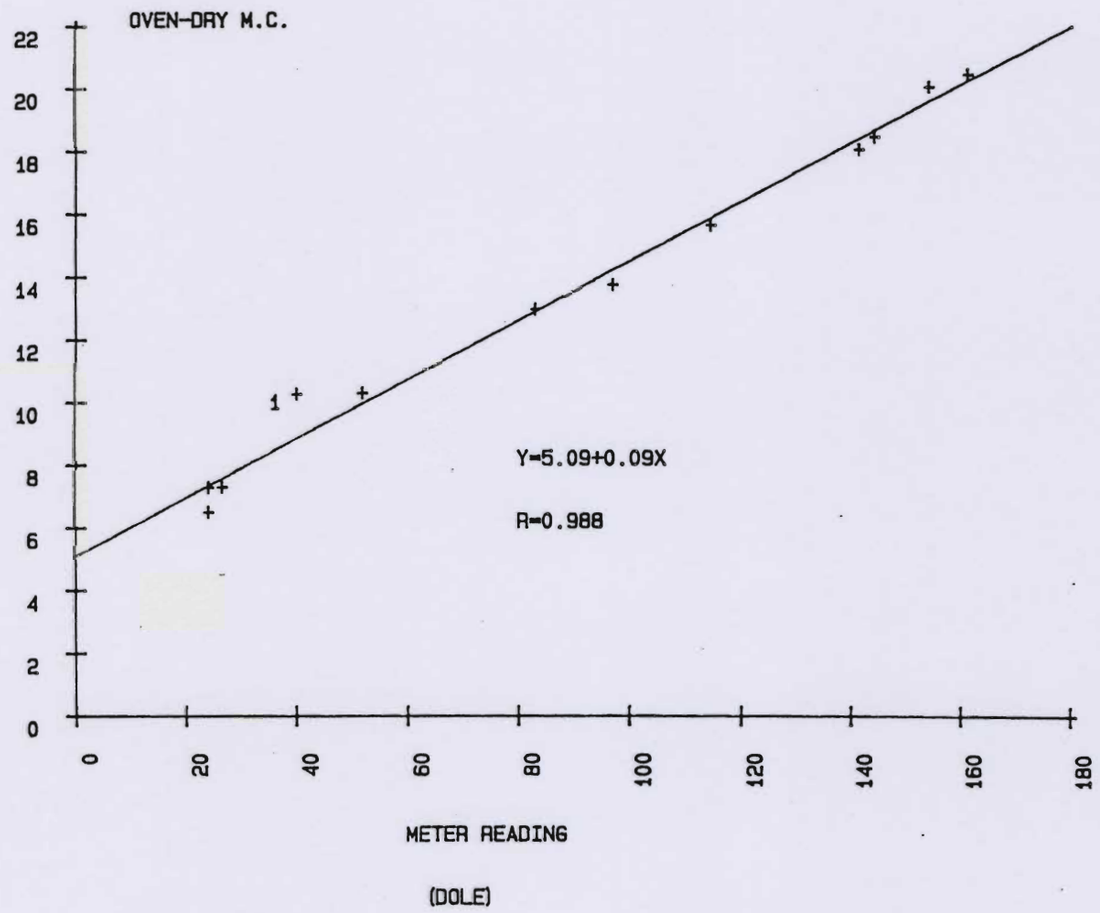


Table 9. Moisture contents predicted by calibration curves compared to oven-dry moisture contents

Y = predicted moisture content
Y-Oven = meter error

Oven-Dry m.c.	M-G6437		M-G6418		M-G6419		Dickey-John DJGMT		Dole 400B	
	Y*	Y-Oven	Y	Y-Oven	Y	Y-Oven	Y	Y-Oven	Y	Y-Oven
6.5	7.38	0.88	7.34	0.84	7.39	+ 0.89	7.40	+ 0.90	7.28	+ 0.78
7.29	7.51	0.22	7.29	0	7.34	+ 0.05	7.50	+ 0.21	7.28	- 0.01
7.30	7.72	0.42	7.71	0.41	7.75	+ 0.45	7.60	+ 0.30	7.51	+ 0.21
10.30	9.84	- 0.46	9.87	- 0.43	9.74	- 0.56	9.78	- 0.52	9.78	- 0.52
10.26	9.67	- 0.59	9.90	- 0.36	9.74	- 0.52	9.58	- 0.68	8.72	- 1.54
12.97	12.59	- 0.38	12.62	- 0.35	12.25	- 0.72	12.35	- 0.62	12.59	- 0.38
13.74	13.36	- 0.38	13.69	- 0.05	13.49	- 0.25	13.64	- 0.10	13.85	0.11
15.64	15.03	- 0.61	15.63	- 0.01	14.84	- 0.80	15.52	- 0.12	15.43	- 0.21
18.06	17.92	- 0.14	19.07	+ 1.01	17.95	- 0.11	18.09	+ 0.03	18.11	+ 0.05
18.46	18.60	+ 0.14	19.26	+ 0.80	18.59	+ 0.13	18.49	+ 0.03	18.11	- 0.35
20.07	19.75	- 0.32	20.49	+ 0.42	19.84	- 0.23	20.27	+ 0.20	19.00	- 1.07
20.47	20.26	- 0.21	20.89	+ 0.42	20.35	- 0.12	20.37	- 0.10	19.63	- 0.84
21.56	21.40	- 0.16	21.74	- 0.02	21.37	- 0.19	21.76	- 0.20	-	-
22.24	22.05	- 0.19	22.70	+ 0.46	-	-	22.35	- 0.11	-	-

B. Meter accuracy

Table 9 also shows the meter errors (Y-oven) in predicting moisture contents. This error is summarized as the correlation coefficients shown in Figures 7-11. The Dole meter was the least accurate, but the correlation coefficient for this curve was nearly 0.99 - certainly high enough to be useful. Correlation coefficients were slightly higher in this study than in Study I. This improvement may be the result of a greater number of moisture levels (14 in this study versus 6 in Study I).

C. Variability in meter readings

Table 10 shows the meter readings and corresponding oven-dry moisture determinations for the meters. For a given moisture level, there was obvious variation in average readings among the three Motomco meters. Variation in average readings between meters was at a minimum in the middle range of moisture contents from approximately 10.3% to 15.64%, and increased again at higher moisture contents. For a given meter, there was also variation in replicate readings taken on the same sample.

This variation was generally at a minimum in the 10.3% to 13.74% moisture range. None of the meters gave better overall reproducibility than the others. The G6347 meter was somewhat less variable in replicate readings than the other two meters at low moisture contents, but more variable than the other two meters at high moisture contents. The G6419 meter appeared to give the most variable readings.

D. Meter sensitivity to changes in moisture content

Meter sensitivity to changes in moisture content is indicated by the slopes of the calibration curves; larger slopes indicate a greater sensitivity to changes. Based on this criteria the three Motomco meters were equivalent in sensitivity. The Dole and Dickey-John are more difficult to compare since their readings are on different scales.

E. Moisture content range

The meters differed somewhat in the range of moisture contents they were able to measure (see Table 10). The Motomco and Dickey-John meters were able to measure moisture contents over the entire range tested (6.5% to 22.24%). The range of the Dole meter was slightly smaller; the two highest moisture levels studied registered off this meter's scale.

II. Variability in oven-dry moisture determinations (Table 10)

The variability between replicate oven-dry measurements was relatively lower than in Study I. About half the time it was within the 0.2% maximum variation allowed by standard oven-dry methods (AACC, 1975; USDA, 1971). This decreased variability is likely due to changes in the oven-dry moisture determination procedure. During the two stage method of Study I weighing error and sample loss from grinding could have increased the variability.

Table 10. Meter readings and oven-dry moisture contents for 14 moisture levels of a single bean mixture

Meter Type										
M-G6347		M-G6418		M-G6419		Dickey-John		Dole		Oven-Dry m.c.	
Meter Readings											
	$\bar{X}$		$\bar{X}$		$\bar{X}$		$\bar{X}$		$\bar{X}$		$\bar{X}$
										6.72	
7.0		2.0		5.0		8.9		24.0		6.68	
6.0	6.7	2.5	2.0	5.0	3.3	8.9	8.9	24.0	24.0	6.40	6.50
7.0		1.5		0.0		8.9		24.0		6.15	
										6.56	
										7.06	
5.0		1.0		3.0		9.0		23.0		7.52	
5.0	5	2.0	1.7	3.0	3.0	8.9	9.0	25.0	24.0	7.30	7.29
5.0		2.0		3.0		9.1		24.0		7.27	
										7.32	
										7.37	
8.5		5.0		5.0		9.3		25.5		7.29	
8.5	8.5	4.5	4.3	6.0	5.7	9.1	9.1	27.0	26.5	7.27	7.30
8.5		3.5		6.0		8.9		27.0		7.26	
										10.68	
20.0		18.0		18.0		11.4		53.0		10.35	
21.0	21	18.0	17.8	19.0	19.0	11.0	11.3	52.0	51.8	10.17	10.30
22.0		17.5		20.0		11.4		50.5		10.10	
										10.20	
										10.21	
20.0		18.0		18.0		11.2		40.0		10.32	
20.0	20	18.0	17.8	19.0	19.0	11.1	11.1	40.0	40.0	10.14	10.26
20.0		17.5		20.0		11.1		40.0		10.27	
										10.38	
										12.38	
37.0		35.0		35.0		14.0		83.0		13.05	
37.5	37.2	35.0	35.0	36.0	35.7	13.8	13.9	83.0	83.0	12.99	12.85
37.0		35.0		36.0		13.8		83.0		12.99	
										13.95	
41.5		42.0		44.0		15.4		97.0		13.69	
42.0	41.7	41.5	41.7	44.0	44.0	14.8	15.2	97.0	97.0	13.44	13.74
41.5		41.5		44.0		15.4		97.0		13.86	
										15.61	
53.0		53.5		52.0		17.1		114.0		15.63	
51.5	51.5	53.0	53.8	54.0	53.3	16.7	17.1	113.0	114.5	15.57	15.64
50.0		55.0		54.0		17.4		116.5		15.71	
										15.66	

Table 10 continued

Meter Type											
M-G6347		M-G6418		M-G6419		Dickey-John		Dole		Oven-Dry m.c.	
Meter Readings											
	$\bar{X}$		$\bar{X}$		$\bar{X}$		$\bar{X}$		$\bar{X}$		$\bar{X}$
										18.16	
68.5		76.0		73.0		19.7		142.0		17.90	
68.0	68.5	75.0	75.3	75.0	73.7	19.8	19.7	140.5	141.5	18.06	18.06
69.0		75.0		73.0		19.6		142.0		18.08	
										18.12	
										18.39	
72.5		76.5		77.0		19.8		144.0		18.54	
72.5	72.5	78.0	76.5	78.0	78.0	20.1	20.1	144.0	144.3	18.44	18.46
72.5		75.0		79.0		20.5		145.0		18.45	
										20.03	
81.0		84.0		85.0		21.9		153.0		20.15	
78.0	79.3	84.0	84.2	87.0	86.3	22.1	21.9	156.0	154.2	20.09	20.07
79.0		84.5		87.0		21.8		153.5		20.02	
										20.33	
82.0		85.0		91.0		21.6		160.0		20.55	
81.0	82.3	89.0	86.7	89.0	89.7	22.4	22.0	164.0	161.2	20.42	20.47
84.0		86.0		89.0		21.9		159.5		20.46	
										20.57	
										21.58	
89.0		92.0		97.0		23.6				21.62	
88.0	89.0	92.0	92.0	96.5	96.5	22.7	23.4	>165		21.49	21.56
90.0		92.0		96.0		23.8				21.56	
										22.28	
94.0		98.0				23.7				22.28	
93.5	92.8	98.0	98.0	>100		24.3	24.0	>165		22.16	22.24
91.0		98.0				23.9				22.22	

DISCUSSION

The results of this study indicate that there are small differences in meter performance within and between brands. Although the calibration curves for the three Motomco meters were similar the variability in average readings between meters for the same samples was frequently large. The G6418 meter consistently predicted higher moisture contents than the other two meters in the upper moisture content range. These results suggest that the internal calibration of this instrument may be at fault: recalibration may improve agreement between meters.

The three Motomco meters were somewhat more accurate than the Dickey-John in the 6.5% to 12.97% moisture range but less accurate in the higher range. These results are in agreement with those of Gutheil et al. (1984) who found that Motomco moisture determinations on corn were more accurate than Dickey-John determinations at low moisture contents (10.2% - 15.5%) but less accurate than Dickey-John determinations at high moisture contents (25% - 28%).

The moisture contents predicted by all five meters tended to be consistently lower than the oven-dry determinations within the moisture content ranges 10.26% to 15.64%, and 20.47% to 22.24% (discounting the Motomco G6418 meter). Gutheil et al. (1984) also found that meter determinations were significantly lower than air-oven determinations at high moisture levels (25% - 28%), but in contrast to our results they found the meter determination to be significantly higher than air-oven determinations at low moisture levels (10.2% - 15.5%). Differences in electrical properties of corn and beans in different moisture content ranges may partially account for the differences between our study and theirs.

All the meters tested showed some variability in replicate readings. Such

variability between replicates is expected when samples containing mixtures of different varieties are analyzed, since varieties differ and the electrical properties of the varieties in contact with the test cell will be somewhat different each time a reading is repeated. The amount of variability between replicate readings can probably not be reduced, but should be taken into consideration by including enough replicates to represent the sample adequately.

With the exception of the Dole meter, the meters tested were able to measure bean moisture contents between 6.5% and 22.2%. This moisture content range seems adequate for use in Rwanda, since most samples analysed in our laboratory generally fall within the range of 11% to 18% moisture. The Dickey-John meter appears to be the best adapted to rapid and accurate moisture measurement in Rwanda. This meter was very accurate, and has the added advantage of internal correction for sample temperature. The Motomco meters are equivalent in accuracy to the Dickey-John, but the calibration curves developed for them thus far are only appropriate for use with samples at 23°C.

The Motomco calibration curves developed in Study II are most similar to the one developed for the pure variety Mutiki 2 (Fig. 5). The predominant varieties found in the mixture used in Study II had approximately the same seed sizes as Mutiki 2. This further supports the idea that seed size may be an important criterion for establishing a group of moisture meter calibration curves applicable to bean mixtures found in Rwanda.

CONCLUSIONS

Calibration curves predicting moisture contents from Motomco moisture meter readings differed according to the mixture or variety tested. The differences between the calibration curves may be due to seed size, electrical properties of the seeds and different amounts of damaged seeds.

Although the calibration curves are reasonably accurate as evidenced by the very high correlation coefficients, this accuracy might be increased in the construction of future calibration curves by increasing the number of moisture levels used and increasing the number of oven-dry and Motomco measures in an effort to overcome the large variability observed in these readings.

Lack of temperature corrections for the calibration curves means that they are only appropriate for use with samples at 23°C.

All moisture meters were reasonably accurate. Although the Dickey-John meter had the highest correlation coefficient, it was not appreciably higher than the other meters. There was considerable variability among Motomco moisture meter readings and within a single meter. Variability within a single meter may be largely a result of the different bean varieties present in a mixture and therefore can not be reduced. Enough replicate measurements must be taken on each bean sample to counteract this variability.

LITERATURE CITED

Gough, M.C. 1983. Moisture meter calibration: A practical guide. Tropical Stored Products Information. 46:17.

Okwelogu, T.N. 1971. Guidance in the selection of moisture meters for durable agricultural produce. Trop. Stored. Prod. Info. 21:19.

Adams, C.F. 1978. "Nutritive Value of American Foods in Common Units." Agricultural Handbook No. 456. Agricultural Research Service, United States Department of Agriculture, Washington, D.C.

Hunt, W.H., and Neustadt, M.H. 1966. Factors affecting the precision of moisture measurement in grain and related crops. Journal of the A.O.A.C. 49(4):757.

Matthews, J. 1962. The accuracy of measurement of known changes in moisture content of cereals by typical oven methods. J. Agric. Eng. Res. 7(3):185.

Warner, M.G.R., and Browne, D.A. 1963. Investigations into oven methods of moisture content measurement of grain. J. Agric. Eng. Res. 8:289.

Bowden, P.J. 1984. Comparison of three routine oven methods for grain moisture content determination. J. Stored Prod. Res. 20(2):97.

Paulsen, M.R., Hill, L.D., and Dixon, B.L. 1984. Corn moisture meter to oven comparisons. Transitions of the ASAE. 27(6):1917.

Gutheil, R.A., Krause, G.F., Brooker, D.B., and Anderson, M.E. 1984. Effect of corn cultivar and sample variance on the performance of three electronic moisture meters. Cereal Chem. 61(4):267.

Hurburgh, C.R. Jr, Hazen, T.E., and Bern, C.J. 1985. Corn moisture measurement accuracy. Transactions of the ASAE. 28(2):634.

Nelson, S.O. 1977. Use of electrical properties for grain-moisture measurement. J. Microwave Power. 12:67.

Lamb, E., and Hardman, L.L. 1986. Final Report of Survey of Bean Varieties Grown in Rwanda. U.S.A.I.D.-Rwanda Local Crop Storage Cooperative Research Project, LCS/FSMII (Research Component): University of Minnesota.

Association of Official Analytical Chemists. 1975. Official methods of analysis (12 ed.) sec. 7.008, p. 130.

United States Department of Agriculture. 1971. GR Instruction 916-6. Chapter XII. "Oven Methods for Determining Moisture Content of Grain and Related Agricultural Commodities." Consumer and Marketing Service, Grain Division, 6505 Belcrest Rd. Hyattsville, MD 20782.

SECTION III

MOISTURE SORPTION ISOTHERMS OF RWANDAN BEAN MIXTURES AND SINGLE VARIETIES

ABSTRACT

Adsorption isotherms were obtained for two Rwandan bean mixtures. Desorption isotherms were obtained for both of these mixtures plus two individual bean varieties. The isotherm data were fit to a modified Henderson equation. The fit of the data to the equation was improved by removing observations at water activities greater than 0.80. The desorption isotherm predicted using the modified Henderson equation and pooled equilibrium moisture content data from the two mixtures and two single varieties was compared to an isotherm reported in the literature for dry edible beans. The isotherms agreed well in the range of 45-70% RH.

INTRODUCTION

The quality and stability of food products during storage is influenced by their equilibrium moisture content (EMC). Equilibrium moisture content is defined as the moisture content at which atmospheric and product water vapor pressures are equal and no desorption (moisture loss) or adsorption (moisture uptake) occurs (Hutchinson and Otten, 1984). Depending on EMC, products may or may not be susceptible to quality changes due to mold growth, enzyme activity or non-enzymatic chemical reactions.

The EMC of food products is related to the equilibrium relative humidity (or water activity) and temperature of the environment. Water activity (a_w) is equal to the equilibrium relative humidity (erh) divided by 100. The relationship between EMC and a_w at any temperature is described by a sorption

isotherm, which is a graphical representation of the equilibrium moisture content on a dry basis (g water per 100 g dry matter) of the food product versus the a_w of the atmosphere surrounding the product. Such plots or isotherms are constructed by allowing products to equilibrate at atmospheres of known a_w and then determining moisture content.

Moisture sorption isotherms are useful for estimating EMCs of food products during storage under given RH and temperature conditions, and have been plotted for many foods including cereals and dry beans. This information can be important in many developing countries, and particularly in tropical climates where stored grains may be subjected to storage atmospheres and temperatures conducive to quality loss.

To date, published moisture sorption data for dry beans has been limited to pure varieties. In certain countries of Africa, however, beans are grown, stored, and consumed as mixtures. In Rwanda, for example, bean mixtures contain an average of 11 different varieties, and the predominant varieties in these mixtures vary according to region (Lamb and Hardman, 1986). The objective of the present study was to determine adsorption and desorption isotherms for several typical Rwandan bean mixtures and pure varieties at normal storage temperatures. These isotherms could then be used to estimate EMCs. The isotherms could also be compared to those in the literature for Phaseolus bean species as well as others such as Vigna species.

LITERATURE REVIEW

Various aspects of moisture sorption have been studied in depth by many researchers. Labuza (1984) has reviewed in detail the principles of moisture

sorption and their application to different groups of food products. For the purposes of this review, basic moisture sorption theory will be briefly discussed followed by specific examples from the literature pertaining to dry beans, other pulses and grains. The discussion will center on factors influencing the general shape of sorption isotherm curves: 1) the composition of the food product, 2) the initial moisture content of the food, and 3) the temperature at which the isotherm is determined. Some of the standard procedures used to determine moisture sorption isotherms will also be reviewed and illustrated with examples taken from research conducted on dry beans and grains. These procedures include: 1) sample preparation; 2) maintenance of constant a_w environment; 3) determination of the equilibrium state; and 4) prevention of quality changes during equilibration and storage.

I. Moisture Sorption Theory

Factors Influencing Isotherm Shape and Equilibrium Moisture Content

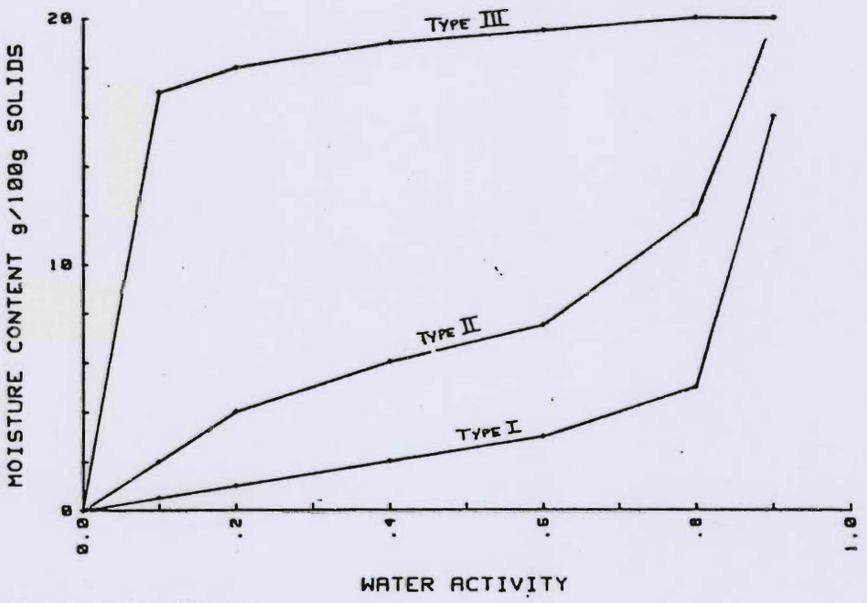
Composition of the Food Product

Figure 12 shows the three common isotherm types exhibited by food products.

Type I isotherms are generally exhibited by anticaking agents; Type III isotherms are exhibited by crystalline products such as sugar. Most foods, including dry beans, exhibit Type II isotherms and are, essentially, hybrids of Types I and III. Type II isotherms are characterized by their sigmoid shape. The greatest changes in EMC per unit change in a_w occur at $a_w < 0.20-0.40$ and $a_w > 0.60-0.70$ (Labuza, 1984).

McCurdy et al. (1980) presented adsorption isotherms at 21°C for white pea

Figure 12. Typical isotherms for different classifications of foods (Labuza, 1984). Type I, anticaking agents; Type II,most foods; Type III, crystalline products.



beans (data of Dexter et al., 1955), Roshina variety beans (data of Jordao and Stolf, 1969), mean values plotted for seven varieties of beans (data of Weston and Morris, 1954) and pinto beans (their own data). These isotherms are shown in Figure 13. Weston and Morris' data are plotted on a wet weight moisture basis, while all other data are plotted on a dry weight moisture basis. This probably accounts in part for the differences noted between their isotherm and the others. Differences between the isotherms shown are likely related to differences in equilibration methods and/or to varietal differences in adsorption properties (McCurdy et al., 1980).

Initial Moisture Content

The initial moisture content of a food product influences its equilibrium moisture content to some extent. A high initial moisture content food has different sorption properties from the same food at a low initial moisture content. Within a certain range of water activities, a food which absorbs moisture during equilibration will have a lower EMC than if it desorbs moisture during equilibration. This property is known as hysteresis, and is illustrated in Figure 14.

Most dried foods such as beans normally follow neither adsorption or desorption curves. They are initially dried to some intermediate level (point C, Figure 14) and then subjected either to further drying or to rehumidification. If the food is dried further, the desorption curve is followed; if the food is rehumidified, it begins to move over to the adsorption curve. Such curves are known as "working" isotherms (Labuza, 1984).

Labuza (1984) gave three reasons for the differences in desorption and adsorption isotherms: 1) During desorption, some solutes may become

Figure 13. Moisture adsorption isotherms of dry beans at 21°C (McCurdy et al., 1980):

O - white pea beans, Dexter et al., 1955;

X - Rosinha variety, Jordao and Stolf, 1969;

Δ - mean of 7 varieties, wet weight basis, Weston and Morris, 1954;

□ - pinto beans, McCurdy et al., 1980.

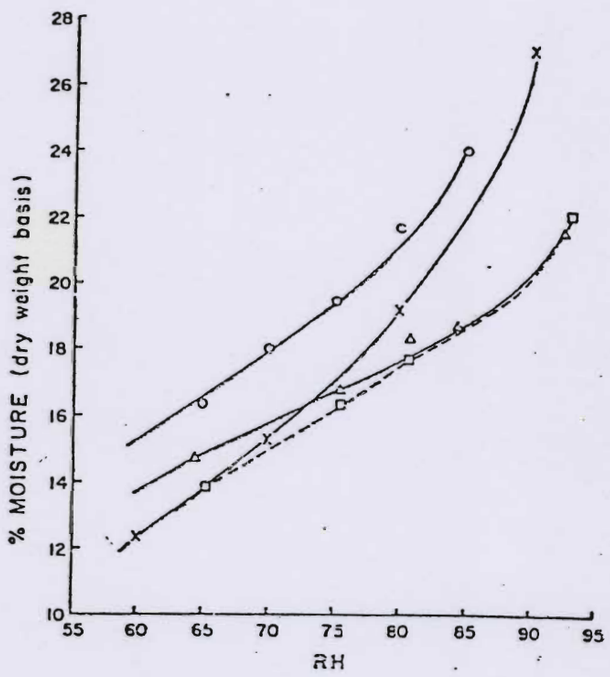
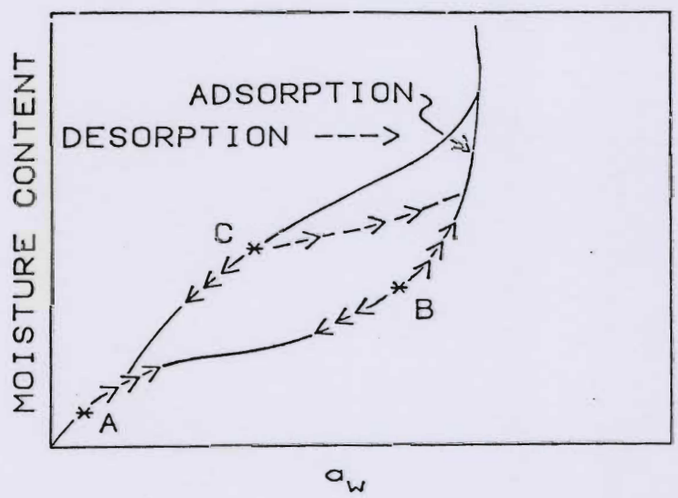


Figure 14. Adsorption-desorption hysteresis loop (Labuza, 1984), showing paths taken by: a dry food during sorption (A), a sample prepared by adsorption to an intermediate level (B), and a sample prepared by desorption (C).

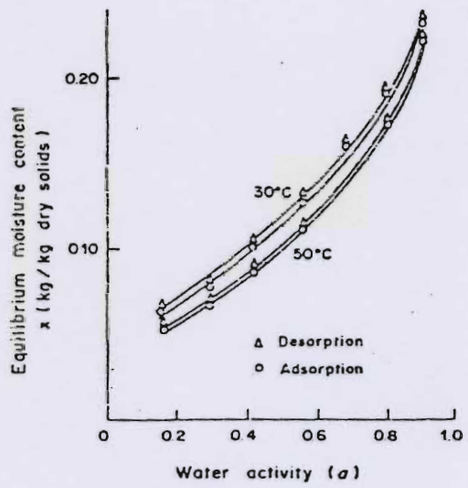


supersaturated below their crystallization a_w and thus hold more water as relative humidity is lowered (usually applies to foods with high sugar content). 2) Capillaries empty differently during desorption. The narrow ends of capillaries retain water below the relative humidity where it should have been released. During adsorption, however, the ends of the capillaries prevent water from entering easily. And, 3) the surface tension and wetting angle from the Kelvin equation (which predicts water activity lowering due to the capillary effect) is different for adsorption than for desorption and results in a higher moisture content for the latter.

Adsorption, desorption, and "working" isotherms have been published for numerous varieties of dry beans and other pulses. Denloye and Ade-John (1985) published adsorption and desorption isotherms for several Nigerian food grains, including cowpeas which are similar in composition to dry beans (Figure 15). Initial moisture content was not specified. The cowpea adsorption curve is almost parallel to the desorption curve between $a_w = 0.20$ and $a_w = 0.90$. The curves begin to approach each other on either side of this range.

Dexter et al. (1955) determined adsorption and desorption isotherms at 4, 10, 21, 27, 32, 38, 43, and 54°C for white pea beans at the following water activities: 0.55, 0.65, 0.75, 0.80, and 0.85. Dry basis (d.b.) initial moisture contents were 25% and 16.3% for the desorption and adsorption curves, respectively. In most cases the desorption curves were only slightly higher than the adsorption curves. Because the a_w levels were all fairly high the adsorption and desorption curves were already starting to approach each other.

Figure 15. Adsorption and desorption isotherms of cowpeas at 30° and 50°C (Denloye and Ade-John, 1985)



Temperature

Temperature also affects the moisture sorption properties of foods and their equilibrium moisture contents. When stored at constant a_w, foods which exhibit a Type II isotherm hold less moisture as temperature increases (Figure 16). Labuza (1984) has discussed this phenomenon in depth. The effect of temperature on EMC is theoretically greatest at low to intermediate a_w; however, results of isotherm studies on dry beans and cowpeas do not always concur.

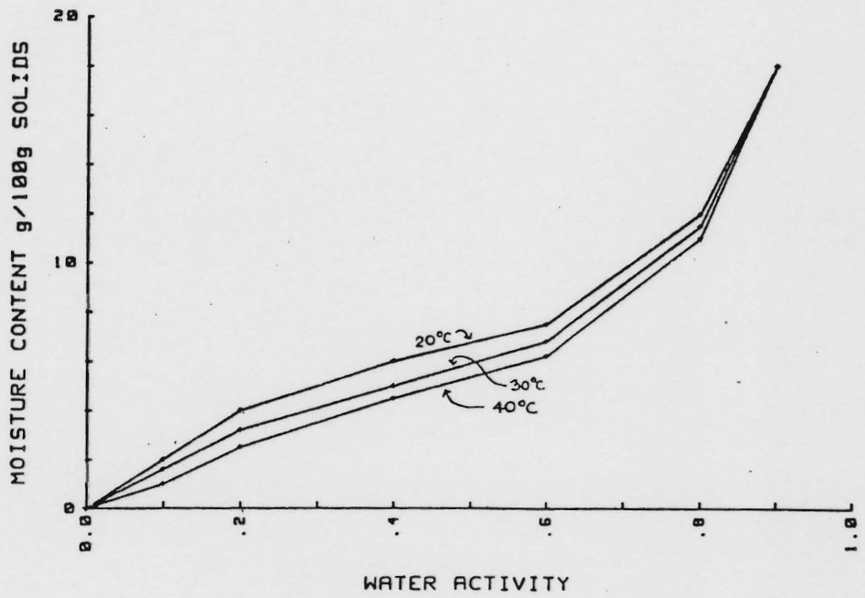
Hutchinson and Otten's (1984) work with white "Seafarer" beans (32% initial moisture content, d.b.) showed that the temperature effect on EMC was fairly constant over the entire relative humidity range. EMC values predicted by the Henderson (1952) and Chung and Pfost (1967) equations in the temperature range of 16 to 49°C differed from each other by < 0.6% to 4%.

Denloye and Ade-John (1985) reported that temperature effects on the EMC of cowpeas increased with relative humidity. Dexter et al. (1955) found that the effect of temperature on EMC was greatest at intermediate relative humidities (55-75%).

II. Procedures for determining Isotherms

Labuza (1984) has emphasized the importance of the basic procedures involved in the collection of isotherm data. The literature on moisture sorption isotherms of dry beans, other pulses and grains reveals at least four steps in the equilibration process wherein procedural differences may occur: 1) sample preparation; 2) establishment of constant relative humidity environments and sample storage; 3) method of determining when equilibration has occurred; and 4) prevention of quality changes during equilibration and storage. These will be discussed separately.

Figure 16. Effect of temperature on moisture sorption of foods (Labuza, 1984)



Preparation of samples for equilibration

Preparation for desorption

Theoretically, initial moisture contents of samples for desorption isotherms should be high enough so that they will lose moisture during equilibration. Samples can be equilibrated as is, or they can first be rewetted to higher moisture contents. It is preferable not to rewet samples; the moisture added during rewetting might be desorbed differently than that which is present naturally. Hutchinson and Otten (1984) determined desorption isotherms of Seafarer beans with an initial moisture content of 32% (d.b.). Dexter et al. (1955) began their desorption process using pea beans containing 25% moisture (d.b.). However, Denloye and Ade-John (1985) rewetted cowpeas and soybeans by soaking them in distilled water, draining and allowing them to equilibrate in closed containers at 10°C for ten days before determining desorption isotherms. Equilibrated moisture contents were not reported. Henderson (1984) added water gradually to Nigerian beans, increasing their moisture content to 20% (d.b.), dried them at room temperature to several lower moisture contents and allowed them to equilibrate for two weeks at 5°C in sealed jars before desorption isotherms were constructed.

Preparation for adsorption

Samples for adsorption should be at a moisture content below that which is in equilibrium with the lowest a_w condition. Labuza (1984) recommended three methods for drying samples to low moisture content: 1) drying at 30°C in a vacuum oven for 30-40 hrs at 27-28" vacuum; 2) freeze-drying at 27-32°C and 100 μHg for 48 hr; or 3) storage over a desiccant for 4-8 weeks. The last method

has the disadvantage of prolonging the time necessary for obtaining the data and the advantage of the lowest cost.

Denloye and Ade-John (1985) dried cowpeas and soybeans in a vacuum oven at 30°C and 5 mm Hg for 18 hr for adsorption isotherms in the range of 0.15 - 0.95 a_w. Initial moisture contents were not reported. Henderson (1984) dried Nigerian cocoa beans to 4.0% (d.b.) in "dry moving air" at 30°C prior to determining adsorption isotherms. McCurdy et al. (1980), working on the high a_w range (0.63 - 0.97, 25°C), was able to use pinto beans at 8.9-9.5% (d.b.) normal initial moisture content to determine adsorption isotherms.

Preparation for working isotherms

Researchers do not always report whether isotherm data is obtained by adsorption or desorption. In these cases, isotherms are determined using samples at their original moisture contents with neither predrying nor addition of moisture; these can usually be classified as "working" isotherms. For example, Weston and Morris (1954) determined EMCs of seven varieties of dry beans (seven isotherms) varying in initial moisture content from 10.3 to 14.9%, d.b. over an a_w range of 0.11 to 0.98. Similarly, Morris et al. (1950) determined isotherms for dry beans (16.3% d.b.) in the a_w range of 0.10 to 1.00. A "working" isotherm depicts desorption on the lower a_w portion below the initial EMC of the sample and adsorption on the upper portion above the initial EMC of the sample. "Working" isotherms are more likely to represent the moisture sorption characteristics of beans during storage than adsorption or desorption isotherms, since beans going into storage usually have 11-14% moisture.

Maintenance of constant a_w environment

Several methods of maintaining constant relative humidity (a_w) environments during isotherm studies have been reported in the literature. Samples are placed in chambers (desiccators, glass jars, or other similar containers that can be sealed) over saturated solutions of organic acids or bases or inorganic salts. Concentrated sulfuric acid solutions have also been used. These solutions maintain a constant vapor pressure in the air above them depending on the solution concentration, on the individual solute and on temperature.

Saturated salt solutions in the form of slurries are convenient in that they can provide a wide range of a_w conditions, they are simple to use and they can give up or take on water without undergoing changes in equilibrium a_w. They have been used in most isotherm studies on dry beans (Weston and Morris, 1954; McCurdy et al., 1980; Hutchinson and Otten, 1984). Greenspan (1977) provided tables of commonly used salts showing the equilibrium a_w values of their saturated solutions at different temperatures. The a_w range was 0.113 (lithium chloride) to 0.973 (potassium chloride) at 25°C.

Labuza (1984) discussed some factors that may affect the a_w maintained over salt solutions. These include: 1) the purity of the salt and water used; 2) the proportion of salt to water and how the saturated state is maintained; and 3) the temperature at which the salt solution is prepared relative to storage temperature. ACS grade salts should be combined with distilled water in clean containers. In each case, the salt slurry should cover the bottom of the container and no salt crystals should protrude above the liquid surface. The solution layer over the salt slurry should be no more than 2 mm thick. The salt slurry should be stirred periodically during the storage period, because gain or

loss of moisture by the solution may change the water activity of the top layer of salt solution.

The salt slurries should be prepared at or above the temperature at which the isotherm is to be determined because the solubility of many salts increases with temperature. The amount of excess salt added at a lower temperature to maintain the proper relative humidity may not be sufficient to maintain the same relative humidity when the salt slurry is transferred to a higher temperature.

Even when a salt slurry has been prepared correctly, the a_w over it is affected by temperature; it generally decreases as temperature increases. Thus the EMC of a food stored over a given saturated salt solution will be somewhat lower at higher temperatures than at lower temperatures. The effect of temperature on relative humidity is not the same for all salts; differences in relative humidity between 5 and 25°C are as small as approximately 0.04% (lithium chloride) up to approximately 7.3% (strontium nitrate) (Greenspan, 1977). These temperature effects are extremely important. Labuza et al. (1985) reviewed more than 150 papers that included sorption isotherms which were often plotted for temperatures considerably higher than 25°C but that assumed the 25°C a_w levels.

Sulfuric acid solutions have also been used in isotherm studies on dry beans (Morris et al., 1950; Dexter et al., 1955). The solution concentrations can be graded to give an infinite range of a_w not affected by temperature shifts. However, these solutions are more corrosive than most saturated salt solutions, particularly at high concentrations (low a_w). They must be titrated to determine the actual final a_w when they lose or gain moisture during equilibration.

A problem associated with using solutions to maintain constant relative

humidity environments is the length of time required for food samples, e.g., beans, to reach equilibrium with the storage atmospheres. Reported equilibration times for dry beans at about 25°C have ranged from three weeks to more than five months, depending on initial moisture content, storage relative humidity and temperature, and the ratio of sample quantity to the quantity of salt slurry or sulfuric acid solution (Morris et al., 1950; Dexter et al., 1955; Weston and Morris, 1954; McCurdy et al., 1980; Hutchinson and Otten, 1984). Prolonged storage at high relative humidities and temperatures may result in the growth of molds and fungi, preventing accurate EMC determination. Equilibration time can be reduced somewhat by reducing the pressure in the constant a_w chamber (Henderson and Pixton, 1981; Labuza, 1984), but this may present other problems including contamination or loss of sample while establishing or releasing the vacuum (Labuza, 1984).

Denloye and Ade-John (1985) described a fluidized bed apparatus used for equilibrating samples of Nigerian maize, cowpeas, groundnuts and soybeans which reduced the equilibration time to about 30 min. It involved an equilibrium cell, a high pressure fan, an electric heater, a heat exchanger, and a sulfuric acid bath. The cell was removed from the apparatus and weighed periodically. Equilibrium was defined as a change in the cell weight of less than 1 mg between weighings. Although the reduction in equilibration time achieved was dramatic, the system was too sophisticated to be practical in most laboratory situations.

An equilibration method requiring no chemicals or sophisticated equipment to provide constant relative humidity environments has been described and used by Henderson (1984) for Nigerian cocoa beans. For the adsorption isotherm, samples were dried to about 4.0% moisture (d.b.) and rewetted to various levels by adding calculated quantities of distilled water to subsamples. For the

desorption isotherm, distilled water was gradually added to raise the bean moisture content to 20% (d.b.). Subsamples were then dried to a series of lower moisture contents, corresponding approximately to those used for determining the adsorption isotherm. All subsamples (about 350 g each) were allowed to equilibrate in sealed containers for two weeks at 5°C. Moisture contents and a_w were then measured, the latter by a dew point method (Pixton and Warbuton, 1971).

A requirement of this method is adequate equilibration time. Labuza (1984) suggested an equilibration time of 3-5 days for food in general depending on sample size and temperature; equilibration time will be longer at lower temperatures. However, the moisture sorption characteristics of samples may become altered during the rewetting treatment. Unequal sorption of water throughout samples could produce inaccurate results.

Each of the various methods for determining moisture sorption isotherms has advantages and disadvantages. The choice of an appropriate method depends on sample composition and size, the temperature and a_w range to be studied and the chemicals and equipment available.

Determination of the equilibrium state

It is important to determine when the equilibrium condition has been attained. If samples are removed from the a_w/temperature environments too soon, the determined moisture contents will be incorrect. If the samples are left in storage too long, microbial growth and chemical changes can occur. In order to compare isotherms from different studies the criteria for determining equilibrium must be the same or similar. In general, equilibrium is said to have been reached when samples have attained "constant weight". For example,

Hutchinson and Otten (1984) weighed white bean samples at 3-day intervals until the weight changed by no more than 1 mg/g solids, or 0.1% dry basis moisture content. Using this criterion, samples weighing approximately 13 g took 30 days or less to equilibrate with saturated salt solutions at 25°C. Denloye and Ade-John (1985), using the fluidized bed apparatus described above, equilibrated grain samples until the weight of the equilibrium cell changed by no more than 1 mg, or 0.005% in dry basis moisture content. Samples took 30 min to equilibrate using this criterion.

Some researchers have not indicated how, or even whether they determined that samples had reached the equilibrium state, but in these cases the storage times reported were probably long enough for samples to have attained equilibrium when the moisture contents were determined. For example, Weston and Morris (1954) stored 100-g samples of seven varieties of dry beans over saturated salt solutions at 25°C for up to 23 weeks. Wet basis moisture contents were determined at weekly intervals based on the original moisture contents and the changes in weights of the samples. Although the authors did not state their criterion the samples were apparently considered to have reached equilibrium when moisture contents changed by no more than 0.1% per week. Morris et al. (1950) stored 50 g samples of Michigan Michelite beans over concentrated sulfuric acid solutions and over water at 25°C for up to five months before samples reached "constant weight". The samples were then stored an additional six months before moisture contents were determined.

Labuza (1984) suggested that samples be weighed at frequent intervals (every three to seven days, depending on whether samples are stored under atmospheric or reduced pressure) until the change in weight is no more than 2 mg/g solids. This corresponds to about a 0.2% change in dry basis moisture content which is not likely to influence the shape of the isotherm.

Prevention of changes in sample quality during equilibration

Changes in food sample quality during equilibration can influence EMC and thus isotherm shape. Mold growth may result in inaccurate moisture content values. Mold growth has been reported on dry beans stored at 0.75 a_w and above and at 25° to 49°C (Morris et al., 1950; Dexter et al., 1955; Weston and Morris, 1954; McCurdy et al., 1980; Hutchinson and Otten, 1984).

It appears that researchers usually do not employ chemical agents to prevent mold growth during isothermal studies, although such means do exist. For example, propionic, acetic, formic and isobutyric acids as well as sodium propionate and ammonium isobutyrate have been found to effectively inhibit mold growth during storage of high moisture grain (U.S. Grain Marketing Research Center, 1973). However, most mold inhibitors affect product a_w during storage (Labuza, 1984) and thus influence EMCs. A small, open vial of toluene (about 5 ml) placed in the constant a_w chambers with samples will inhibit microbial growth without influencing product a_w, but then these samples should not be used for sensory evaluation (Labuza, 1984).

If mold inhibitors are used, the dosage will depend on the specific chemical applied, the grain moisture content and the length of storage; wetter grain requires a high dosage. Studies conducted at the U.S. Grain Marketing Research Center (1973) have indicated that propionic acid applied at levels of 0.3 - 0.6% and 0.8 - 1.2% ensure safe storage of up to one year for corn containing approximately 22% and 43% moisture (d.b.), respectively.

The same research center also tested the relative preservative effects of potassium sorbate, sorbic acid, calcium propionate, sodium propionate, acetic acid, and propionic acid applied at 0.5% and 1% on 22, 25, and 28% moisture

(d.b.) corn. The first three chemicals were applied as powders and the rest as liquids. Samples were stored at 27°C and were considered to be mold-free if fewer than 10% of the kernels were affected. Propionic acid was the most effective mold inhibitor at both application levels, and all moistures samples remained mold-free for more than 17 weeks. Acetic acid was as effect as propionic acid at 22 and 25% moisture, but less effective at 28% moisture. At the 0.5% application level, samples treated with the dry powders remained mold-free for only one week or less at 28% moisture, 1-4 weeks at 25% and 1-7 weeks at 22% moisture. Increasing the application levels of the dry powders to 1.0% improved their effectiveness slightly at the two lower moisture contents. At 28% moisture, however, increased effectiveness was only observed with calcium propionate (10 weeks storage mold-free).

In a laboratory study, Dunkel et al. (1982) found that sorbic acid applied at levels of 0.3 and 1.0% to 28.4% moisture (d.b.) wheat samples stored at 30°C and 0.85 a_w prevented visable mold growth on 80% and 100% of the kernels, respectively. Mold growth, principally Aspergillus flavus, was observed on more than 90% of the infested kernels.

In a larger experiment, 300-kg lots of wheat (69% moisture, d.b.), were treated with 0.1 and 0.3% sorbic acid. The grain was solar-dried to 9.3% moisture (d.b.) and stored in bags for 72 days. Visible reduction of fungal growth on the sorbic acid treated wheat was less dramatic than in the laboratory test. The authors attributed this to the high initial moisture content of the wheat which chemically altered the sorbic acid molecules and to incomplete contact of the sorbic acid with the wheat kernels. The use of anti-microbial agents such as sorbic acid in isotherm research should be investigated more fully, since their effects on product a_w during storage is not known (Labuza,

1984).

This review should aid in obtaining and interpreting moisture sorption isotherms for Rwandan beans. The principal factors influencing the shape of an isotherm for a given food product are the type and composition of the food product, its initial moisture content and the temperature at which the isotherm is determined. The type of food product determines whether the isotherm will be Type I, II, or III. A type II isotherm is typical of most foods, including dry beans. The product's initial moisture content determines whether the isotherm will be a desorption, adsorption, or "working" curve. Products having fairly high initial moisture contents lose moisture during equilibration, producing desorption curves whereas those having very low initial moisture contents gain moisture during equilibration producing an adsorption curve. Products having intermediate initial moisture contents yield "working" curves. A food product having a high initial moisture content will equilibrate to a higher final moisture content than the same food product having a very low initial moisture content. This is responsible for the hysteresis phenomenon observed in moisture sorption isotherms. The largest differences between desorption and adsorption moisture contents are usually seen in the intermediate range of relative humidities; desorption and adsorption curves begin to approach each other at low and high relative humidities. The temperature at which the isotherm is determined also influences its shape. EMC usually decreases with increasing temperature.

The procedures involved in collecting isotherm data include: 1) preparation of samples for equilibration; 2) storage of samples in constant relative humidity environments; 3) determination of the equilibrium state; and 4) prevention of quality changes in samples during equilibration. Problems or

errors in any of these procedures will affect the shapes of the isotherms and prevent direct comparison of them with those determined in other studies.

The objectives of this study were: 1) to determine moisture sorption isotherms for Rwandan bean mixtures and varieties; 2) to compare these isotherms with those reported for beans and legumes in the literature; and 3) to use this information to predict the equilibrium moisture contents and, indirectly, the keeping quality of Rwandan beans during storage under normally encountered relative humidity and temperature conditions.

METHODOLOGY

I. Beans

A. Varieties

Approximately 3000 g each of two varieties (Mutiki 2, oblong, red speckled with white and Muhondo, round yellow) were grown at the ISAR Experimental Station, Rubona, during the February - May, 1985 growing season. The beans were harvested in late May, when their moisture content was judged to be approximately 18% (wet basis). The pods were removed and the beans were transported to OPROVIA in tightly closed plastic buckets. The beans were stored in these buckets in the OPROVIA laboratory at room temperature (ca 23°C) for approximately 24 hours before they were prepared for storage.

B. Mixtures

Approximately 5000 g of a typical bean mixture (Mixture 1) was purchased from a merchant in Kigali in early June, 1985. Approximately 50 kg of a

second mixture (Mixture 2) was purchased from a farmer in Ruhengeri at the same time. Only 5000 g of Mixture 2 was used for this study; the rest was used for other experiments. The mixtures were chosen primarily on the basis of their high initial moisture content, which was judged by biting to be between 17 and 18%. An attempt was also made to choose mixtures which were dissimilar in predominant varieties and seed sizes. Varietal classification of 100 seeds chosen randomly from each mixture, according to the method developed by Lamb and Hardman (1986) are found in Table 11. Varieties were not classified by shininess or size. Mixture 1 contained predominantly long (90%) monochromatic (67%) beans whereas Mixture 2 contained primarily long (42%) and round flat (44%) monochromatic (69%) beans.

C. Determination of Initial Moisture Contents

Oven-dry moisture contents of the two varieties and mixtures were determined according to AACC Method 44-15A, two stage drying procedure for grains having an initial moisture content of $\geq$ 16%. The first stage consisted of air-drying about 30 g of seed in a well-ventilated area (on top of the drying oven) for at least 24 hours to reduce the moisture content to below 15%. In the second stage, the air-dried seed was ground for 90 seconds in a micro mill (Belart Technilab 500; Cat. No. 37250, Belart Products, 61 Industrial Road, Pequannock, NJ 07440) to the consistency of a fine flour. For each variety/mixture, five replicate subsamples of this flour, each weighing 2.0000 to 3.0000 g, were placed in small aluminum drying dishes and dried in a mechanical convection oven (Blue M Stabil-Therm, Model OV-500C-2Y, Blue M Co., Blue Island, IL 60606) for one hour at 130°C. The moisture content (wet basis) was determined according to

Table 11. Varietal classification of Rwandan bean Mixtures 1 and 2

Mixture	Seed Shape[a]	Seed Coat Color Pattern[b]	Color	%
1	lo	mc	rg	50
	lo	zb	cr/n	12
	ro	tt	cr/br	10
	lo	tt	rg/cr	5
	lo	mc	jbr	5
	lo	mc	jbr	4
	lo	mc	n	4
	lo	hln	j	4
	lo	tp	cr/n	4
	lo	zb	jbr/n	4
	lo	tl	cr/pr	1
	lo	tt	pr/cr	1
2	rp	hlbr	cr	26
	rp	hlbr	br	18
	lo	zb	cr/n	15
	lo	hlbr	jbr	12
	lp	tp	cr/n	8
	lo	mc	pr	5
	lo	mc	n	5
	ro	tt	cr/n	4
	lo	mc	rg	3
	lo	tl	rg/cr	2
	ro	zb	cr/jbr	2

[a] lo = elongate, oval
ro = rounded, oval
rp = rounded, flat
lp = elongate, flat

[b] mc = single color
zb = zebra-striped
tp = flecked
tt = speckled
tl = mottled
hl- = having a hilum ring of another color

[c] n = black
br = brown
rg = red
pr = purple
cr = cream
j = yellow
jbr = yellow-brown

the formula:

$$\% \text{ moisture} = \frac{\frac{EB}{D} + C}{A} \times 100, \quad \text{where}$$

A = g of original sample before air drying

B = g of original sample remaining after air drying

C = g of original sample lost during air drying

D = g of ground subsample of the air dried sample comprising an oven dried replicate

E = g of moisture lost during drying of the oven dried replicate

The initial moisture contents of the varieties and mixtures are shown in Table 12.

II. Preparation of Beans for Equilibration

A. Desorption Isotherms

Desorption isotherms were obtained for both the varieties and the mixtures by allowing undried samples of whole beans to equilibrate under conditions of controlled relative humidity and temperature. The relative humidity environments were maintained in desiccators (Nalge # 5310, 250 mm, Fisher Scientific Co.) using five different saturated salt solutions. Table 13 lists the five salts used and the water activities produced at the temperatures used in the experiment (Greenspan, 1977). The 15°C and 30°C storage temperatures were maintained in controlled temperature incubators (Precision Model 815, Precision Scientific Group, 3737 W. Cortland Street, Chicago, IL 60647). The 23°C temperature was maintained in a closed metal cabinet in the laboratory.

Table 12. Initial moisture contents of bean varieties and mixtures

Variety/mixture	Percent moisture
Mutiki 2	24.75
Muhondo	19.25
Mixture 1	15.78
Mixture 2	20.05

Table 13. Water activities (a_w) above selected saturated salt solutions (Greenspan, 1977)

Saturated Salt Solution	15°	23°	30°
LiCl	0.11	0.11	0.11
$MgCl_2$	0.33	0.33	0.32
$Mg(NO_3)_2$	0.56	0.53	0.51
NaCl	0.76	0.75	0.75
KCl	0.86	0.84	0.84

Fifteen 150-g lots of undamaged, clean beans from each variety and mixture were weighed on an analytical balance (Sauter Model 424, Postfach 250, D-7470, Albstadt 1-Ebingen, West Germany) and mixed with 0.3% sorbic acid (Aflaban DF, 100% active sorbic acid, Monsanto Co., St. Louis, Missouri 63166). The sorbic acid was added to prevent mold growth on samples during equilibration, particularly on those stored at relative humidities $\geq$ 75% (Dunkel et al, 1982).

The sorbic acid-treated samples were wrapped individually in nylon mesh or cheese cloth packets and placed in the desiccators. Samples were weighed at weekly intervals until the weight change was $\leq$ 2 mg/g of dry weight, indicating that the samples had reached equilibrium (Labuza, 1984).

B. Adsorption Isotherms

Adsorption isotherms were obtained for the two mixtures only. Approximately 3000 g of each mixture was dried to approximately the moisture content corresponding to the lowest a_w level used in the experiment. In this case, the lowest a_w used was approximately 0.11 which has been reported to correspond to an equilibrium moisture content in dry beans of approximately 6% (wet basis) at 25°C (Weston and Morris, 1954). Each 3000 g lot of beans was divided into smaller-sized portions, spread out in thin layers on metal trays and dried in the mechanical convection oven. Mixture 1 was dried for approximately 192 hours at 40°C, and then for an additional 48 hours at 45°C after which time the moisture content was 6.86%. Mixture 2 was dried at 45°C to a moisture content of 7.78% for approximately 96 hours. Drying was discontinued at these moisture contents due to time constraints.

After drying, the beans from each mixture were cooled briefly at room

temperature; then each mixture was allowed to cool in a tightly covered plastic container until the next day. The beans were then weighed out into fifteen 150-g lots and placed in the respective desiccators as described above. Sorbic acid (0.3%) was mixed with samples stored at water activities $\geq$ 0.75%. Samples were weighed at weekly intervals until equilibrium was reached.

III. Determination of Equilibrium Moisture Contents

As samples reached equilibrium, their moisture contents were determined according to AACC Method 44-15A. The one stage drying procedure with sample grinding was used for samples having equilibrium moisture contents < 16%. The two stage drying procedure with sample grinding during the second stage was used for samples having an EMC $\geq$ 16%.

After the moisture contents of approximately two-thirds of the samples (about 60) had been determined, we began to notice unacceptable variance in moisture contents between replicates of the same sample, sometimes in the order of 1% moisture or more. Discrepancies were more prevalent in the most recently processed samples. At the same time, we noted that the micro mill bearing assembly was showing wear, and associated the moisture content discrepancies with overheating of the mill during grinding. All further moisture content determinations were temporarily suspended pending the arrival of replacement parts for the mill.

When, after approximately 20 weeks storage, localized mold growth began to develop on five samples at all three temperatures and $a_w \geq 0.75$ before they had reached equilibrium, their moisture contents were determined by the whole bean method (AACC Method 44-15A for corn and beans, at 103°C) before the

mold growth became too widespread. For each sample, three replicates of about 10 g each were dried for 72 hours. Moisture content was determined according to the formula.

$$\% \text{ moisture} = \frac{\text{loss in weight during drying}}{\text{wet weight of sample}} \times 100$$

Since the replacement parts for the mill had not arrived after approximately three more weeks, and all of the remaining samples had then reached equilibrium, moisture contents were determined for all the samples using the whole bean method described above. In the cases where one of the replicates deviated from the others by ± 0.2% moisture, it was not used in the determination of the mean.

IV. Moisture Sorption Isotherms

For each adsorption or desorption isotherm, mean equilibrium moisture contents (wet basis) were plotted against storage a_w at each of the three storage temperatures. The isotherms were then examined for differences on the basis of variety versus mixtures, adsorption versus desorption, and temperature.

The equilibrium moisture content data were also fit to the following equation referred to as the modified Henderson equation (Pfost, 1981).

$$M = \left[\frac{\ln (1 - RH)}{-k (T + C)}\right]^{\frac{1}{n}}$$

where:

M	=	grain moisture content, percent d.b.
RH	=	water activity (relative humidity, decimal)
T	=	temperature, °C
k,n,c	=	parameters for the equation

Nonlinear regression techniques were used to find the parameters k, n, c for the six data sets -- four desorption tests and two adsorption tests.

RESULTS AND DISCUSSION

I. Equilibration Time/Rate

Desorption samples generally took from 9 to 13 weeks to equilibrate. Samples held at the lower water activities and temperatures usually took the longest to equilibrate. Adsorption samples generally took from 6 to 17 weeks to equilibrate. Samples held at the higher water activities and lower temperatures usually took the longest to equilibrate.

Differences in amounts of moisture lost and gained were observed between samples particularly after the first two weeks of storage (Tables 14 and 15). Differences seemed to be related to the initial moisture content of the sample and to storage a_w and temperature. The farther away the original samples were from equilibration with the storage conditions, the more moisture they gained or lost during the initial two weeks of storage. The desorption sample having the highest initial moisture content, Mutiki 2, lost the most moisture of the four samples at all a_ws and temperatures. The desorption sample having the lowest initial moisture content, Mixture 1, lost the least moisture of the four samples at all a_ws and temperatures. (Due to this mixture's relatively low initial moisture content, samples stored at the higher water activities adsorbed moisture to reach equilibrium. This was also true of some of the Muhondo samples at the same a_ws and temperatures.)

Within each mixture and variety, the amount of moisture lost increased with decreasing relative humidity at a given temperature, and increased with temperature at a given RH. As samples approached equilibrium, amounts of moisture lost decreased and differences between samples were less obvious.

Table 14. Comparison of amounts of moisture lost by desorption after two weeks storage

Approx. Storage a_w	Moisture Loss (g)											
	Mixture 1. Initial moisture = 15.8% (w.b.)			Mixture 2. Initial moisture = 20.1% (w.b.)			Mutiki 2. Initial moisture = 24.8% (w.b)			Muhondo. Initial moisture = 19.3% (w.b.)		
	15°	23°	30°	15°	23°	30°	15°	23°	30°	15°	23°	30°
0.11	10.17	13.08	14.93	15.76	18.51	20.64	22.32	25.16	27.15	11.38	14.62	16.76
0.33	7.14	9.55	11.68	13.09	15.48	17.90	18.94	22.00	23.21	8.54	11.23	13.57
0.55	2.47	5.03	6.40	11.06	11.76	14.16	14.29	17.76	20.37	4.99	7.66	9.83
0.75	+0.98[a]	+2.21	+1.54	3.69	4.92	6.95	7.85	9.96	11.74	+0.05	1.12	2.18
0.84	+8.09	+5.75	+5.97	1.95	2.19	3.83	3.25	6.89	7.99	+4.03	+1.65	+1.24

[a] + signs indicate that moisture was gained by those samples during storage

Table 15. Comparison of amounts of moisture gained by adsorption samples after two weeks storage

Approx. Storage a_w	Mixture 1. Initial moisture = 6.9% (w.b.)			Mixture 2. Initial moisture = 7.8% (w.b.)		
	15°	23°	30°	15°	23°	30°
0.11	1.40	0.48	-0.32[a]	-0.05	-1.08	-2.27
0.33	2.26	2.50	2.34	1.91	1.49	0.91
0.55	3.75	4.23	4.74	5.28	4.53	4.28
0.75	5.30	7.26	10.51	5.80	7.80	9.50
0.84	8.53	7.98	11.77	8.82	9.82	12.03

[a] - signs indicate that moisture was lost by those samples during storage

Differences in amounts of moisture gained in adsorption samples between mixtures 1 and 2 were generally smaller than the differences in amounts of moisture lost in desorption samples. This is probably due to some extent to the similarity in initial moisture contents of the two mixtures. (Due to the fairly high initial moisture of both mixtures, 6.9% and 7.9% w.b., respectively, some samples stored at a_w = about 0.11 lost moisture to reach equilibrium.) Within each mixture, amounts of moisture gained decreased with decreasing relative humidity, and generally increased with temperature at a given relative humidity. As samples approached equilibrium, amounts of moisture gained decreased.

Equilibration times for dry beans reported in other studies vary from two weeks to more than 20 weeks, and likely depend on the equilibrium method and sample size in addition to sample moisture and storage relative humidity and temperature conditions (Dexter et al., 1955; Morris et al., 1950; Weston and Morris, 1984; McCurdy et al., 1980; Hutchinson and Otten, 1984; Denloye and Ade-John, 1985). The increase in equilibration time with decreasing temperature has also been observed by other researchers (Dexter et al. 1955 and Hutchinson and Otten 1984).

Differences in amounts of moisture lost or gained with changes in a_w have been reported for dry beans (Morris et al., 1950; Dexter et al., 1955) which confirm the results reported in the present study. Morris observed that the rate of change in moisture content of Michigan Michelite beans stored at 25°C (16.3% initial moisture, d.b.) was proportional to RH at values of 70% and above, and inversely proportional to RH at values of 60% and below. Dexter noted both temperature and relative humidity dependent differences in rates of moisture change in pea beans. For low initial moisture samples, rates of moisture change increased with temperature and storage RH. For high initial

moisture samples, rates of moisture change increased with temperature and decreased with storage RH.

Weston and Morris (1954) reported differences in rates of moisture change between seven varieties of dry beans which they related to varietal differences in the rate of water entry through bean micropiles and seedcoats. Light and dark red kidney beans, both of which had fairly low initial moisture contents, also had particularly high rates of moisture uptake at high relative humidities compared to the other varieties. While rates of moisture change are likely variety-related to some extent, neither Weston and Morris' results nor the results of this study show this conclusively due to the differences in initial moisture of the samples tested.

It seems clear from the results outlined above that initial moisture content, storage RH and temperature influence rates of moisture change of dry beans under laboratory conditions. These factors are also important in large scale storage. However, in large scale storage, equilibration time will also be influenced to a large extent by the kind of exposure the beans have to the environment. Under normal warehouse conditions in Rwanda, 90-100 kg woven jute or woven polyethylene bags of beans are stacked in large piles or pallets. Storage temperature and RH vary according to season and to region, but are usually in the range of 15-25°C and 60-70% RH (unpublished data, Alternative Storage Methods Component). Temperatures as high as 30°C have been measured in some warehouses during the day. Moisture equilibration at the interior of these large piles, where there is normally little air circulation, will take much longer than at the exterior of the pile where the beans are directly exposed to the atmosphere. If the beans are at a high enough moisture content to favor mold growth, discoloration, and other quality changes, and storage temperatures

also favor these changes, prolonged storage could result in significant quality loss.

II. Quality Changes

Localized patches of mold were first observed after 13 weeks storage in Mixture 1 adsorption samples at 15 and 30°C and a_w = about 0.84. The mold was initially noted on the outside of the nylon mesh bags containing the samples, and may have resulted from inadvertent contact with moisture on the inside of the desiccator. The equilibrium moisture contents of these samples were determined before equilibrium was reached; it was feared that further mold growth would affect the final moisture content determination. For all samples where localized mold growth was observed, moisture content determinations were made on undamaged seeds. Other adsorption and desorption samples stored under the same conditions later became contaminated as well as some samples stored at all three temperatures and a_w = about 0.75. These samples had already reached equilibrium.

Beans stored at all three temperatures and water activities 0.75 and 0.85 developed off-odors and colors during storage. The samples began to smell rancid and musty and to darken in color as early as four weeks into the storage period in the highest water activity/temperature treatment.

The development of quality changes on beans stored at higher temperatures and water activities in this study confirm results of other isotherm studies (Morris et al., 1950; Dexter et al., 1955; McCurdy et al., 1980; Hutchinson and Otten, 1984). The storage times before mold growth was noted in these studies were generally shorter than in the present study. Treatment of samples with sorbic acid likely slowed down the onset of mold growth to some extent.

III. Isotherms

Desorption and adsorption equilibrium moisture contents of the mixtures and varieties are shown in Table 16. Moisture sorption isotherms determined from the EMC's are shown in Figures 7 to 28*. Moisture sorption isotherms predicted from the equilibrium moisture content data according to the modified Henderson equation (Pfost, 1981) are shown in Figures 29 to 40. In the latter set of figures, the fitted results (isotherms) are presented as lines and the experimental data points as symbols.

A. Adsorption Isotherms - Mixtures 1 and 2

Adsorption data was obtained for water activities $\geq$ 0.3244 in Mixture 1, and for water activities $\geq$ 0.5140 in Mixture 2 (Table 16). As mentioned earlier, since the initial moisture contents of both mixtures were fairly high, samples stored at lower relative humidities lost moisture during equilibration. The relatively high initial moisture of both mixtures was due to the method used to prepare samples for storage (drying at 40-45°C in a forced air oven). Increasing drying time beyond a certain point did not significantly reduce bean moisture content. The beans had apparently reached moisture contents in approximate equilibrium with the relative humidity/temperature conditions in the oven.

*N.B. Water activity values in Figures 7 to 28 are plotted incorrectly: values should differ slightly at each temperature. Refer to Table 16 for correct values.

Table 16. Desorption and desorption equilibrium moisture contents (%, wet basis) of Rwandan bean mixtures and varieties at three temperatures and five water activity levels.[a]

Beans	Storage a_w	Adsorption EMC (%, w.b.) 15°	23°	30°	Desorption EMC (%, w.b.) 15°	23°	30°
Mixture 1	0.11	4.73	4.40	4.55	5.43	4.78	4.66
	0.33-0.32	7.38	7.35	8.15	8.57	8.03	7.62
	0.56-0.51	10.98	10.16	9.45	11.93	10.81	9.90
	0.76-0.75	15.21	14.97	15.91	16.43	15.93	15.96
	0.86-0.84	22.47	19.30	18.32	22.43	19.27	18.39
Mixture 2	0.11	5.00	4.64	4.84	5.62	5.04	4.97
	0.33-0.32	7.83	7.69	7.64	8.69	8.28	7.98
	0.56-0.51	11.38	10.58	9.81	12.39	11.17	10.26
	0.76-0.75	16.27	15.86	16.13	17.04	16.25	16.54
	0.86-0.84	22.70	19.59	18.82	22.69	19.88	18.64
Mutiki 2	0.11				5.54	4.66	4.50
	0.33-0.32				9.25	8.00	7.60
	0.56-0.51				12.10	10.78	9.86
	0.76-0.75				16.86	16.15	16.17
	0.86-0.84				23.17	19.66	19.90
Muhondo	0.11				5.38	4.43	4.26
	0.33-0.32				8.37	7.87	7.43
	0.56-0.51				11.79	10.65	9.71
	0.76-0.75				16.21	15.57	15.63
	0.86-0.84				22.29	19.03	18.09

[a] In the adsorption columns, values above lines (_____) are actually desorption values
and in desorption columns, values below lines (_____) are actually adsorption values.

Figure 17. Adsorption moisture sorption isotherms for Mixture 1 at three temperatures

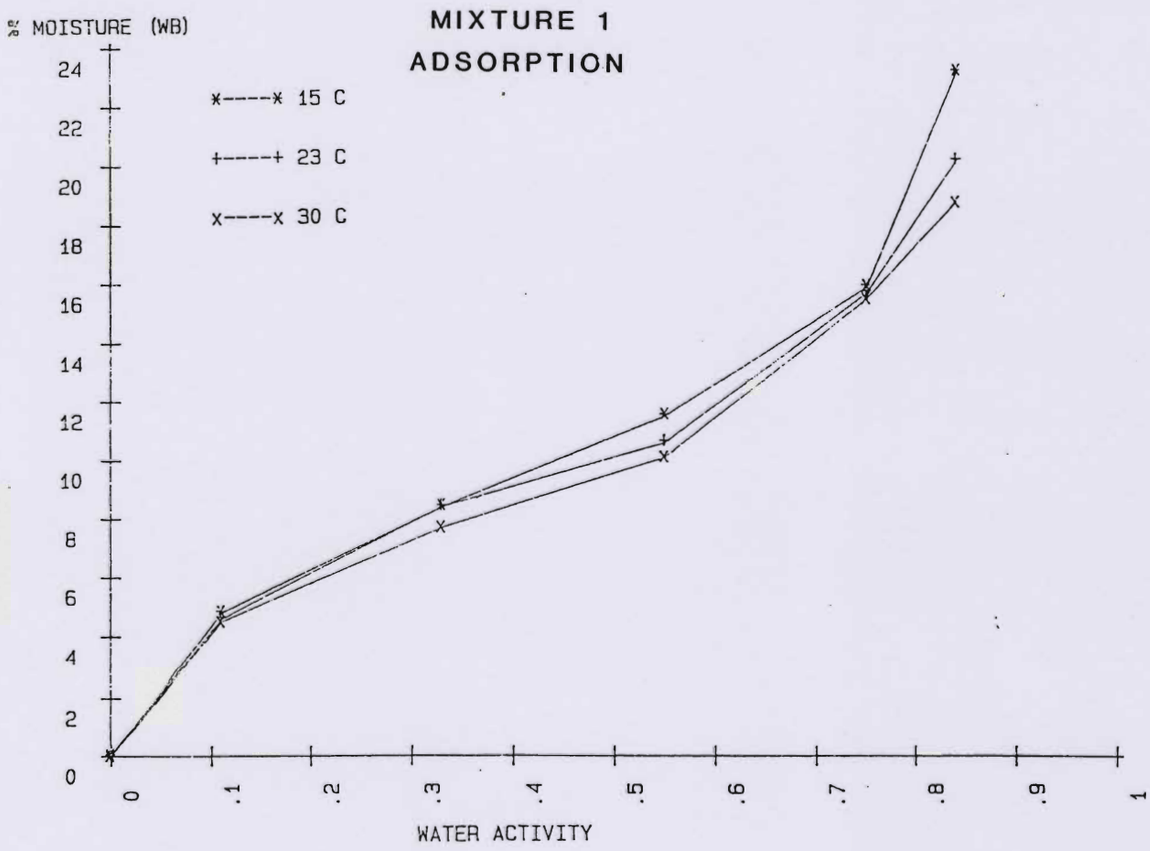


Figure 18. Adsorption moisture sorption isotherms for Mixture 2 at three temperatures

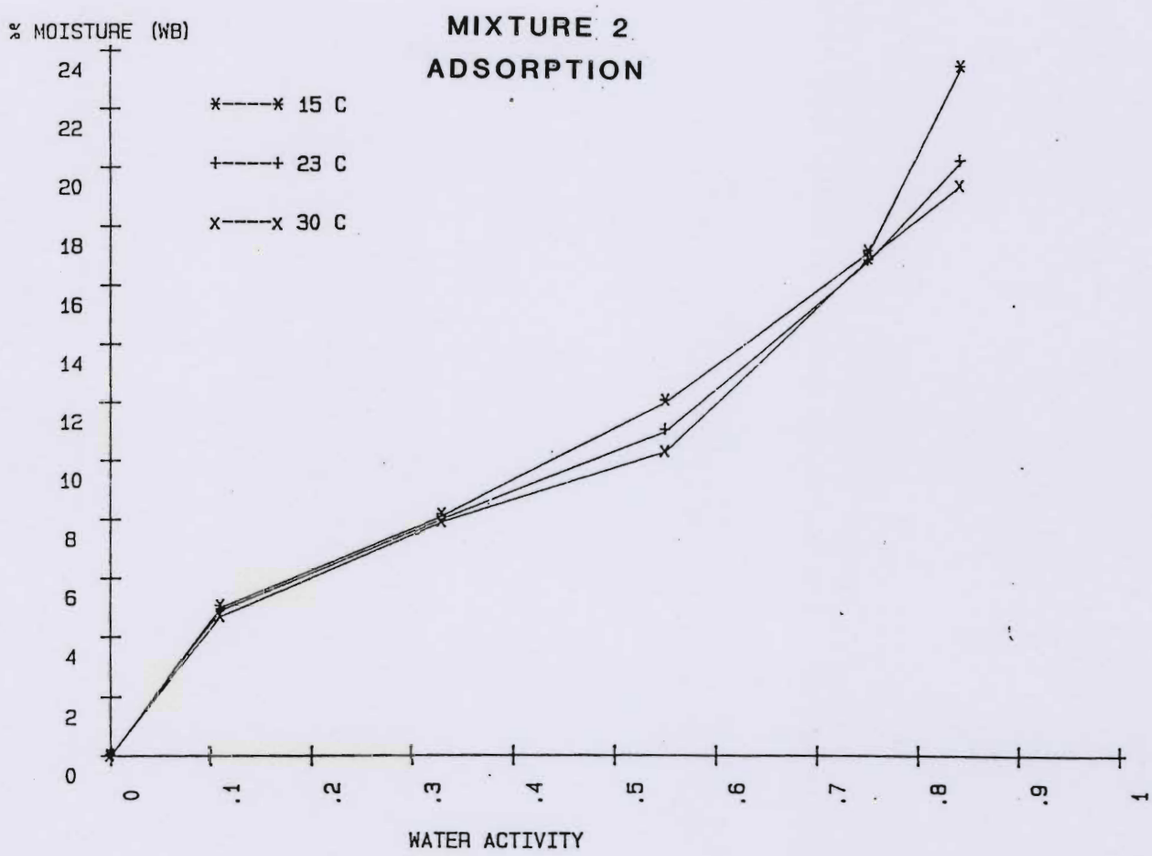


Figure 19. Desorption moisture sorption isotherms for Mixture 1 at three temperatures

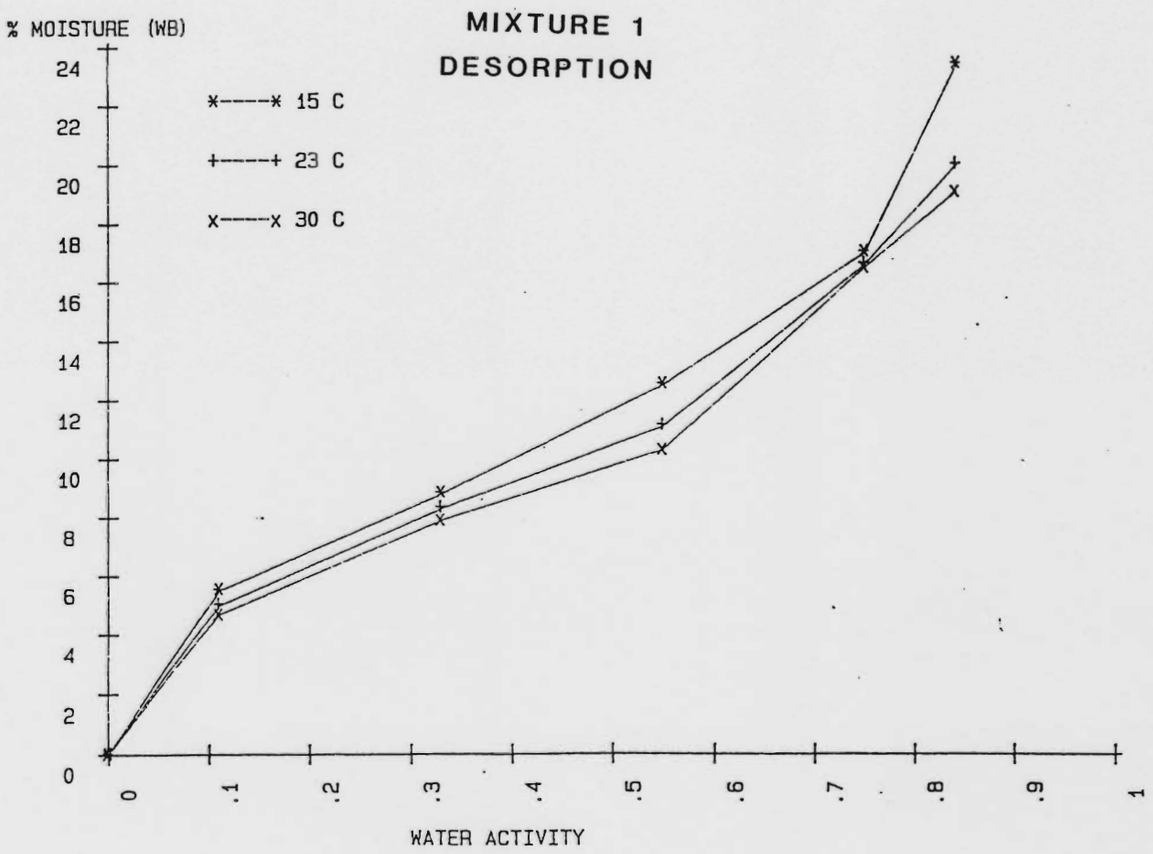


Figure 20. Desorption moisture sorption isotherms for Mixture 2 at three temperatures

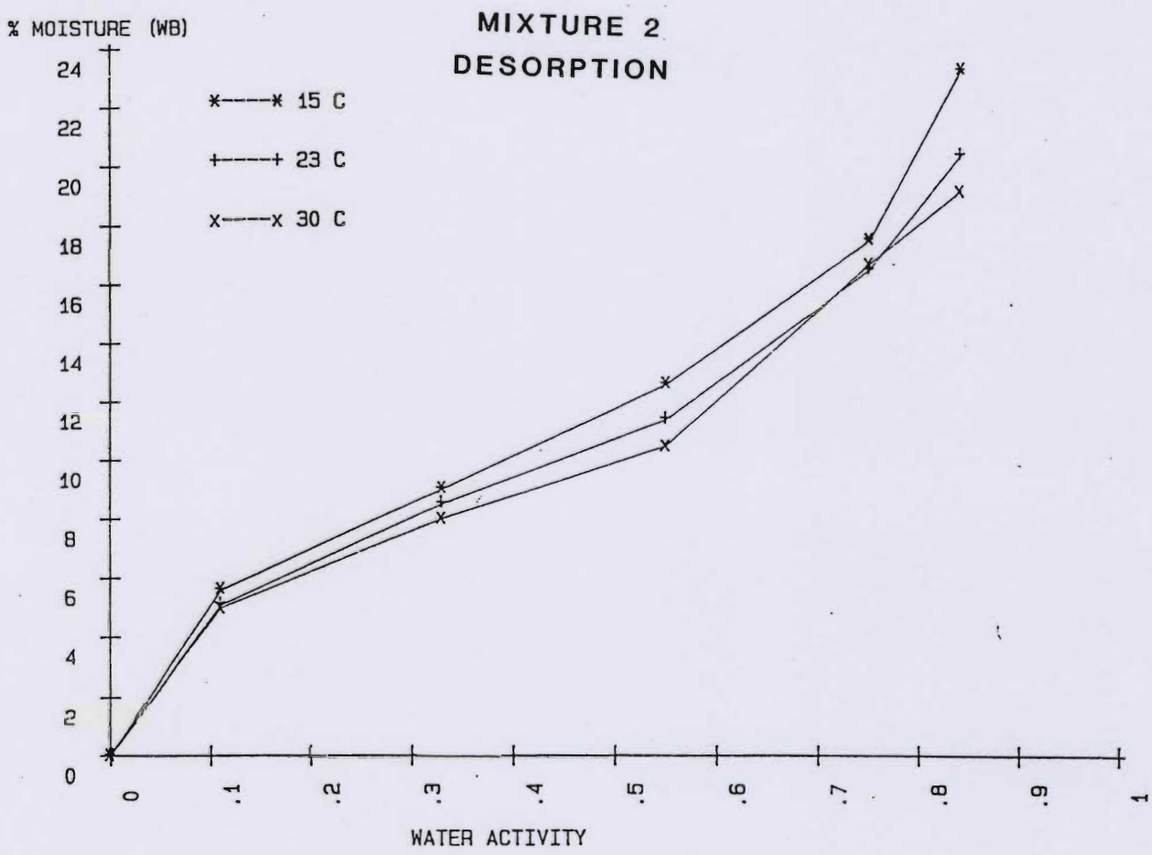


Figure 21. Desorption moisture sorption isotherms for variety Mutiki 2 at three temperatures

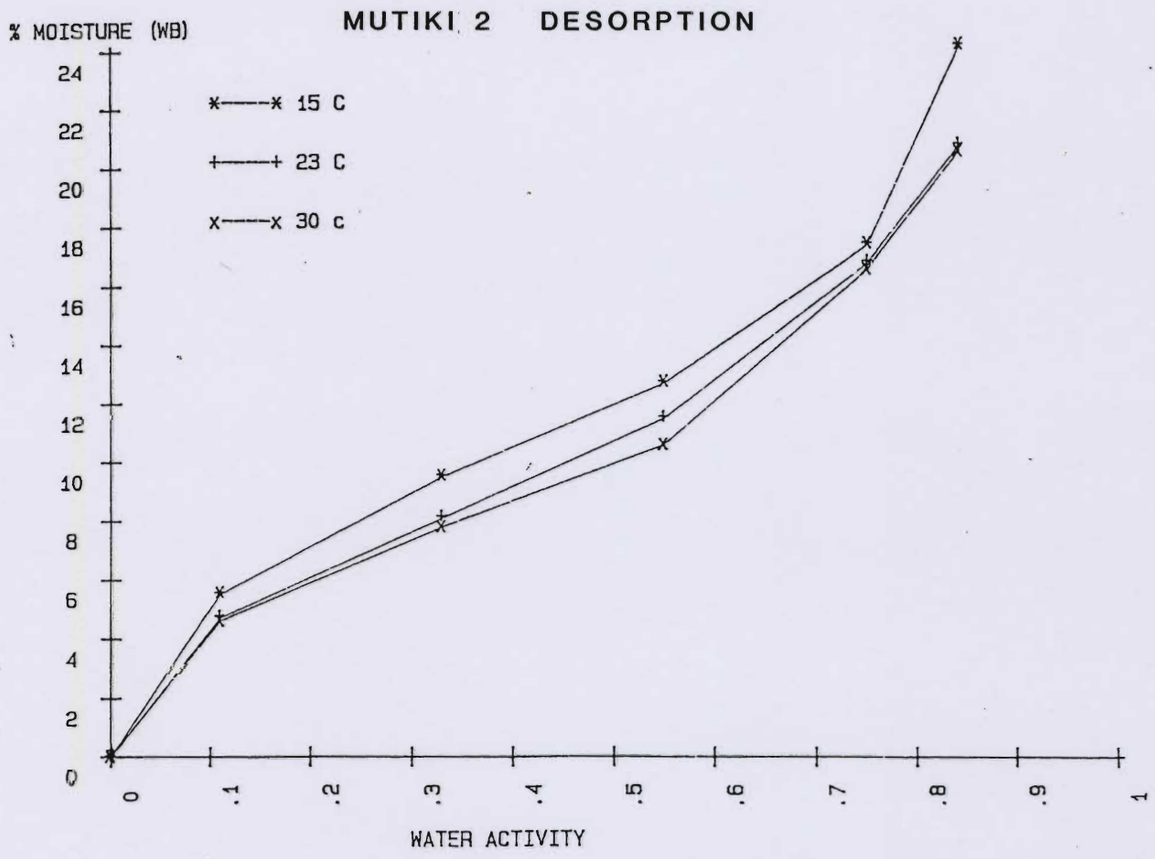


Figure 22. Desorption moisture sorption isotherms for Muhondo variety at three temperatures

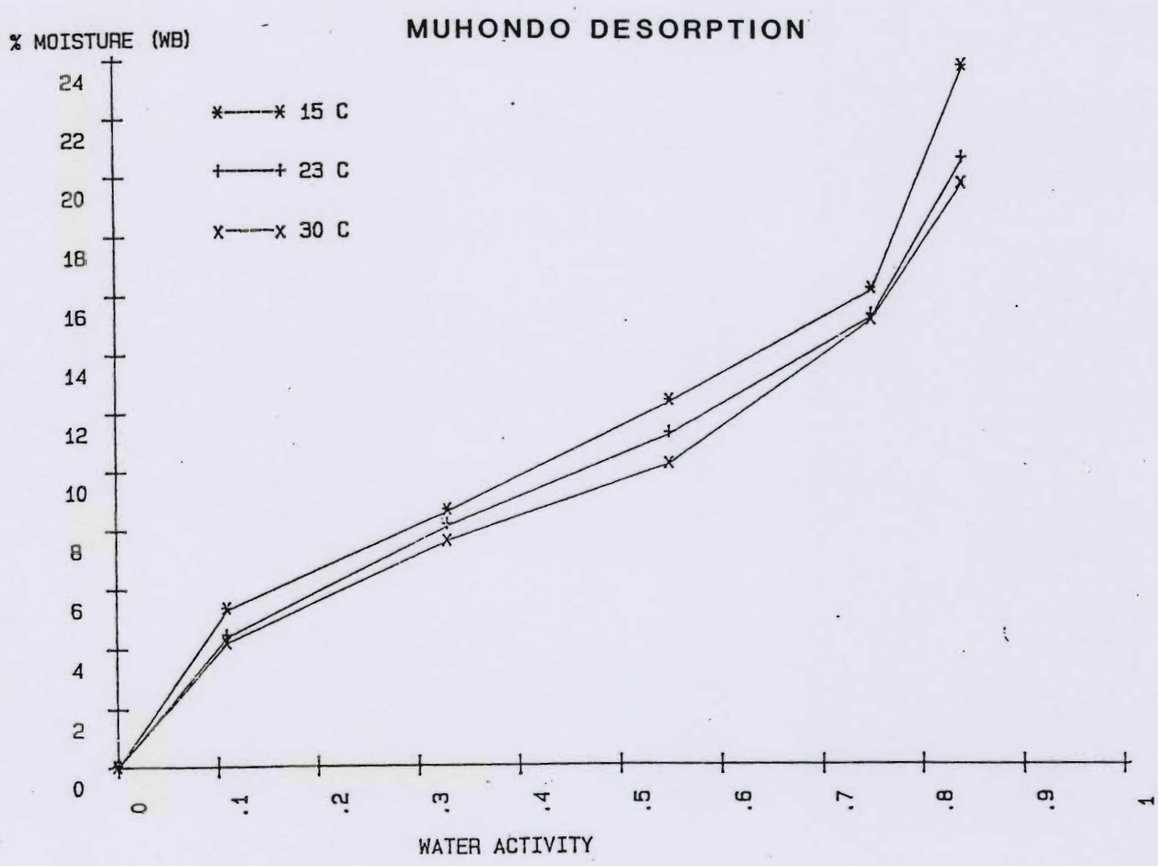


Figure 23. Comparison of desorption and adsorption moisture sorption isotherms for Mixture 1 at 15°C

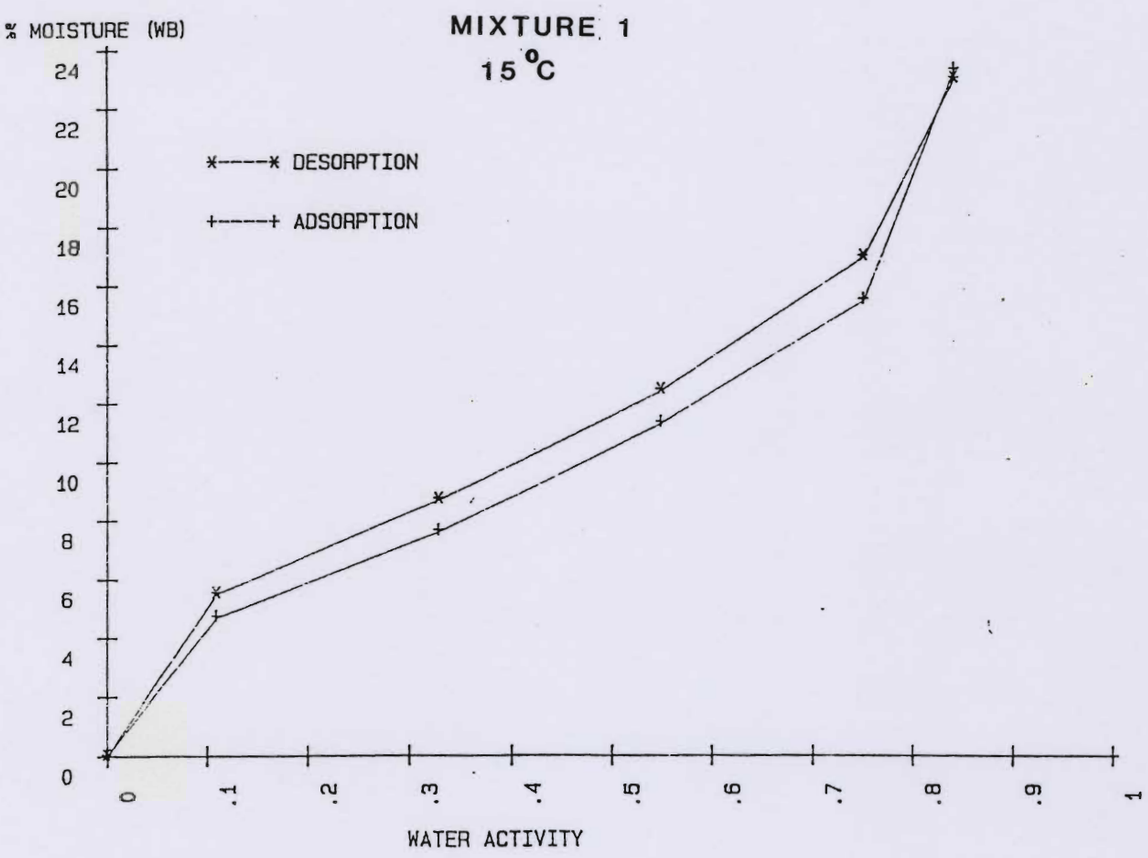


Figure 24. Comparison of desorption and adsorption moisture sorption isotherms for Mixture 1 at 23°C

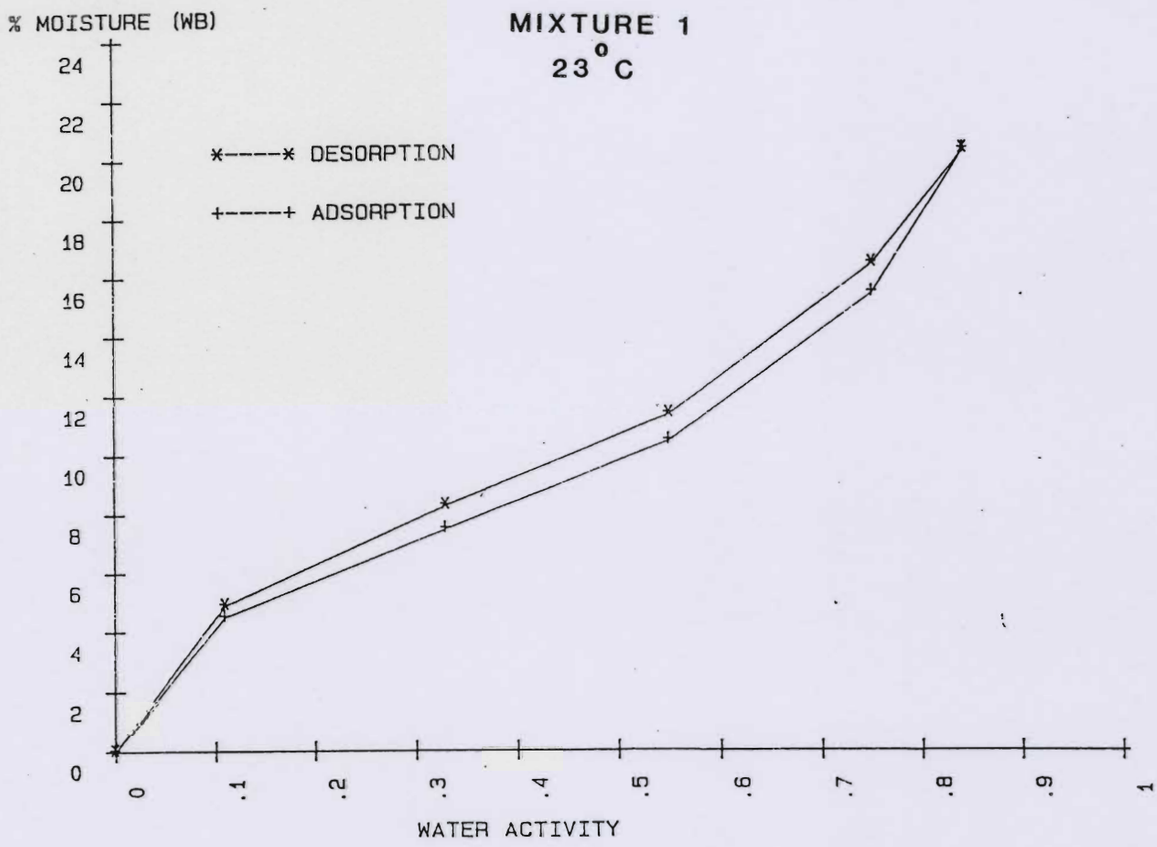


Figure 25. Comparison of desorption and adsorption moisture sorption isotherms for Mixture 1 at 30°C

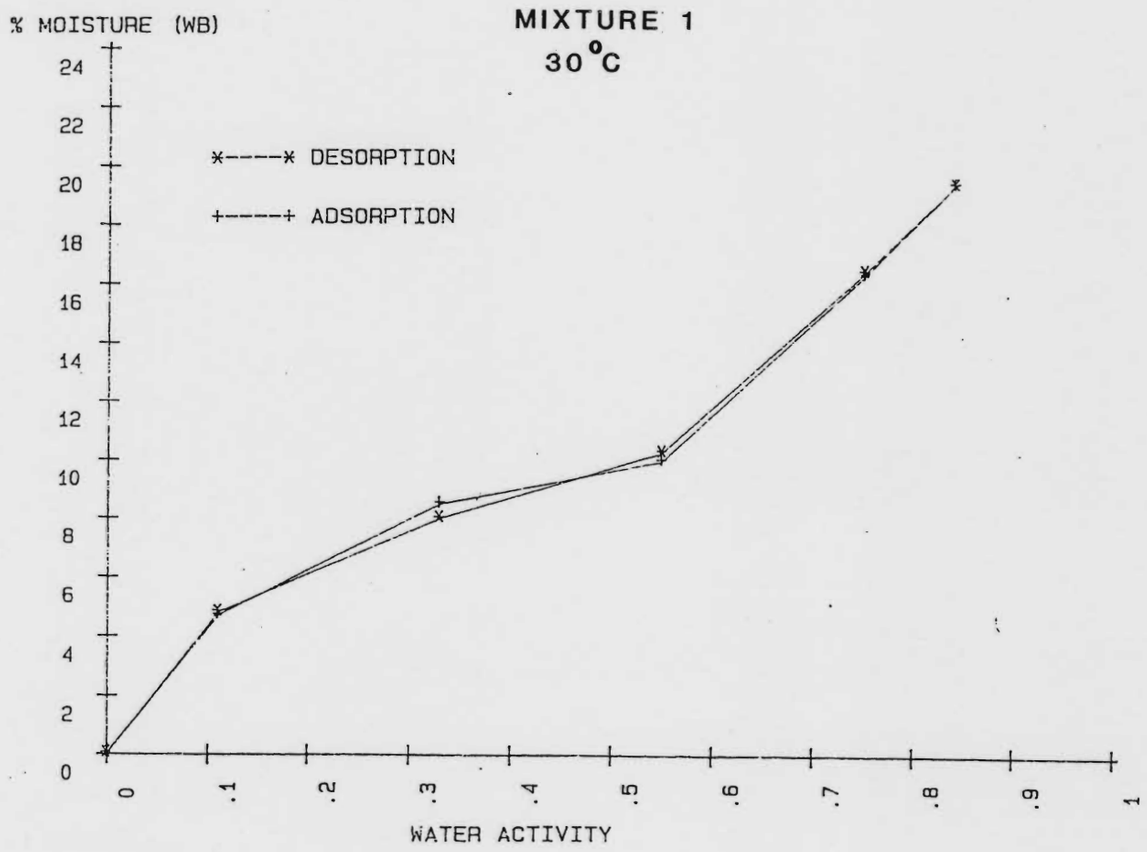


Figure 26. Comparison of desorption and adsorption moisture sorption isotherms for Mixture 2 at 15°C

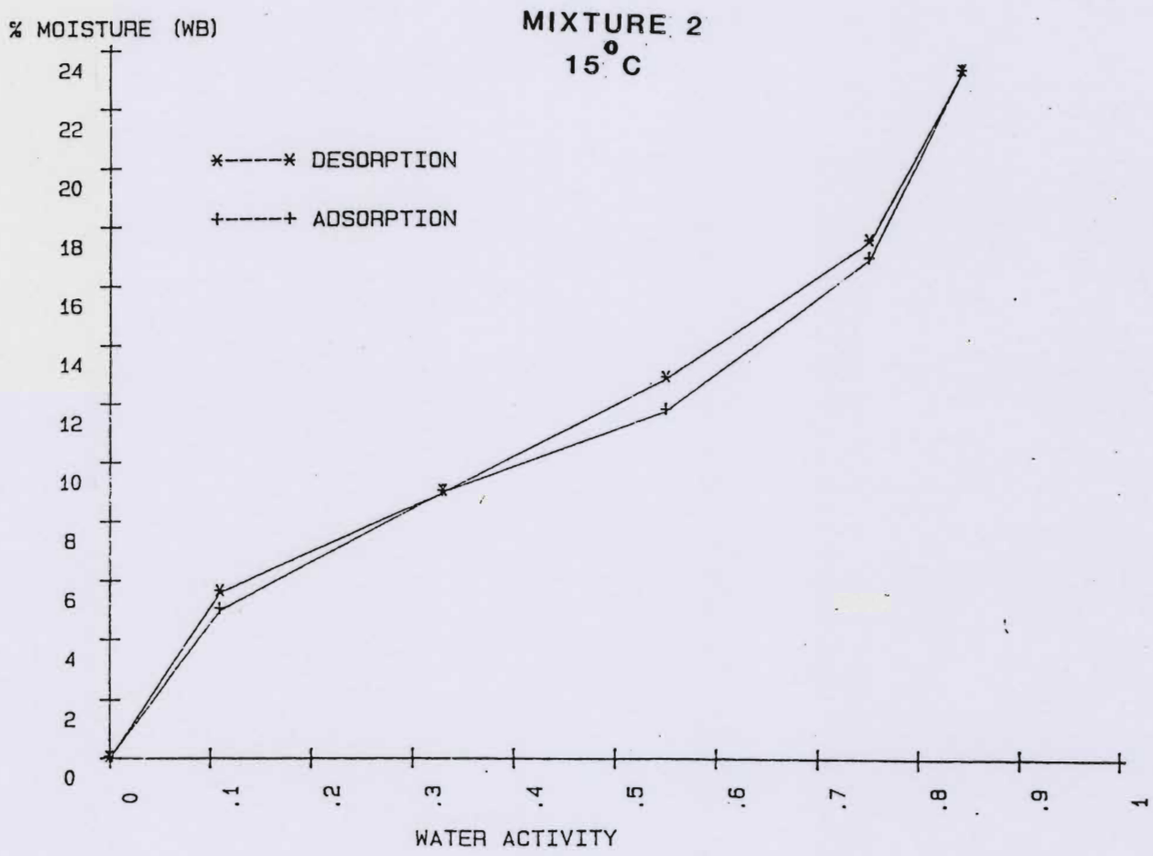


Figure 27. Comparison of desorption and adsorption moisture sorption isotherms for Mixture 2 at 23°C

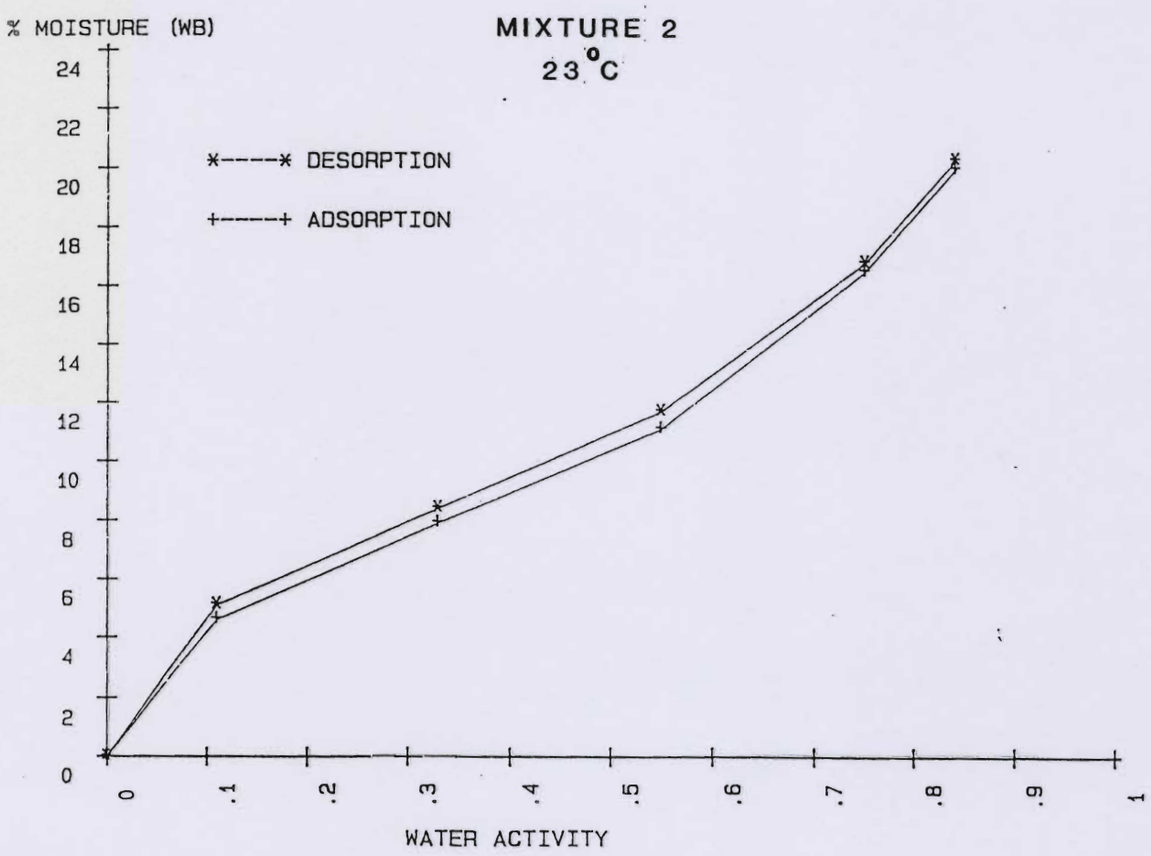


Figure 28. Comparison of desorption and adsorption moisture sorption isotherms for Mixture 2 at 30°C

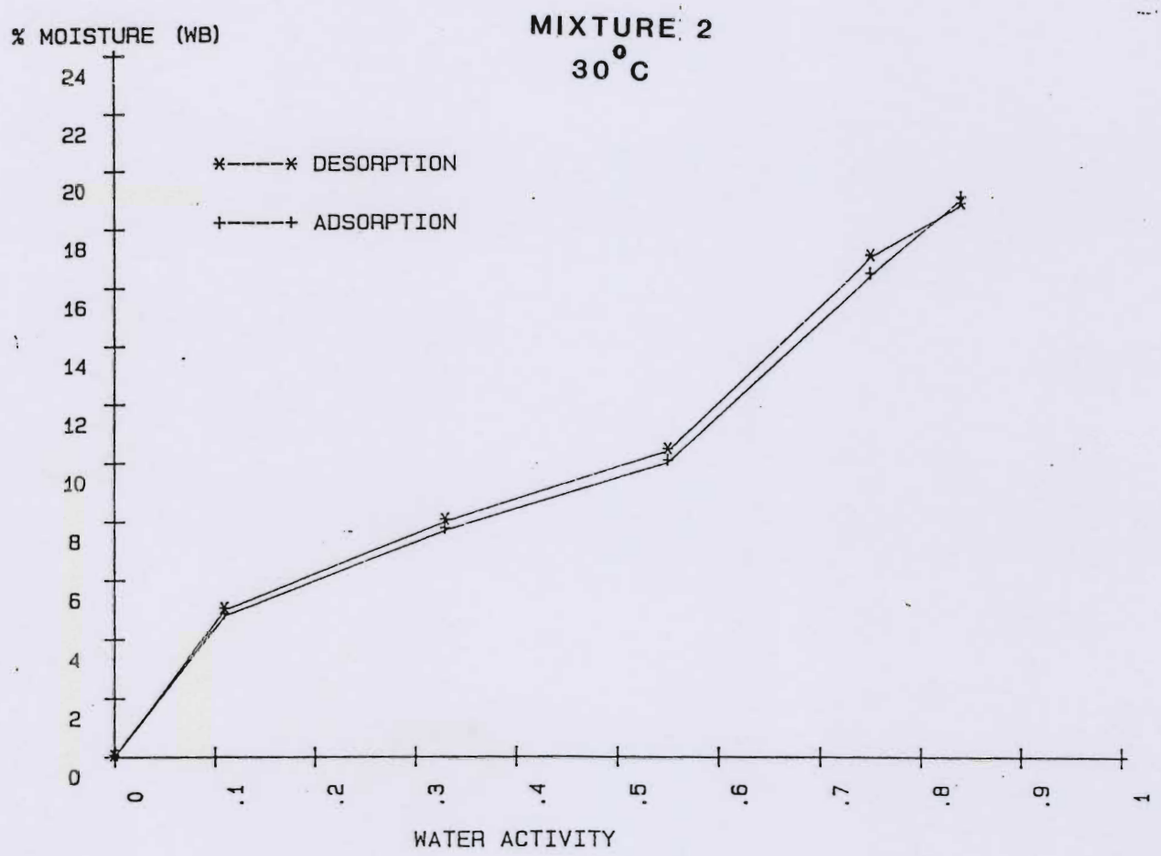


Figure 29. Adsorption equilibrium moisture isotherms predicted by modified Henderson equation at 15, 23, and 30°C for Mixture 1

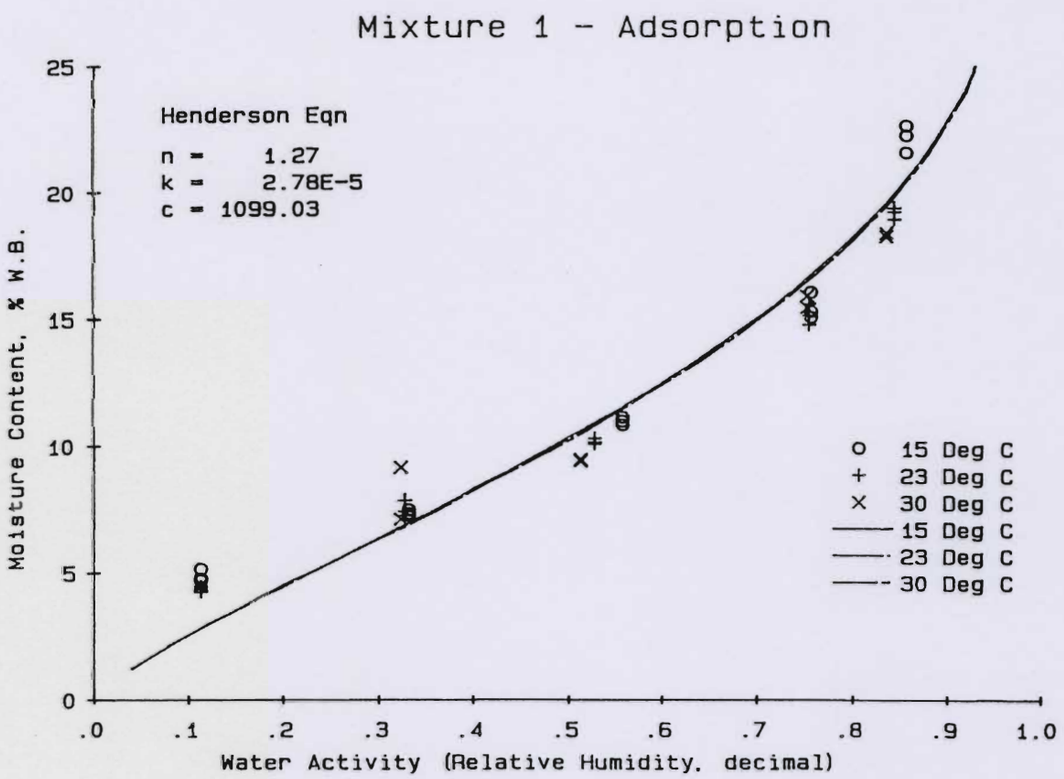


Figure 30. Adsorption equilibrium moisture isotherms predicted by modified Henderson equation at 15, 23, and 30°C for Mixture 2

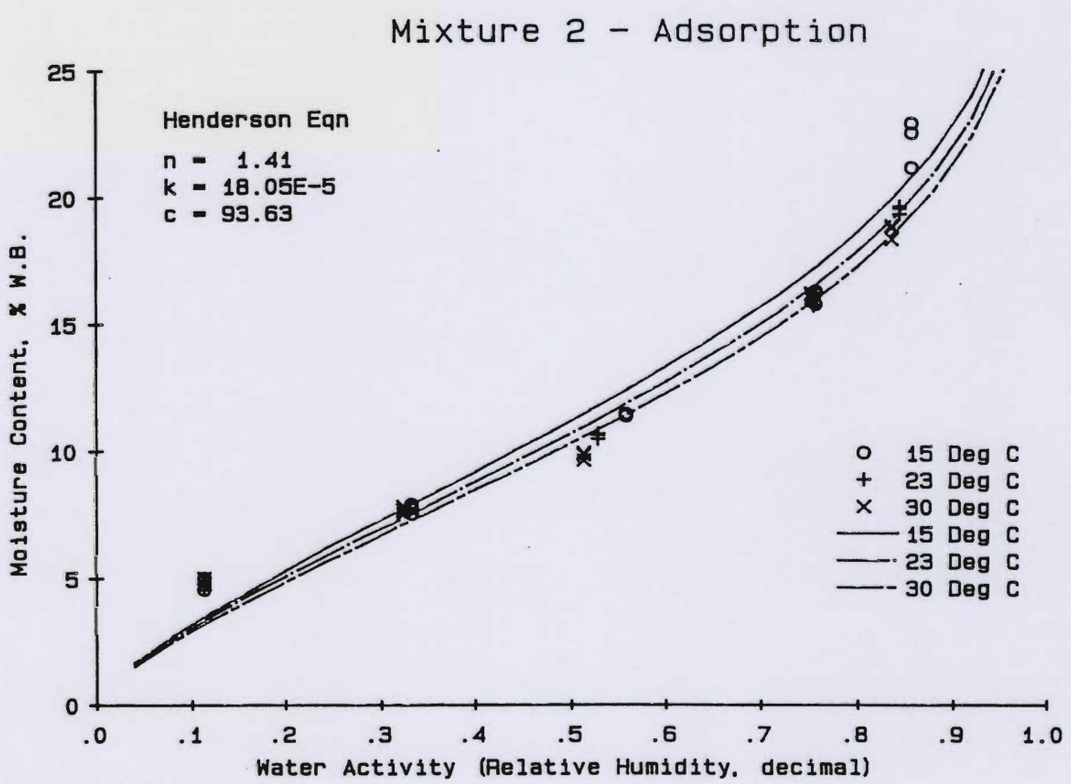


Figure 31. Adsorption equilibrium moisture isotherm predicted by modified Henderson equation at 15, 23, and 30°C for Mixture 1 with observations at $a_w > 0.8$ removed

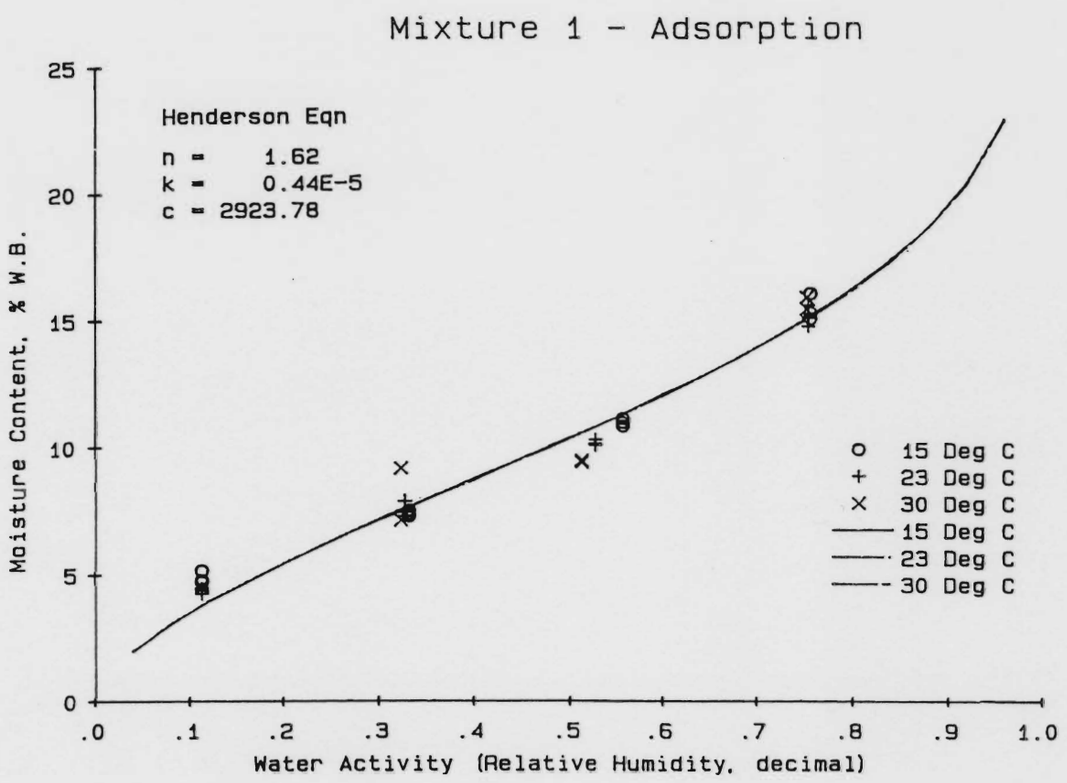


Figure 32. Adsorption equilibrium moisture isotherm predicted by modified Henderson equation at 15, 23, and 30°C for Mixture 2 with observations at $a_w > 0.8$ removed.

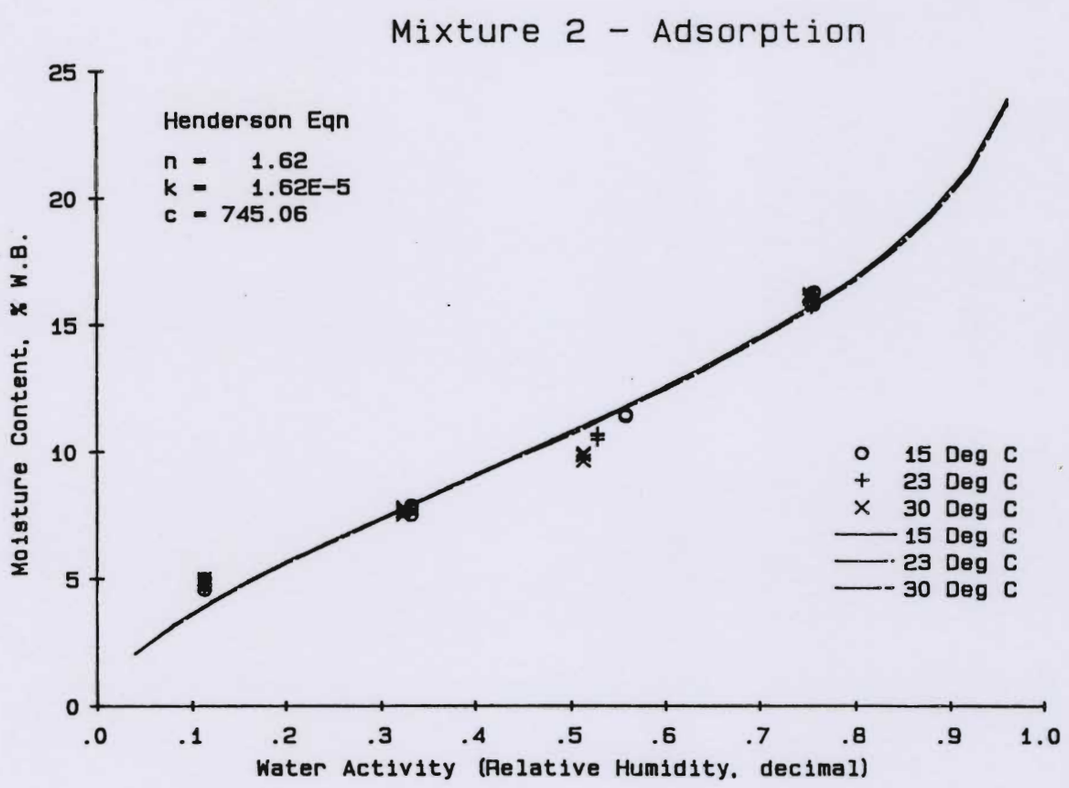


Figure 33. Desorption equilibrium moisture isotherms predicted by modified Henderson equation at 15, 23, and 30°C for Mixture 1

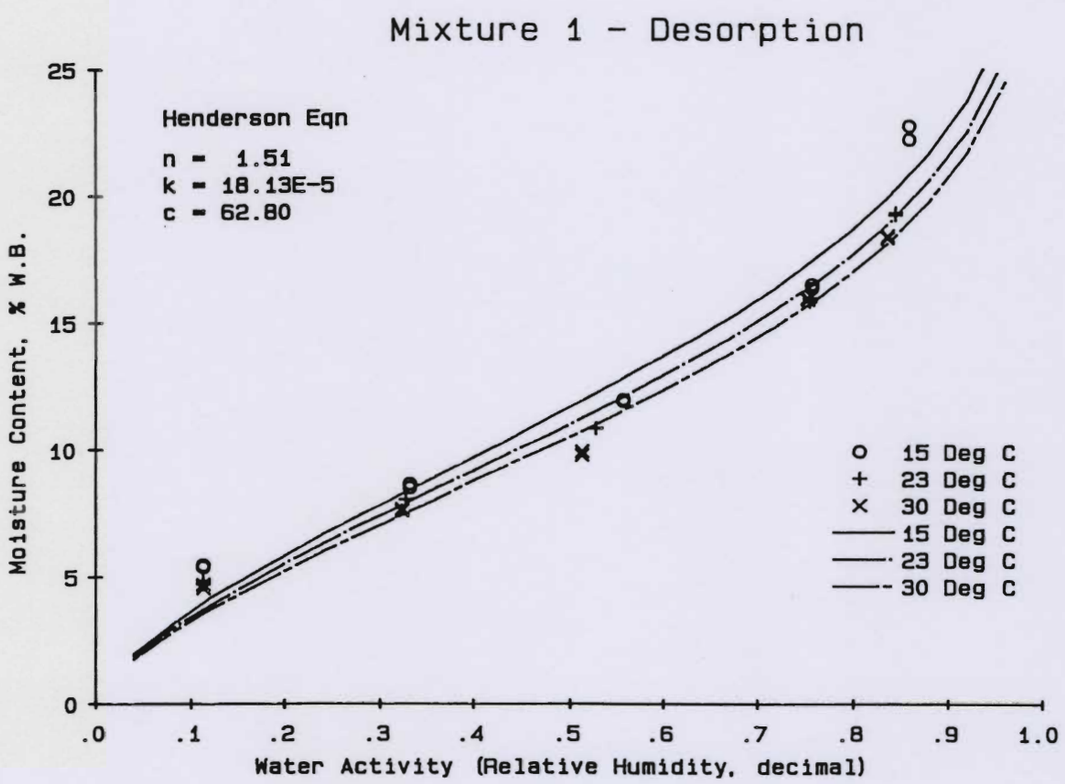


Figure 34. Desorption equilibrium moisture isotherms predicted by modified Henderson equation at 15, 23, and 30°C for Mixture 1 with observations at $a_w > 0.8$ removed

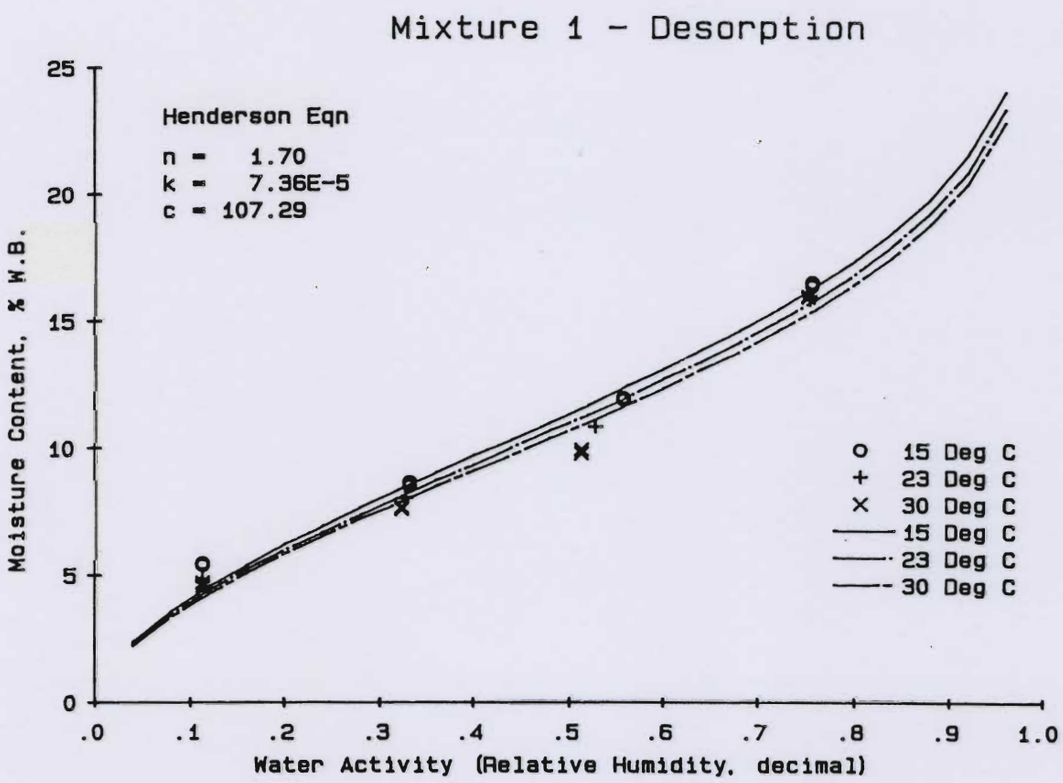


Figure 35. Desorption equilibrium moisture isotherms predicted by modified Henderson equation at 15, 23, and 30°C for Mixture 2

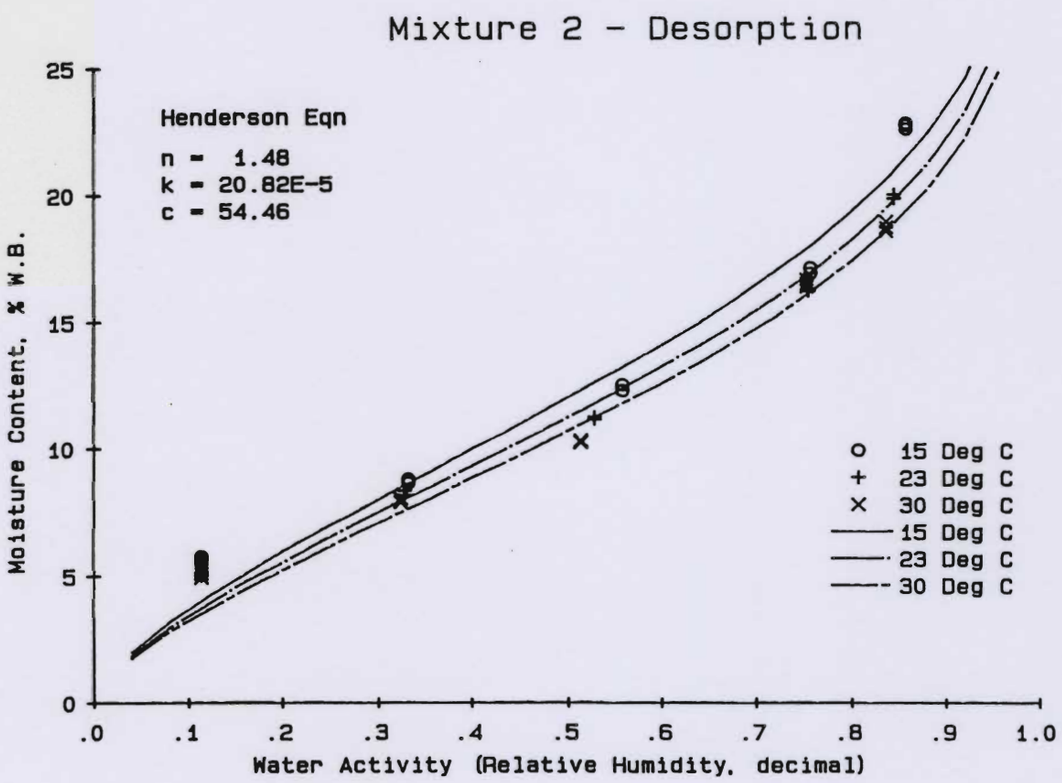


Figure 36. Desorption equilibrium moisture isotherms predicted by modified Henderson equation at 15, 23, and 30°C for Mixture 2 with observations at > 0.8 removed

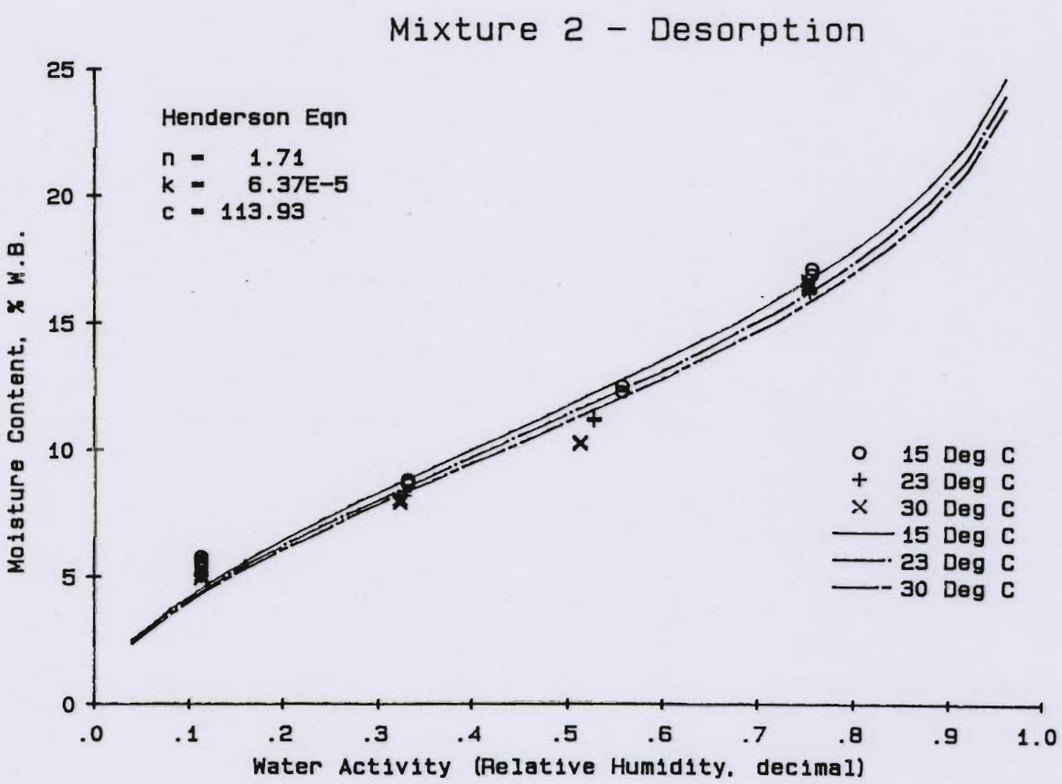


Figure 37. Desorption equilibrium moisture isotherms predicted by modified Henderson equation at 15, 23, and 30°C for Mutiki 2 variety

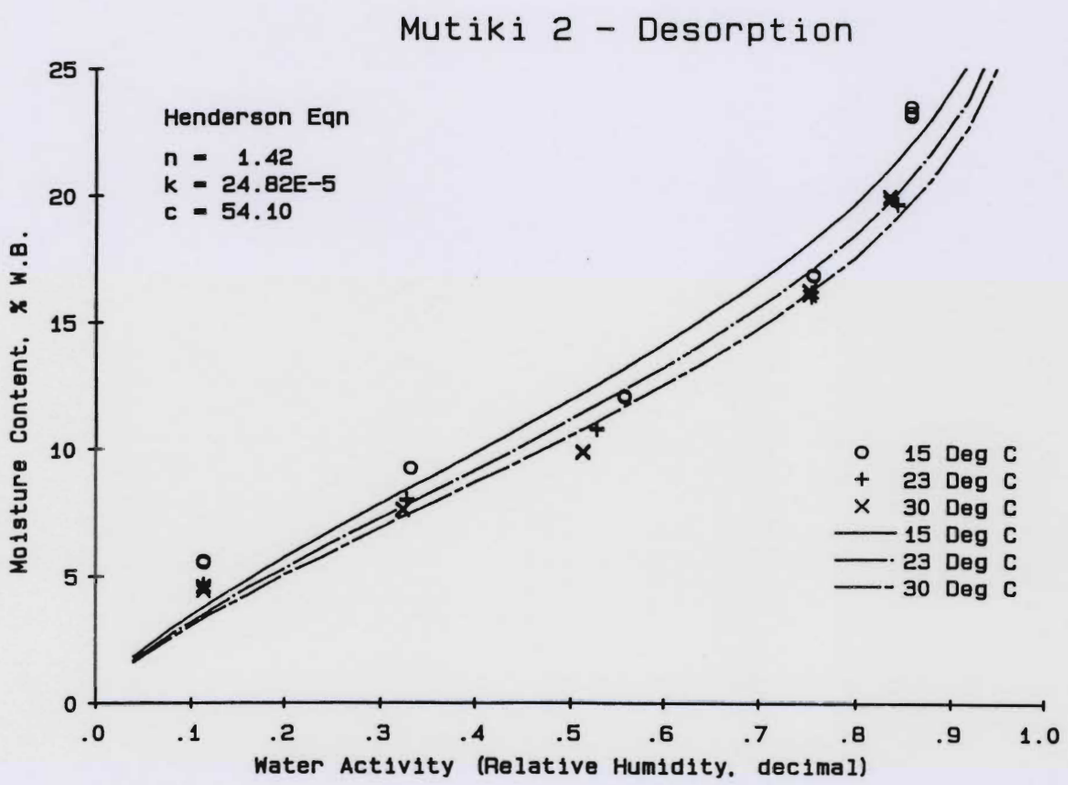


Figure 38. Desorption equilibrium moisture isotherms predicted by modified Henderson equation at 15, 23, and 30°C for Mutiki 2 variety with observations at $a_w > 0.8$ removed

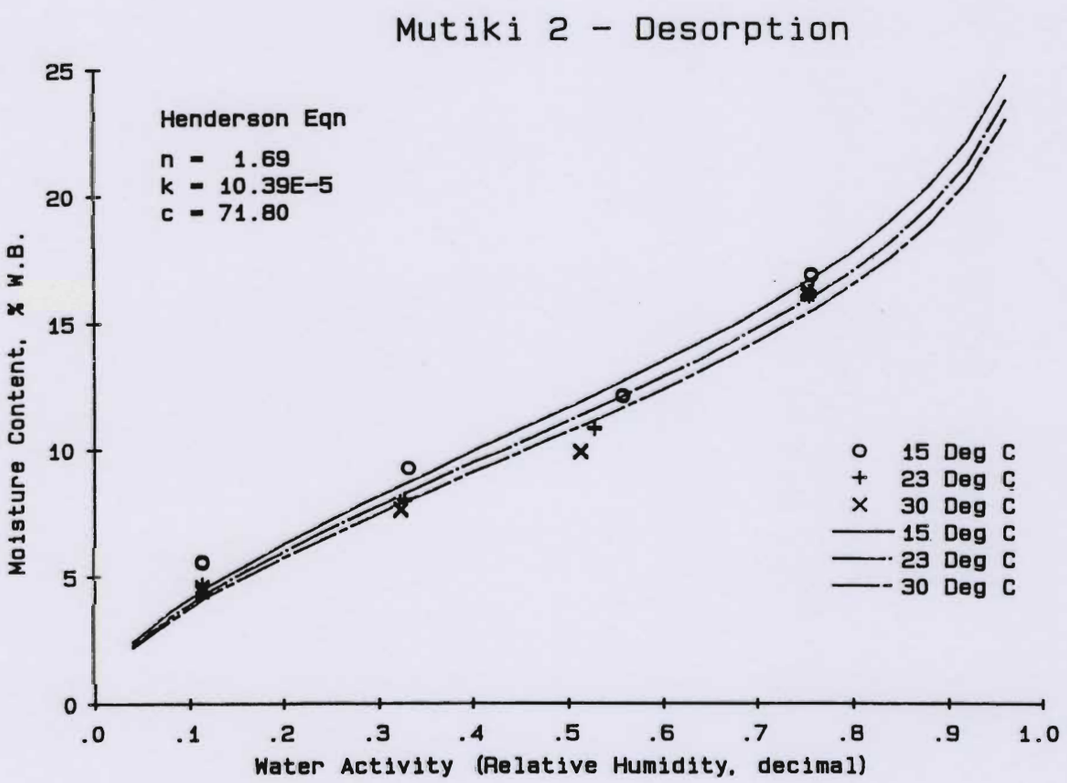


Figure 39. Desorption equilibrium moisture isotherms predicted by modified Henderson equation at 15, 23, and 30°C for Muhondo variety

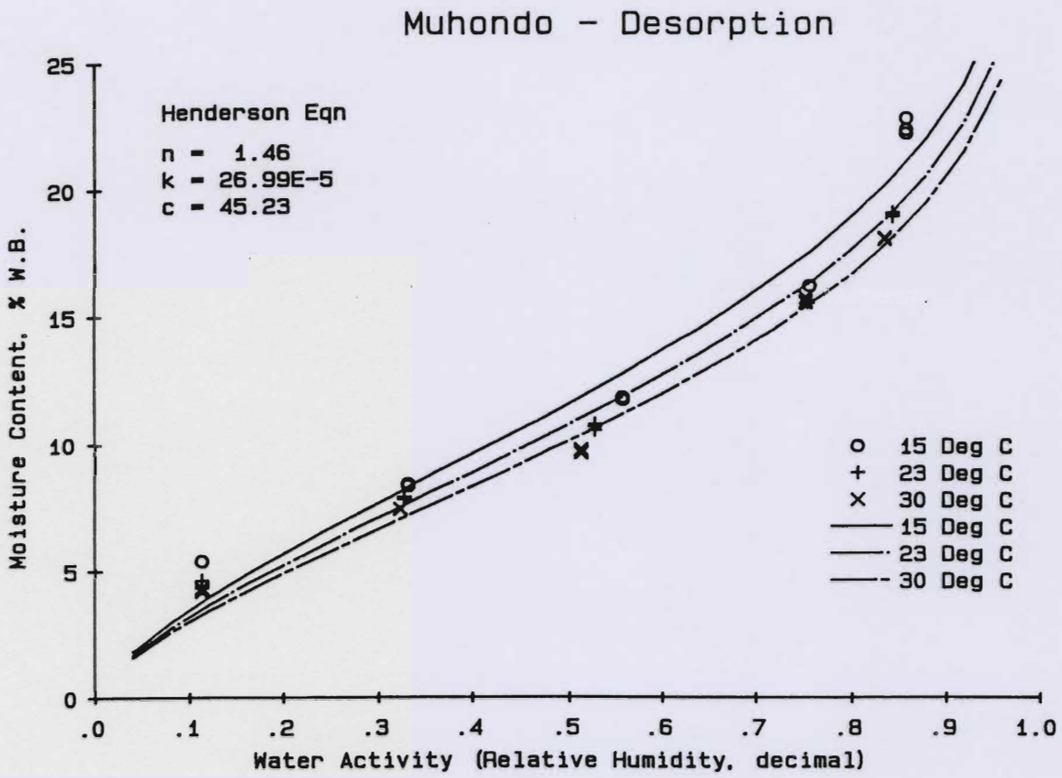
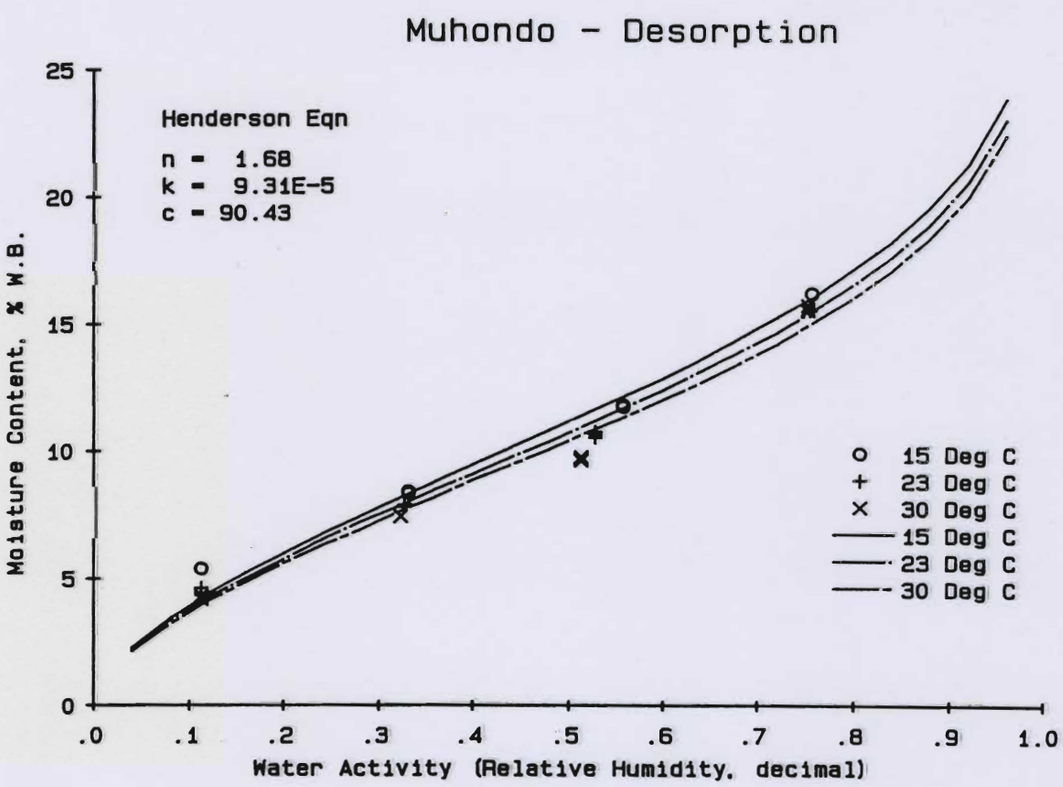


Figure 40. Desorption equilibrium moisture isotherms predicted by modified Henderson equation at 15, 23, and 30°C for Muhondo variety with observations at $a_w > 0.8$ removed



Within each mixture, adsorption EMC's at a given water activity generally decreased with increasing temperature (Figures 17 and 18). The effect of temperature on EMC was most noticeable at water activities greater than about 0.33. At a_w = about 0.75, equilibrium moisture contents in both mixtures and at all three temperatures were very similar, whereas at a_w = about 0.85, they were very different, particularly at 15°C.

Theoretically, the effect of temperature on decreasing EMC at a constant a_w in foods such as dry beans which follow a Type II isotherm should be greatest at low to intermediate water activities (Labuza, 1984). That this was not observed in either mixture is perhaps due in part to difficulty in maintaining the appropriate water activity at each temperature using the saturated salt solutions. It is also possible that the sorbic acid added to prevent microbial growth may have somehow influenced the EMC of some samples (Labuza, 1984).

Adsorption EMC's appeared to be slightly dependent on bean mixture: Mixture 2 samples generally equilibrated to slightly higher moisture contents than Mixture 1 samples at a given water activity and temperature.

The adsorption isotherm predicted using the modified Henderson equation for Mixture 1 (Figure 29) shows little temperature effect; the isotherm predicted for Mixture 2 (Figure 30) shows some temperature effect at water activities greater than approximately 0.33. In general, the equation was not flexible enough to fit the data well over the entire range of water activities and temperatures. Since there was some question about the accuracy of the equilibrium moisture content results for the high water activity (15°C temperature tests), the equation was fit again by omitting all observations at water activities greater than 0.80. The results are

shown in Figure 31 for Mixture 1 and in Figure 32 for Mixture 2. These results show a better fit to the data at the lower water activities (less than 0.75) which is the most important range for most storage applications.

B. Desorption Isotherms - Mixtures 1 and 2; Varieties Mutiki 2 and Muhondo

Desorption data were obtained for mixture 1 at water activities ≤ 0.56; for Mixture 2 and Muhondo, at water activities ≤ 0.84; and for Mutiki 2 at all water activities (Table 16). At a given water activity, desorption EMCs also generally decreased with increasing temperature (Figures 19 through 22). Discrepancies similar to those described with adsorption EMCs in Mixtures 1 and 2 occurred at a_w = about 0.75 and 0.85.

Desorption isotherms predicted for the mixtures and varieties using the modified Henderson equation are shown in Figures 33 through 40. Removing observations at the high water activities (> 0.80) provided a better fit to the data. At a given water activity, equilibrium moisture contents decreased with increasing temperature; this temperature effect was fairly constant at water activities greater than about 0.33.

For a given water activity and temperature, the four samples generally had similar EMC's. Mixture 2 tended to equilibrate to slightly higher moisture contents than the other three samples, and Muhondo tended to equilibrate to slightly lower moisture contents than the other three samples. The largest differences in EMCs between samples were always at water activities ≥ 0.75.

Because the desorption data for the two mixtures and the two varieties appeared to be similar, all the data was pooled and fit to a single equation. The pooled results are shown in Figure 41 with the high water

activity data (> 0.80) included and in Figure 42 with the high water activity data excluded. Again, excluding this latter data results in a better fit to the equation.

IV. Comparison of Desorption and Adsorption Isotherms - Mixtures 1 and 2

For a given RH and temperature, desorption EMCs were higher than adsorption EMCs (Table 16; Figures 23 through 28). At a given water activity, the largest differences between desorption and adsorption EMCs were at 15°C; differences decreased as temperature increased. At all temperatures, desorption and adsorption EMCs began to approach each other at water activities > 0.70-0.80 and < 0.20.

At a given temperature, noticeably more moisture was held during desorption than during adsorption within the intermediate water activity range (hysteresis effect). These results agree with those reported for cowpeas and soybeans (Denloye and Ade-John, 1985).

V. Comparison of Predicted Desorption Isotherm with Literature Values

The equation with three different sets of parameters is compared at 23°C in Figure 43. The equations resulting from fitting the pooled data both with high water activities included and excluded are plotted along with an equation for edible beans presented in the ASAE Agricultural Engineers Yearbook (1983). The equation resulting from pooled data with high water activities excluded is close to the equation from the ASAE standard, particularly over the range of relative humidities from 45 to 70% which correspond to moisture contents from 10 to 15% w.b. Again, this is the most significant range for storage applications.

Figure 41. Desorption equilibrium moisture isotherms predicted by modified Henderson equation at 15, 23, and 30°C using pooled data from both mixtures and varieties

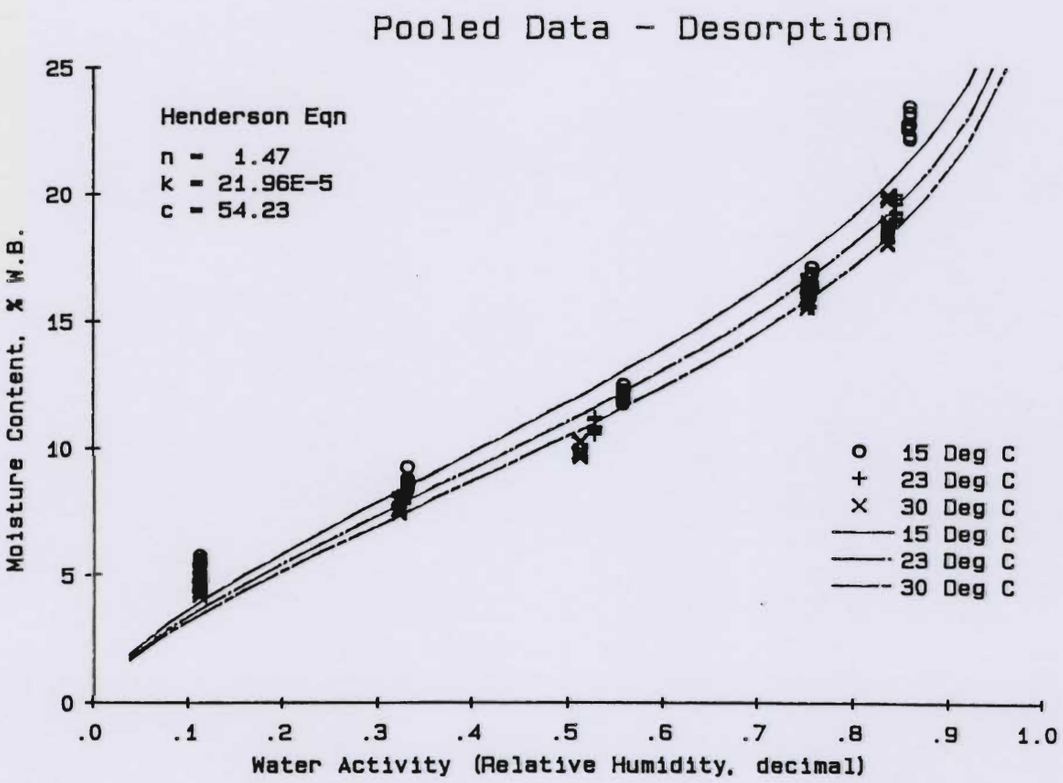


Figure 42. Desorption equilibrium moisture isotherms predicted by modified Henderson equation at 15, 23, and 30°C using pooled data from both mixtures and varieties with observations at $a_w > 0.8$ removed

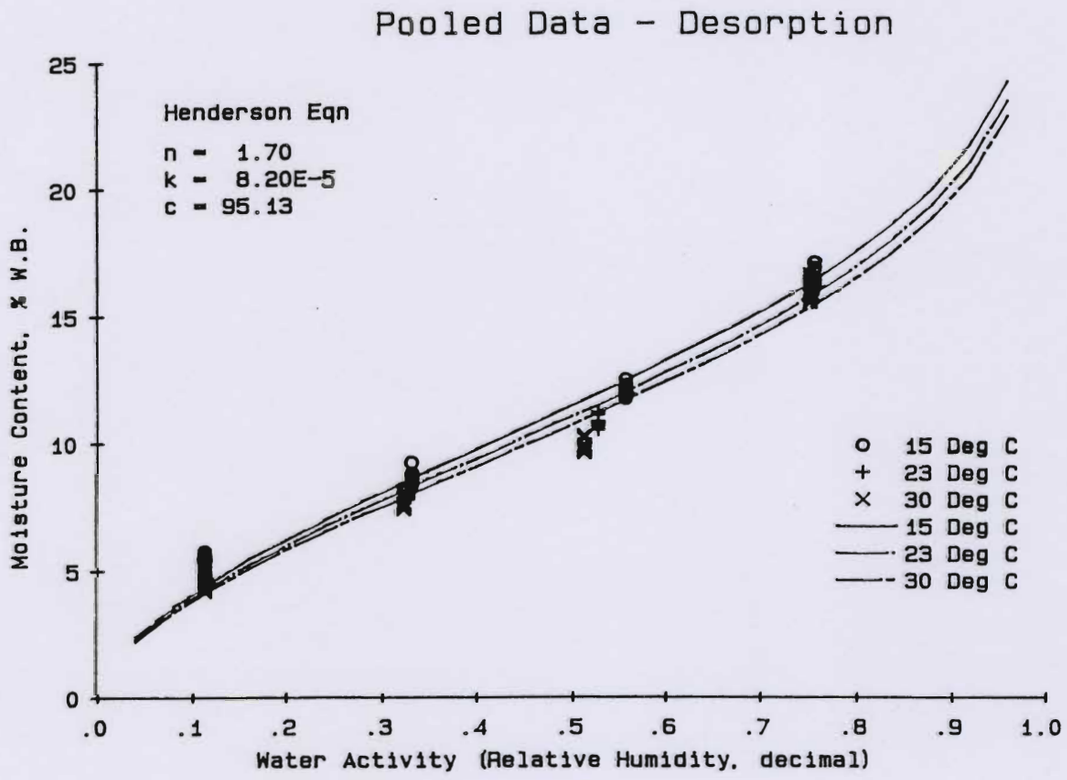
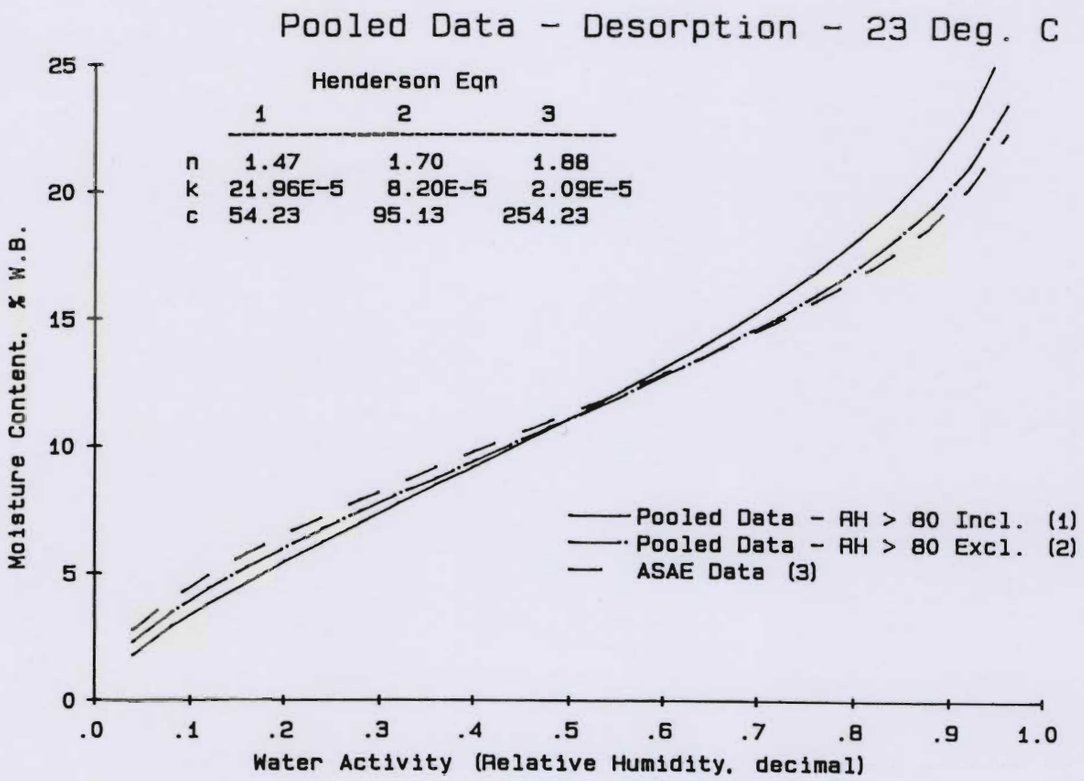


Figure 43. Comparison of desorption moisture isotherms predicted by modified Henderson equation at 23°C: 1) This study, pooled data, all observations, 2) this study, pooled data, observations at a_w >0.8 removed, and 3) ASAE data



CONCLUSIONS

Differences in amounts of moisture gained or lost were observed between samples after two weeks storage. These differences seemed to be related to the initial m.c. of the beans and to storage water activity and temperature.

Off-odors and discoloration were also noted after four weeks in samples stored at approximately 0.85 water activity. Mold growth was first noted after 13 weeks in Mixture 1 adsorption samples stored at 15 and 30°C and a_w = about 0.84. Other adsorption and desorption samples stored under the same conditions later became contaminated as well as some sample stored at all three temperatures and a_w = about 0.75.

Adsorption and desorption isotherms were determined for Rwandan bean varieties and mixtures. Both adsorption and desorption EMCs usually decreased with increasing temperature. The effect of temperature on equilibrium moisture contents was most noticeable at water activities greater than about 0.33.

Desorption EMCs were higher than adsorption EMCs at all temperatures. Desorption and adsorption EMCs began to approach each other at water activities 0.70 to 0.80 and 0.20.

The adsorption and desorption equilibrium moisture content data were fit to the modified Henderson equation (Pfost, 1981). In all cases the fit of the data to the equation was improved by removing observations at water activities > 0.80.

Adsorption and desorption EMCs of the samples were fairly similar. Adsorption and desorption isotherms using pooled data from the mixtures and varieties are likely adequate to estimate equilibrium moisture contents of Rwandan beans stored under the conditions used in this study.

The desorption isotherm predicted using the modified Henderson equation and pooled EMC data from the two mixtures and the two varieties stored at 23°C was compared to an isotherm reported in the literature for dry edible beans (ASAE, 1983). The isotherms agreed well in the a_w range of 0.45-0.70 RH, particularly when observations at water activities > 0.80 in the present study were excluded.

LITERATURE CITED

Agricultural Engineers Handbook. 1983. "Moisture Relationships of Grains." ASAE D245.4. St. Joseph, MI 49085.

American Association of Cereal Chemists. 1970. Approved Methods of the American Association of Cereal Chemists. AACC. St. Paul, MN.

Anon, 1973. "Grain Preservatives for High-Moisture Food Grains", U.S. Grain Marketing Research Center, Agricultural Research Service, U.S. Department of Agriculture, Manhattan, Kansas.

Chung, D.S., and Pfost, H.B. 1967. Adsorption and desorption of water vapor by cereal grains and their products: Part I-III. Trans. Am. Soc. Agric. Eng. 10:549.

Denloye, A.O., and Ade-John, A.O. 1985. Moisture sorption isotherms of some Nigerian food grains. J. Stored Prod. Res. 21(2):53.

Dexter, S.T., Anderson, A.L., Pfahler, P.L., and Benne, E.J. 1955. Responses of white pea beans to various humidities and temperatures of storage. Agron. J. p. 246-250.

Dunkel, F., Lung, P.Z., Chuan, L., and Yin, H.F. 1982. Insect and fungal response to sorbic acid-treated wheat during storage in South China. J. Econ. Entomology. 75:1083.

Greenspan, L. 1977. Humidity fixed points of binary saturated aqueous solutions. J. Res. National Bureau of Standards - Section A. Physics and Chemistry. 81A(1), 89-96.

Henderson, S.M. 1952. A basic concept of equilibrium moisture. Trans. Am. Soc. Agric. Eng. 33:29.

Henderson, S. 1984. The moisture content - equilibrium relative humidity relationship of cocoa beans. J. Stored Prod. Res. 20(1):1.

Henderson, S., and Pixton, S.W. 1981. Relative humidity control in equilibrium studies. J. Sci. Food Agric. 32:1145.

Hutchinson, P.H., and Otten, L. 1984. Equilibrium moisture content of white beans. Cereal Chem. 61(2):155.

Jordao, B.A. and Stolf, S.R. 1969-70. Curva de saturacao do feijao de mesa variedade rosinha. Coletanea do Instituto de Tecnologia de Alimentos. 3:425.

Labuza, T.P. 1968. Sorption phenomena in foods. Food Technol. 22:263.

Labuza, T.P. 1984. "Moisture Sorption: Practical Aspects of Isotherm Measurement and Use". American Association of Cereal Chemists: St. Paul, MN.

Labuza, T.P., Kaanane, A., and Chen, J.Y. 1985. Effect of temperature on the moisture sorption isotherms and water activity shift of 2 dehydrated foods. J. Food Sci. 50:385.

Lamb, E.M., and Hardman, L.L. 1986. Final Report of Survey of Bean Varieties Grown in Rwanda. US AID-Rwanda Local Crop Storage Cooperative Research, LCS/FSMII (Research Component): University of Minnesota.

McCurdy, A.R., Leung, H.K., and Swanson, B.G. 1980. Moisture equilibration and measurement in dry pinto beans (Phaseolus vulgaris). J. Food Sci. 45:506-508.

Morris, H.J., Olsen, R.L., and Bean, R.L. 1950. Processing quality of varieties and grains of dry beans. Food Technol. 4:247.

Pfost, H.B. 1981. Summarizing and reporting equilibrium data for grains. ASAE Paper No. 76-3520, St. Joseph, MI 49085.

Pixton, S.W., and Henderson, S. 1981. The moisture content equilibrium relative humidity relationship of malt. J. Stored Prod. Res. 17:191.

Pixton, S.W., and Warbuton, S. 1971. Moisture content-equilibrium relative humidity relationships of some cereal grains at different temperatures. J. Stored Prod. Res. 6:283.

Weston, W.J., and Morris, H.J. 1954. Hygroscopic equilibria of dry beans. Food Technol. 8:353.

SECTION IV

LARGE SCALE BAGGED STUDY

ABSTRACT

Approximately 4.5 tonnes of a dry bean mixture (Phaseolus vulgaris) grown in Rwanda were dried to 8.8, 12.1, and 14.4% moisture in 750 kg batches in a 1-tonne capacity dryer at 40°C. The beans were treated with 0.1% actellic and stored in moisture-impermeable plastic bags in warehouses in three different agroclimatic regions of the country. Samples from each warehouse and moisture level were evaluated for cookability, other physical qualities and for sensory hardness, preference and acceptability at 2-month intervals for 24 months. At the time this manuscript was prepared only the 0 to 8 month data had been tabulated. Several more months will need to pass before any meaningful evaluation of the data can occur. Tables of the first eight months data are included. These tables can be used to record future data and to illustrate any trends or differences due to storage location or moisture content.

INTRODUCTION

This large scale bag study is of central importance to the Cookability and Sensory Preference component. The other eight studies in some way support or extend the results of this one.

In this study beans are stored in warehouses in different agroclimatic regions of the country in an effort to determine which of the storage sites within Rwanda are best for maintaining the cookability, sensory quality and germinability of Rwandan beans. Large quantities of a typical bean mixture

are stored for a two year period. During this storage time the beans are sampled at two month intervals and tested extensively. This large number of tests conducted on a single bean mixture will provide a data base from which a wide variety of knowledge can be gained.

The more specific objectives of this large scale bagged study are: 1) To determine which of three storage locations in Rwanda is best for maintaining the cookability, sensory quality and germinability of Rwandan beans. 2) To determine the relationship between sensory hardness and instrumental hardness. 3) To determine how storage time and the moisture content of the beans affect the sensory preference, sensory acceptability, market value, instrumental hardness, germinability, color, and uncooked bean quality. 4) To determine whether different methods of soaking beans before cooking reduce the hardness of the beans and/or affect the sensory hardness or preferences for the beans. And 5) to determine the length of time necessary to pressure cook beans stored for 0, 1 and 2 years.

MATERIALS AND METHODS

I. Beans

Approximately 4500 kg of beans from the January 1986 harvest were purchased from producers in different regions of Rwanda in early February and delivered to the OPROVIA warehouse at Kicukiro. According to Mr. Phocas Kayinamura, project manager, the beans were purchased in regions where GRENARWA usually purchases bean stocks, and in approximately the usual proportions: 30% of the beans came from Kibungo, 30% from Mutara, 25% from

Mayaga, and 15% from Ruhengeri-Gisenyi. The beans were delivered in 90-100 kg jute bags. The approximate moisture content of the beans in each bag was determined using a Motomco moisture meter (Model 919, Motomco, Inc., 267 Vreeland Ave., Box 300, Paterson, NJ 07543) and a Motomco/oven-dry moisture content calibration curve developed in the OPROVIA laboratory for a Rwandan bean mixture. The equation for the calibration curve was: % moisture = 8.31 + 0.13 (Motomco reading). Any bag lots having moisture contents less than 15% were not accepted. The beans were stored for several days in bags in the OPROVIA warehouse until they were mixed together.

II. Preparation of Final Mixture

The beans were mixed together in the proportions given above (30:30:25:15) by dumping them out into a pile on the floor of the warehouse and mixing them well with shovels. A sample of the resulting mixture was examined for varietal content by OPROVIA's bean quality scientist and by the director of GRENARWA. The mixture would have been rejected for use in the study had it not contained predominant varieties normally found in GRENARWA'S stocks. The oven-dry moisture content of the beans after mixing was 16.7%.

III. Drying Procedure

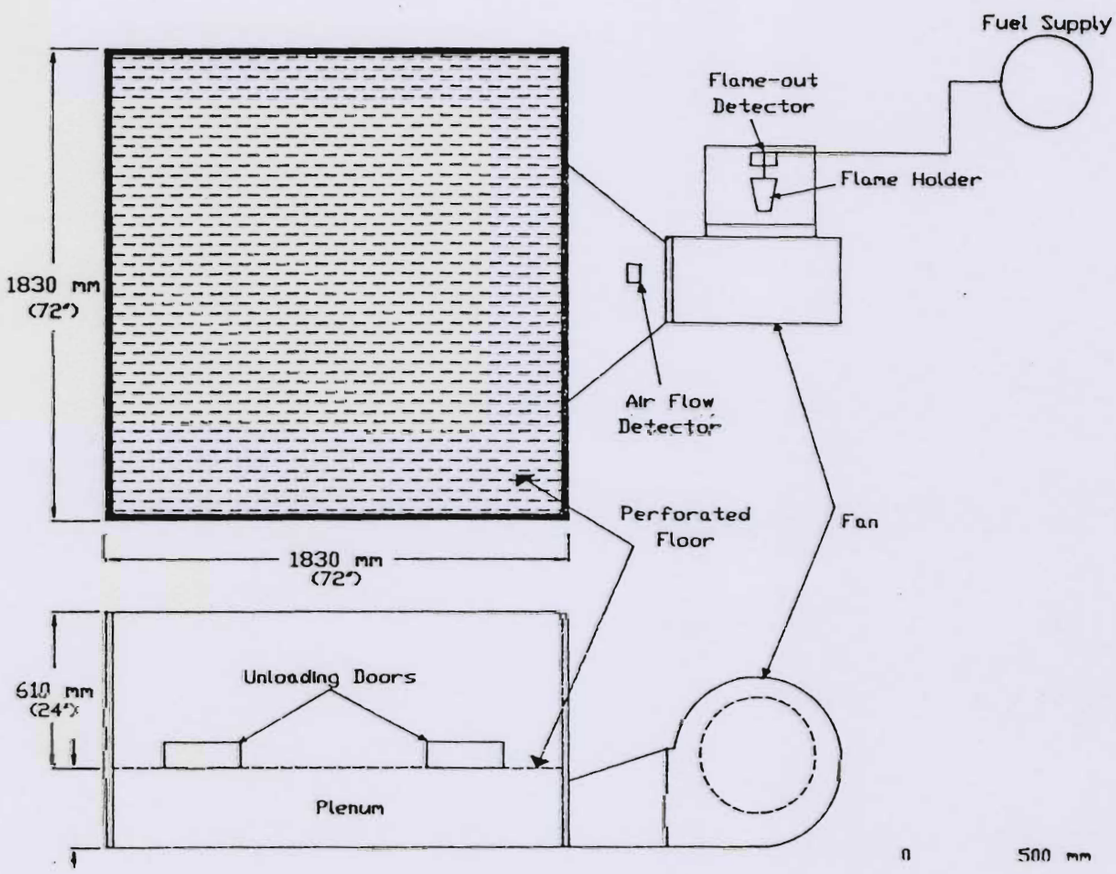
Approximately 1400 kg of the mixed beans were sun-dried over a two-day period in a single layer on a canvas tarpaulin to reduce their moisture content to approximately 15%. At night the beans were taken inside and stored in jute bags in the warehouse. The oven-dry moisture content of the beans after sun-drying was 14.4%.

One half of the remaining beans (about 1500 kg) was dried to approximately 12% moisture and the other half to approximately 9% moisture in a one-tonne capacity dryer constructed at the University of Minnesota Department of Agricultural Engineering. The dryer consisted of a butane-fueled gas burner to heat air to the desired temperature, a centrifugal fan to force the heated air through the plenum chamber, and a drying chamber (Figure 44).

The beans were dried to the target moisture levels in 750 kg batches about 45 cm (1.5 ft) deep. The temperature of the heated air was monitored by a copper-constantan thermocouple placed in a small hole drilled in the air duct at the base of the plenum chamber and connected to a temperature monitor (Model 8110-25, Cole Parmer Instruments, 7425 N. Park Ave., Chicago, IL 60618). The gas burner was regulated so that the drying air temperature did not exceed 40°C (104°F).

Moisture content was measured periodically during drying on composite samples of about 500 g using the Motomco. Subsamples making up the composite sample were taken with a grain trier from the center of the bean mass, from each of the four corners and from the four points midway between each corner about 20 cm (8 in) in from the sides of the dryer, for a total of nine locations. Samples were allowed to cool for 30 min before testing. When the approximate target moisture content (9 or 12%) was reached, the gas burner was turned off and the beans were cooled with ambient air for approximately 30 min. Generally, the beans were left in the dryer overnight, unloaded the following morning and stored temporarily in jute bags next to the dryer while the other batch for that moisture content was dried.

Figure 44. Schematic diagram of bean dryer



IV. Insecticide Treatment and Storage

The beans at each moisture content (9, 12, 15%) were treated with 0.1% actellic (1 kg actellic/1000 kg) of beans). The beans were dumped in a pile on the floor of the warehouse and the actellic was sprinkled on top of the pile and mixed in well with shovels. Approximately 10 kg of beans at each moisture content were set aside for baseline oven-dry moisture content determinations, varietal analysis, instrumental and sensory analysis, and for use in the Laboratory Storage Study. The oven-dry moisture contents of the three lots of beans before storage were 8.8, 12.1, and 14.4% respectively.

Thirty-six heavy duty plastic garbage bags were filled with about 30 kg of beans of each of the three moisture classes, and sealed well with duct tape. Each bag was placed inside of a 90 kg size woven polyethylene bag which was also sealed with duct tape. Also for each of the three moisture classes, three unlined woven jute bags were filled with 30 kg of beans and tied closed with rope. All of the bags were tagged inside and out with the name of the study, the moisture content of the beans, packaging dates, termination of storage dates and the storage location.

Twelve plastic-lined bags and one unlined jute bag of beans at each moisture content were delivered by truck to GRENARWA warehouses in three different agroclimatic regions of Rwanda: Kora (high altitude, low mean temperature), Kibungo (low altitude, high mean temperature), and Nyanza (moderate altitude, moderate mean temperature). (See section 9 of this report, Bean Varietal study for altitudes and mean temperatures in each region.) At the warehouses each lot of beans of a given moisture class was stacked on a separate wooden palette and kept apart from other regular storage

stocks.

Temperature and relative humidity conditions in the warehouses were monitored using 7-day recording hygrothermographs (Bacharach No. 227015; Bacharach Instruments Co., 625 Alpha Dr., Industrial Park, Pittsburgh, PA 15238). The warehouse managers were responsible for changing the hygrothermograph charts and rewinding the clock mechanisms each week. Charts were collected and analysed for mean weekly temperature and relative humidity.

V. Laboratory and Sensory Tests

The following baseline tests were conducted on samples of each moisture class: 1) breakdown of bean types in the mixture; 2) seedcoat color analysis; 3) damage analysis; 4) germination tests; 5) instrumental hardness; 6) sensory hardness; and 7) sensory preferences. After two months storage and at two month intervals up to and including 24 months of storage, a plastic-lined bag at each moisture content was removed from storage at each of the three warehouses and delivered to the OPROVIA laboratory. All tests except 1) were repeated at these 2 month intervals. Oven-dry moisture contents (AACC, 1975) Method 44-15A for whole beans were also determined. A sample of about 1 kg was also taken from the unlined jute bags at each warehouse: seedcoat color analysis, damage analyses, oven-dry moisture content determinations, and instrumental hardness tests were performed on these samples at 2 month intervals. A description of the procedures for each test follows.

A. Breakdown of bean types in the mixture

The bean types in samples in each moisture class were classified according to Lamb and Hardman (1986)(See Section I), except that types were not classified by shininess or size. The number of beans of each type in a 100 g sample and the percent by weight of each type in that same sample were determined by the bean quality technician (Bean and Sorghum Storage Survey component). The number and the percent by weight of beans in a 100-g sample of each moisture class are shown in Table 17.

B. Seedcoat color analysis

Six bean types were chosen for seedcoat color analysis according to their predominance in the mixture or how well they might be expected to show color changes during storage (i.e. light-colored varieties were chosen over dark-colored varieties) (see Table 18) using the Munsell color system (see Section VII of this report, 'Influence of Drying on Cookability' for a detailed description of this system). The Munsell color chips which best matched the seedcoat color of each type were compared at two month intervals to evaluate changes in hue, value, and/or chroma. The same six types were used in color analyses in the Lab Storage Study II.

C. Damage analyses

Three lots of 100 beans from each moisture content were analyzed for damage in a number of different categories by the bean quality technician. Samples were also analyzed for test weight - the weight in grams of a standardized volume of sample, 0.907 liter (1 qt) (see Table 19). For a

complete description of the damage analyses procedure see Dunkel et al. (1986)(See Section VI). Summary tables will be constructed from the data as time progresses.

D. Germination tests

Germination tests were conducted using two 100 bean replicates from each treatment. A detailed description of the germination test procedure is found in Section VII of this report, 'Influence of Drying on Cookability'. Summary tables and plots of the data will be constructed to show the effect of moisture content and warehouse location over time.

E. Instrumental hardness tests

Mean grams force and percent of the sample registering $\geq$ 450 g force (% hard-to-cook) were determined for each treatment. Detailed descriptions of the cooking and instrumental hardness testing procedures are found in Section XI of this report, 'Bean Varietal study'. Summary tables and plots of the data will be constructed to show the effect of moisture content and warehouse location on instrumental hardness over time. Plots will also be constructed to show the relationship of instrumental hardness to sensory preferences and sensory hardness over time by moisture content and storage location.

Table 17. Breakdown of bean types in mixture by moisture content

Shape[a]	Seedcoat Color Pattern[b]	Color[c]	Number of Beans in 100g/% by weight		
			% Moisture		
			8.8	12.1	14.4
lo	mc	rg	45/19.8	77/22.6	42/19.6
lo	hlbr	cr	36/13.8	41/12.2	46/12.5
ro	mc	rg	34/7.2	-	34/7.2
ro	mc	br	31/6.9	31/9.2	-
lo	tt	rg/cr	28/11.8	-	-
ro	tt	cr/br	28/6.9	25/8.0	27/7.9
ro	mc	rs	27/5.4	-	-
ro	mc	n	17/3.4	22/4.6	22/4.6
lo	zb	cr/n	12/2.5	15/5.4	18/6.4
ro	rr	cr/n	16/3.1	22/6.2	-
ro	mc	jbr	12/3.0	-	10/2.3
lo	mc	pr	12/3.3	16/5.7	13/4.3
lo	tp	cr/n	6/2.1	-	-
lo	tl	cr/pr	6/2.0	-	-
lo	hln	j	5/1.2	-	6/2.4
lo	tt	rs/rg	4/1.4	-	-
lo	mc	n	-	24/6.8	-
lo	hlbr	rs	-	21/6.1	-
lo	tt	rg/cr	-	18/7.4	11/3.6
ro	mc	j	-	14/5.3	-
ro	mc	jbr	-	12/3.8	-

Table 17 continued

Shape[a]	Seedcoat Color Pattern[b]	Color[c]	Number of Beans in 100g/% by Weight % Moisture		
			8.8	12.1	14.4
lo	tl	jbr/br	-	5/1.1	-
lo	tp	rg/cr	-	1/0.9	-
lo	tt	cr/n	-	-	26/7.6
lo	mc	rs	-	-	6/1.5
lo	zb	jbr/n	-	-	5/1.8
lo	mc	g	-	-	3/0.5
others			16	-	8/3.3
		Total of beans	335	344	277

[a] lo = elongated oval
ro = rounded oval

[b] mc = single color
hlbr = brown hilum ring
tt = speckled
zb = zebra striped
tp = flecked
tl = mottled
hln = black hilum ring

[c] rg = red
cr = cream
br = brown
rs = pink
n = black
j = yellow
pr = purple
g = gray

Table 18. Description of bean varieties used for color analysis

Variety #	Seed Shape[a]	Seedcoat Color Pattern[b]	Color[c]
1	lo	hln	j
2	lo	tt	rg/cr
3	lo	hlbr	cr
4	ro	hln	br
5	ro	tt	cr/n
6	lo	mc	rg

[a] lo = elongated oval
ro = rounded oval

[b] hln = black hilum ring
tt = speckled
hlbr = brown hilum ring
mc = single color

[c] j = yellow
rg = red
cr = cream
br = brown
n = black

Table 19. Baseline damage analyses and test weight data of the bean mixture at three moisture contents[a]

Damage Categories	Moisture Content								
	8.8%			12.1%			14.4%		
	1st lot	2nd lot	3rd lot	1st lot	2nd lot	3rd lot	1st lot	2nd lot	3rd lot
Wrinkled	12[b]	12	9	26	18	18	12	16	11
Shriveled	2	-	14	16	12	10	7	16	12
Discolored	1	2	1	1	-	-	-	-	-
Insect Damage	1	1	-	1	1	4	-	4	1
Dented	16	10	13	6	11	12	3	8	3
Torn Pericarp	8	10	14	8	9	10	7	6	5
Broken	-	2	-	-	-	-	-	2	-
Germinated	-	1	-	1	-	-	-	-	-
Visible Mold	-	-	-	-	2	2	-	1	-
Rodent Damage	-	-	-	-	-	-	-	-	-
Test Weight	826.5 g[c]			830.6 g			841.4 g		

[a]Damage analysis categories taken from Dunkel et al., 1986. (See Section VI).

[b]Number of beans affected in a 100 gm sample.

[c]Single determination.

F. Sensory hardness tests

Five to ten trained subjects judge the hardness of samples at the OPROVIA laboratory. The subjects judge two replicates of each treatment in the same test session (18 samples). Descriptions of the cooking procedure and subject training and testing procedures are found in Section I of this final report, 'Development of Standard Laboratory Sensory and Cookability Tests'.

Due to the lag time between training of the subjects and the beginning of the test sessions (approximately 17 months), not all of the original subjects wre still available to judge samples when the actual testing began. Additional subjects were trained and original subjects gained additional experience judging samples during practice sessions run at approximately 8 months and 16 months after the original training period. Results of the training and practice sessions indicated that subjects' judgments of the same samples usually agreed well, and therefore that they had learned to descriminate differences in hardness between samples similarly.

Summary tables and plots of data will be constructed to show the effect of moisture content and warehouse location on sensory hardness over time. Plots will also be constructed to show the relationship of sensory hardness and sensory preferences over time by moisture content and warehouse location.

G. Sensory acceptability and preference tests

Three groups of 40-50 adult consumers (20-50 years of age) evaluated samples for preference at OPROVIA, Gahanga Nutritional Center and Kanombe

military camp. Consumers at OPROVIA were office personnel and warehouse workers and were selected to include approximately equal numbers of males and females. Consumers at the nutritional center were parents of children brought to the center for nutritonal care; females usually outnumbered males. Consumers at the military camp were camp personnel and their spouses; males usually outnumbered females. The experimental design for the preference tests was a Latin Square; each consumer group always evaluated the same three samples (see Table 20). Descriptions of the cooking and preference test procedures are found in Section I of this final report, 'Development of Standard Laboratory, Sensory and Cookability Tests'. Consumers were questioned orally about the acceptability of samples at the military camp by research technicians and at the nutritional center by technicians and staff nutritionists. Written response forms were used at OPROVIA.

Summary tables and plots of the data will be constructed over time to show the effect of moisture content and warehouse location on acceptability (percentage of consumers willing to eat the beans on a normal basis), preferences (mean preference level expressed as a percentage of the hedonic scale length), and market values (ratio of the price consumers would be willing to pay for 1 kg of the bean sample to the price of 1 kg of a bean mixture at the local market multiplied by 100).

Table 20. Latin square experimental design for sensory preference tests

Warehouse Location	Sensory Test Site		
	OPROVIA	Kanombe	Gahanga
	Moisture Content Tested, %		
Kibungo	8.8%	12.1%	14.4%
Nyanza	12.1%	14.4%	8.8%
Kora	14.4%	8.8%	12.1%

VI. Additional Tests

A. Effect of soaking solutions on instrumental and sensory hardness and sensory preferences

The testing procedures used to evaluate the influence of soaking solutions on instrumental and sensory attributes of beans after one year and two years storage (2/87 and 2/88, respectively) were developed in a series of preliminary tests in April-August 1986. Since this report has been prepared in advance of the actual running of these tests, it contains only a detailed description of how we intend the tests to be conducted.

1. Beans

The bean sample used for the soaking study will be the moisture content storage treatment having the highest level of instrumental hardness after one and two years storage.

2. Soaking solutions and cooking procedures

Approximately six cups of undamaged beans are soaked for twelve hours in plastic buckets in four liters of the solutions shown in Table 21. All the solutions are prepared using tap water. The soaked beans are drained and rinsed three times with tap water by pouring off the water and adding more each time. A six cup sample of unsoaked undamaged beans is rinsed in the same manner and cooked as a control, for a total of six treatments. Samples are placed in large metal cookpots and tap water is added to cover the beans.

Table 21. Solutions used for soaking study

Solution	Concentration (w/w basis)
Tap water	
Rock salt (obtained at local market)	1%
Un-iodized table salt (obtained at local market)	1%
Sodium bicarbonate (Arm and Hammer)	0.5%
Sodium bicarbonate	1%

One and a half teaspoon of iodized salt (IOZO brand) are added to all treatments before heating.

3. Cooking procedures

The samples are covered, brought to a boil on charcoal-fueled cookstoves (brazéros), and cooked for three hours after boiling starts. Boiling tap water is added as needed during cooking to maintain the water level and boiling rate.

4. Sensory and instrumental hardness tests

The detailed procedures for sensory and instrumental hardness tests and analysis of the data are described in Section I of this final report, 'Development of Standard Laboratory Sensory and Cookability Tests'. All sensory tests for the soaking study are conducted at OPROVIA, using written response forms. First, ten trained subjects judge the hardness of the six treatments. Subjects judge two samples of each treatment in a single test session. Immediately following the sensory hardness test, a group of 40 to 50 consumers evaluate the treatments for preference. A portion of beans from each treatment is then tested for instrumental hardness (mean grams force, % hard-to-cook beans) in the laboratory.

Sensory and instrumental data from all treatments will be tabulated and compared to determine which treatments reduce instrumental hardness and which are judged best by the consumer panel. An acceptable level of instrumental hardness might be defined

arbitrarily as 300-350 MGF/20-30% $\geq$ 450 g, since instrumental hardness tests of freshly harvested unsoaked beans cooked for three hours are generally in this range and are well-accepted by consumers. Plots of the data will be constructed to show the effect of soaking solution or sensory and instrumental hardness and sensory preferences, and the relationship between sensory and instrumental hardness and preferences for each solution.

B. Establishment of pressure cooking times for fresh and hard beans

The cooking procedures used to establish pressure cooking times for fresh and hard beans were developed in a series of tests in June-August 1986.

1. Beans

Pressure cooking times will be established for a fresh bean mixture stored < 1 month after harvest and for hard beans from the Large Scale Bagged Storage Study. The hard beans will be taken from the storage treatment having the highest instrumental hardness level after one year (2/87) and two years (2/88) storage.

2. Pressure cooking times

Samples will be cooked at 15 psi for 5 min intervals from approximately 30 min to 90 min (13 different cooking times). Preliminary pressure cooking tests on fresh and hard beans indicated that cooking times in this range would reduce instrumental hardness to an acceptable level, 300-350 MGF/20-30% $\geq$ 450 g.

3. Pressure cooking procedure

Approximately one-third cup of intact, undamaged beans are rinsed well and added to one-half teaspoon of iodized (IOZO brand) salt and eight cups water in a 6 qt Presto stainless steel pressure cooker. The pressure cooker is closed according to the manufacturer's instructions and the pressure regulator is put on immediately. The cooker is heated on the 'high' setting of an electric hotplate until the pressure regulator begins to rock gently. The cooking time is counted from the start of the rocking motion; the hotplate is regulated as necessary to maintain a gentle rocking motion of the regulator. After cooking, the pressure cooker is removed from the heat and allowed to cool until the air vent pressure lock drops indicating that the pressure has dropped to zero. The pressure regulator and cover are removed and the beans are drained and transferred to small enamel dishes or plastic trays (covered) for cooling to room temperature.

4. Instrumental hardness tests

The procedure for instrumental hardness tests is found in Section I of this final report, 'Development of Standard Laboratory Sensory and Cookability Tests'.

To determine the pressure cooking times which give an acceptable instrumental hardness level for beans of different ages, pressure cooking time in minutes will be plotted against instrumental hardness (mean grams force and percent $\geq$ 450 g) and a best-fitting curve will

be drawn by eye to describe the relationship between hardness and cooking time. The cooking time at which an acceptable level of hardness is reached can be read directly from the graph.

C. Water hardness analyses

Since increases in calcium ion concentration due to evaporation during cooking might be expected to have a negative effect on bean cookability, two samples of fresh tap water taken on two different days from the OPROVIA lab in Kicukiro were analysed for hardness (mg/L of $CaCO_3$) before and after boiling. A third sample was also boiled for 15 and 40 min and compared for differences in hardness.

RESULTS

Instrumental hardness and moisture content determination data for beans stored in plastic and jute bags at 0, 2, 4, 6 and 8 months of storage are shown in Tables 22 and 23, respectively. Sensory preference and hardness data for beans stored in plastic bags are shown in Table 24.

Due to the known variability in both sensory tests and instrumental hardness tests, it would be premature to draw any conclusions from only eight months data. The tables allow for the addition of more data points as the study progresses.

Germination capacity data for beans are shown in Table 25. Germination capacities of samples at all three moisture contents before storage were fairly low, from 50% (8.8% moisture) to 64% (14.4% moisture). Reasons for these low values are unclear, particularly since reported germination

capacities for Rwandan bean mixtures before storage (approximately 12% initial moisture) have been as high as 91% (Dunkel et al., 1986). After two months storage, germination capacities of beans stored at the Nyanza and Kibungo warehouses had recovered noticeably. Reasons for this phenomenan are also unclear. Again, it would be premature to darw any conclusions from the germination data collected thus far. As the study progresses, additional data points will be added to the table and evaluated for trends by warehouse and initial moisture content.

At the same time this manuscript was prepared, color change and damage analysis data were only available for the 0 and 2 months sampling times. Data will continue to be collected and evaluated as the study progresses. Munsell color change data for six varieties of beans stored in plastic bags are shown by warehouse and initial moisture content in Tables 26 to 34, and damage analyses for beans stored in plastic and jute bags are shown in Tables 35 to 40. At two months of storage the amounts of damage were similar at all three warehouses and moisture contents for beans stored either in plastic or jute bags. A slight increase in discolored seeds indicates that some color changes are already taking place in some varieties at all moisture contents.

Test weight analyses of beans in plastic bags before storage and after two months storage were contradictory. Beans having the highest moisture content also had the highest test weight before storage, while beans having the lowest moisture content had the highest test weight after storage. Test weight is expected to decrease with increasing moisture content, since lower moisture beans are more dense and weigh more per unit volume than higher moisture beans. The time 0 data is likely in error.

Results of the water hardness analyses are shown in Table 41. Hardness ranged from 70 to 200 ppm (mg/L $CaCO_3$). Heating water to boiling appeared to increase $CaCO_3$ concentration slightly, while continued boiling appeared to decrease the concentration, perhaps due to precipitation of $CaCO_3$ on to the sides of the cooking vessel. Heating water during cooking does not appear to cause any dramatic changes in water hardness which might affect bean cookability.

CONCLUSIONS

Any conclusions would be premature at this stage. This study is of primary importance to the goals of the overall research project. The future data collection, tabulation and analysis should answer many important questions relating to the storage of Rwandan beans.

Table 22. Influence of Warehouse Location, Initial Moisture Content and Storage Time on Instrumental Hardness of Beans in Plastic Bags.

I. Percent Hard-to-Cook (≥ 450 g)

Warehouse	% Moisture	Storage Time, Months												
		0	2	4	6	8	10	12	14	16	18	20	22	24
Kora	8.8	19	34	22	13	23	18	29	40	40	42	51	51	48
	12.1	24	36	31	12	26	24	32	46	44	50	46	52	48
	14.4	18	38	43	9	32	34	37	61	49	50	72	61	60
Nyanza	8.8	19	39	32	30	37	30	32	38	41	58	62	48	52
	12.1	24	21	27	32	39	36	38	44	50	59	94	69	62
	14.4	18	38	36	34	47	39	43	54	63	72	97	93	68
Kibungo	8.8	19	34	33	24	35	33	27	44	47	48	48	46	65
	12.1	24	44	37	28	37	36	39	32	53	48	64	60	68
	14.4	18	32	31	35	41	42	42	69	62	69	83	80	89

II. Mean Grams Force[a]

Kora	8.8	311	378	347	324	341	370	378	396	400	405	412	417	419
	12.1	317	381	376	321	364	388	382	420	403	427	413	419	426
	14.4	312	385	388	333	384	385	397	440	412	429	458	435	435
Nyanza	8.8	311	391	398	354	374	392	386	397	397	423	447	410	431
	12.1	317	353	393	382	385	393	409	404	423	439	489	463	452
	14.4	312	374	405	371	413	384	430	420	439	452	494	477	467
Kibungo	8.8	311	379	402	330	369	389	384	405	428	421	423	408	442
	12.1	317	388	414	368	383	398	407	378	432	428	444	443	456
	14.4	312	378	409	386	398	419	419	456	448	456	477	475	486

[a] values are means of 100 determinations on randomly selected individual beans

Table 23. Influence of Warehouse Location, Initial Moisture Content and Storage Time on Instrumental Hardness of Beans in Jute Bags.

I. Percent Hard-to-Cook (≥ 450 g)

Warehouse	% Moisture	Storage Time, Months												
		0	2	4	6	8	10	12	14	16	18	20	22	24
Kora	8.8	19	30	35	19	18	20	27	39	36	42	50	49	52
	12.1	24	33	32	23	23	18	31	37	44	38	53	54	55
	14.4	18	31	34	25	21	30	32	46	46	45	61	63	64
Nyanza	8.8	19	33	33	22	32	16	33	46	36	47	58	59	71
	12.1	24	33	34	23	32	28	31	41	45	52	65	65	82
	14.4	18	33	38	26	36	41	38	56	53	58	77	75	86
Kibungo	8.8	19	42	36	31	28	31	27	46	36	63	61	58	74
	12.1	24	33	34	28	35	33	34	43	39	56	63	63	82
	14.4	18	36	39	30	42	47	45	41	50	58	70	66	91
II. Mean Grams Force[a]														
Kora	8.8	311	367	390	323	355	337	381	396	363	402	412	411	424
	12.1	317	377	374	357	347	345	385	386	396	391	426	426	434
	14.4	312	376	377	365	349	373	387	401	391	407	437	430	441
Nyanza	8.8	311	355	365	354	384	354	373	394	387	405	437	429	453
	12.1	317	380	376	348	367	366	379	396	396	417	442	438	472
	14.4	312	379	386	370	375	399	388	422	422	430	458	458	483
Kibungo	8.8	311	385	364	358	356	381	364	390	380	443	440	438	462
	12.1	317	359	373	368	386	386	374	393	394	432	438	441	471
	14.4	312	373	377	369	397	409	417	384	418	434	451	450	484

[a] values are means of 100 determinations on randomly selected individual beans

Table 24. Influence of Warehouse Location, Initial Moisture Content and Storage Time on Sensory Hardness and Preferences for Beans in Plastic Bags.

I. Sensory Hardness (mean score averaged over judges, 1 = not hard at all, 9 = extremely hard)

Warehouse	% Moisture	Storage Time, Months												
		0	2	4	6	8	10	12	14	16	18	20	22	24
Kora	8.8	3.6	2.7	2.7	4.0	3.6	3.4	3.0	3.6	—	—	—	—	—
	12.1	3.9	2.7	3.6	3.4	3.3	3.5	3.6	3.1	—	—	—	—	—
	14.4	2.7	3.2	3.9	5.3	2.9	3.8	3.3	3.5	—	—	—	—	—
Nyanza	8.8	3.6	2.3	5.0	2.5	3.8	3.1	3.5	4.1	—	—	—	—	—
	12.1	3.9	3.2	2.9	2.1	3.9	3.6	3.9	6.2	—	—	—	—	—
	14.4	2.7	2.6	4.1	4.5	3.2	4.1	3.8	6.5	—	—	—	—	—
Kibungo	8.8	3.6	3.1	3.4	3.3	3.8	4.2	3.3	2.6	—	—	—	—	—
	12.1	3.9	2.7	4.5	2.8	3.5	3.1	3.1	5.3	—	—	—	—	—
	14.4	2.7	3.3	2.5	4.6	3.2	4.0	4.5	6.1	—	—	—	—	—
II. Percentage acceptability														
Kora	8.8	59	81	88	76	98	82	94	83	74	98	98	94	94
	12.1	64	73	80	94	92	94	83	93	93	97	90	64	98
	14.4	72	77	66	58	80	76	63	73	75	78	79	28	67
Nyanza	8.8	59	57	74	80	84	80	86	88	87	91	76	76	88
	12.1	64	74	72	83	75	91	54	49	69	72	70	53	41
	14.4	72	69	68	66	77	76	63	46	43	33	39	24	29
Kibungo	8.8	59	59	77	67	86	80	86	76	72	90	98	91	100
	12.1	64	60	60	70	91	91	54	71	57	76	80	68	53
	14.4	72	61	41	90	76	73	64	55	59	46	34	7	13
III. Mean Preference Scores (expressed as percentage of scale length)														
Kora	8.8	60	74	70	64	65	69	71	71	58	72	79	67	68
	12.1	63	66	80	84	79	85	74	78	75	75	76	69	80
	14.4	65	61	62	57	61	67	56	54	64	64	61	52	68
Nyanza	8.8	60	55	75	72	74	73	74	79	70	78	75	72	76
	12.1	63	57	52	67	65	73	53	43	57	63	58	67	59
	14.4	65	70	64	60	62	58	58	52	48	48	50	45	46
Kibungo	8.8	60	46	63	64	72	62	73	61	56	70	78	81	83
	12.1	63	56	58	62	68	66	62	61	55	58	67	59	68
	14.4	65	57	63	74	71	71	60	55	50	52	50	31	38
IV. Relative Market Value		$\left[\frac{\text{Price/kg consumers willing to pay for sample}}{\text{Current price/kg at market}}\right] \times 100$												
Kora	8.8	88	85	84	83	81	80	85	85	75	78	86	82	84
	12.1	89	98	97	98	95	100	102	96	92	99	85	83	94
	14.4	90	93	91	82	92	93	89	85	84	73	65	70	83
Nyanza	8.8	88	90	90	90	95	89	101	97	91	99	81	88	90
	12.1	89	92	94	89	92	95	86	75	81	70	62	84	76
	14.4	90	79	83	79	77	69	72	68	66	54	62	64	69
Kibungo	8.8	88	83	95	88	94	93	95	87	80	74	77	92	94
	12.1	89	77	77	80	83	76	82	76	73	65	72	74	72
	14.4	90	95	84	90	84	86	93	79	75	73	69	53	56

Table 25. Effect of Warehouse, Moisture Content and Storage Time on Percentage Germination Capacity of Beans Stored in Plastic Bags.

Warehouse	% Moisture	Germination Capacity, Percent[a] (Storage Time, Months)												
		0	2	4	6	8	10	12	14	16	18	20	22	24
Kora	8.8	50	49	76	40	36	46	19	88	72	54	69	65	89
	12.1	58	48	94	61	64	87	18	89	72	79	82	90	93
	14.4	64	52	76	65	54	69	17	60	32	75	75	91	78
Nyanza	8.8	50	60	90	49	55	86	16	60	72	60	86	76	91
	12.1	58	89	51	65	36	18	16	72	51	74	77	68	58
	14.4	64	77	50	58	63	18	4	42	11	48	72	71	56
Kibungo	8.8	50	63	76	36	52	59	43	67	36	73	84	86	77
	12.1	58	78	70	62	23	76	21	8	68	77	82	98	78
1	14.4	64	76	80	47	21	56	3	10	9	21	42	45	23

[a] means of two replicate 100 bean tests

Table 26. Munsell Color Change Data (Plastic Bags)

Warehouse: Kora Initial Moisture Content: 8.8%

Variety	0 Months	2 Months
yellow/green	5Y $\frac{7}{10}$, $\frac{7}{8}$	7.5Y $\frac{7}{10}$
red	5R $\frac{2}{6}$ and 10R $\frac{2}{4}$	5R $\frac{2}{6}$, $\frac{3}{6}$
cream	7.5YR $\frac{7}{4}$ and 10YR $\frac{8}{4}$	7.5YR $\frac{7}{4}$ and 10YR $\frac{7}{4}$
brown	10YR $\frac{4}{4}$, $\frac{5}{4}$	–[a]
zebra-striped cream background	7.5YR $\frac{8}{2}$ and 5YR $\frac{9}{2}$	7.5YR $\frac{8}{4}$
red/purple	–[b]	10RP $\frac{3}{1}$, $\frac{2}{1}$

[a] unable to find variety in 2 month sample.
[b] 0 month data in error

Guide to Abbreviations
Y = yellow
R = red
YR = yellow/red
RP = red/purple

Example: 10YR hue
$\frac{4}{4}$ degree of lightness (value)
degree of saturation (chroma)

as value increases, color is lighter
as chroma increases, color is more saturated

Table 27. Munsell Color Change Data (Plastic Bags)

Warehouse: Kora Initial Moisture Content: 12.1%

Variety	0 Months	2 Months
yellow/green	7.5Y $\frac{7}{6}$, $\frac{7}{8}$	7.5Y $\frac{5}{8}$, $\frac{7}{8}$
red	7.5R $\frac{2}{4}$, $\frac{2}{6}$	5R $\frac{2}{4}$, $\frac{2}{6}$
cream	10YR $\frac{8}{2}$	10YR $\frac{7}{2}$
brown	10YR $\frac{4}{4}$	10YR $\frac{3}{4}$, $\frac{4}{4}$
zebra-striped cream background	7.5YR $\frac{8}{2}$	7.5YR $\frac{7}{4}$
red/purple	-[a]	10RP $\frac{2}{2}$

[a]0 month data in error.

Guide to Abbreviations
Y = yellow
R = red
YR = yellow/red
RP = red/purple

Example: 10YR hue
$\frac{4}{4}$ degree of lightness (value)
degree of saturation (chroma)

as value increases, color is lighter
as chroma increases, color is more saturated

Table 28. Munsell Color Change Data (Plastic Bags)

Warehouse: Kora Initial Moisture Content: 14.4%

Variety	0 Months	2 Months
yellow/green	-[a]	7.5Y $\frac{6}{10}$, $\frac{7}{8}$ and 5Y $\frac{7}{8}$
red	-[a]	2.5R $\frac{2}{8}$ and 5R $\frac{2}{8}$
cream	7.5YR $\frac{8}{4}$	10YR $\frac{6}{2}$
brown	10YR $\frac{3}{6}$	10YR $\frac{3}{4}$, $\frac{3}{6}$
zebra-striped cream background	7.5YR $\frac{8}{4}$	-[b]
red/purple	10RP $\frac{2}{4}$, $\frac{3}{2}$	10RP $\frac{2}{2}$

[a]unable to find variety in 0 month sample.
[b]unable to find variety in 2 month sample.

Guide to Abbreviations
Y = yellow
R = red
YR = yellow/red
RP = red/purple

Example: 10YR hue
$\frac{4}{4}$ degree of lightness (value)
degree of saturation (chroma)

as value increases, color is lighter
as chroma increases, color is more saturated

Table 29. Munsell Color Change Data (Plastic Bags)

Warehouse: Nyanza Initial Moisture Content: 8.8%

Variety	0 Months	2 Months
yellow/green	5Y $\frac{7}{10}$, 5Y $\frac{7}{8}$	7.5Y $\frac{8}{8}$ and 5Y $\frac{5}{8}$
red	5R $\frac{2}{6}$ and 10R $\frac{2}{4}$	5R $\frac{2}{8}$ and 2.5R $\frac{2}{6}$
cream	7.5YR $\frac{7}{4}$ and 10YR $\frac{8}{4}$	2.5YR $\frac{6}{2}$ and 10YR $\frac{6}{4}$
brown	10YR $\frac{4}{4}$ and 10YR $\frac{5}{4}$	10YR $\frac{3}{4}$
zebra-striped cream background	7.5YR $\frac{8}{2}$ and 5YR $\frac{9}{2}$	7.5YR $\frac{7}{4}$
red/purple	-[a]	10RP $\frac{2}{2}$

[a]0 month data in error.

Guide to Abbreviations
Y = yellow
R = red
YR = yellow/red
RP = red/purple

Example: 10YR hue
$\frac{4}{4}$ degree of lightness (value)
degree of saturation (chroma)

as value increases, color is lighter
as chroma increases, color is more saturated

Table 30. Munsell Color Change Data (Plastic Bags)

Warehouse: Nyanza Initial Moisture Content: 12.1%

Variety	0 Months	2 Months
yellow/green	7.5Y $\frac{7}{6}$, $\frac{7}{8}$	7.5Y $\frac{6}{10}$, $\frac{7}{8}$ and 2.5Y $\frac{6}{8}$
red	7.5R $\frac{2}{4}$, $\frac{2}{6}$	2.5R $\frac{3}{6}$, $\frac{2}{6}$
cream	10YR $\frac{8}{2}$	10YR $\frac{3}{4}$ and 7.5 $\frac{7}{4}$
brown	10YR $\frac{4}{4}$	10YR $\frac{3}{4}$
zebra-striped cream background	7.5YR $\frac{8}{2}$	7.5YR $\frac{8}{4}$
red/purple	-[a]	10RP $\frac{2}{1}$

[a]0 month data in error.

Guide to Abbreviations
Y = yellow
R = red
YR = yellow/red
RP = red/purple

Example: 10YR hue
$\frac{4}{4}$ degree of lightness (value)
degree of saturation (chroma)

as value increases, color is lighter
as chroma increases, color is more saturated

Table 31. Munsell Color Change Data (Plastic Bags)

Warehouse: Nyanza Initial Moisture Content: 14.4%

Variety	0 Months	2 Months
yellow/green	-[a]	5Y $\frac{7}{10}$, $\frac{7}{8}$
red	-[a]	-[b]
cream	7.5YR $\frac{8}{4}$	-[b]
brown	10YR $\frac{3}{6}$	7.5YR $\frac{4}{4}$
zebra-striped cream background	7.5YR $\frac{8}{4}$	7.5YR $\frac{7}{6}$
red/purple	10RP $\frac{2}{4}$, $\frac{3}{2}$	10RP $\frac{2}{1}$

[a]unable to find variety in 0 month sample.
[b]unable to find variety in 2 month sample.

Guide to Abbreviations
Y = yellow
R = red
YR = yellow/red
RP = red/purple

Example: 10YR hue
$\frac{4}{4}$ degree of lightness (value)
degree of saturation (chroma)

as value increases, color is lighter
as chroma increases, color is more saturated

Table 32. Munsell Color Change Data (Plastic Bags)

Warehouse: Kibungo Initial Moisture Content: 8.8%

Variety	0 Months	2 Months
yellow/green	5Y $\frac{7}{10}$, $\frac{7}{8}$	7.5Y $\frac{6}{6}$ and 5Y $\frac{7}{8}$
red	5R $\frac{2}{6}$ and 10R $\frac{2}{4}$	5R $\frac{2}{6}$, $\frac{3}{6}$
cream	7.5YR $\frac{7}{4}$ and 10YR $\frac{8}{4}$	7.5YR $\frac{8}{2}$
brown	10YR $\frac{4}{4}$, $\frac{5}{4}$	10YR $\frac{3}{6}$ and 7.5YR $\frac{3}{4}$
zebra-striped cream background	7.5YR $\frac{8}{2}$ and 5YR $\frac{9}{2}$	-[a]
red/purple	-[b]	10RP $\frac{2}{2}$, $\frac{3}{2}$

[a] 0 month data in error.
[b] unable to find variety in 2 month sample.

Guide to Abbreviations
Y = yellow
R = red
YR = yellow/red
RP = red/purple

Example: 10YR hue
$\frac{4}{4}$ degree of lightness (value)
degree of saturation (chroma)

as value increases, color is lighter
as chroma increases, color is more saturated

Table 33. Munsell Color Change Data (Plastic Bags)

Warehouse: Kibungo Initial Moisture Content: 12.1%

Variety	0 Months	2 Months
yellow/green	7.5Y $\frac{7}{6}$, $\frac{7}{8}$	7.5Y $\frac{7}{10}$ and 5Y $\frac{7}{8}$
red	7.5R $\frac{2}{4}$, $\frac{2}{6}$	5R $\frac{3}{4}$
cream	10YR $\frac{8}{2}$	5YR $\frac{8}{2}$ and 7.5YR $\frac{7}{4}$
brown	10YR $\frac{4}{4}$	5.5YR $\frac{3}{6}$, $\frac{3}{4}$
zebra-striped cream background	7.5YR $\frac{8}{2}$	7.5YR $\frac{8}{4}$ and 10YR $\frac{7}{4}$
red/purple	-a	10RP $\frac{2}{2}$

[a]0 month data in error.

Guide to Abbreviations
Y = yellow
R = red
YR = yellow/red
RP = red/purple

Example: 10YR hue
$\frac{4}{4}$ degree of lightness (value)
degree of saturation (chroma)

as value increases, color is lighter
as chroma increases, color is more saturated

Table 34. Munsell Color Change Data (Plastic Bags)

Warehouse: Kibungo Initial Moisture Content: 14.4%

Variety	0 Months	2 Months
yellow/green	-[a]	5Y $\frac{6}{6}$ and 7.5Y $\frac{7}{12}$
red	-[a]	5R $\frac{2}{6}$
cream	7.5YR $\frac{8}{4}$	10YR $\frac{8}{4}$
brown	10YR $\frac{3}{6}$	7.5YR $\frac{4}{4}$ and 10YR $\frac{3}{6}$
zebra-striped cream background	7.5YR $\frac{8}{4}$	7.5YR $\frac{8}{4}$, $\frac{7}{6}$
red/purple	10RP $\frac{2}{4}$, $\frac{3}{2}$	10RP $\frac{2}{1}$, $\frac{2}{2}$

[a]unable to find variety in 0 month sample.

Guide to Abbreviations
Y = yellow
R = red
YR = yellow/red
RP = red/purple

Example: 10YR hue
$\frac{4}{4}$ degree of lightness (value)
degree of saturation (chroma)

as value increases, color is lighter
as chroma increases, color is more saturated

Table 35. Effect of time on damage levels in beans stored at three moisture contents in unlined jute bags at Kora

Damage Category	Moisture Content					
	8.8%		12.1%		14.4%	
	0 Months	2 Months	0 Months	2 Months	0 Months	2 Months
Wrinkled	11[a]	16	21	15	13	12
Shriveled	8	10	13	8	12	6
Discolored	1	11	-	12	-	8
Insect Damage	1	-	2	-	2	1
Dented	13	6	7	7	5	7
Torn Pericarp	11	-	9	-	6	-
Broken	1	3	-	1	1	1
Germinated	-	-	-	-	-	-
Visible Mold	-	-	-	-	-	2
Rodent Damage	-	-	-	-	-	-
Test Weight, g	826.5[b]	-[c]	830.6	-	841.4	-

a) Number of beans damaged in a 100 g sample (mean of three determinations)

b) Single determination

c) Insufficient sample

Table 36. Effect of time on damage levels in beans stored at three moisture contents in unlined jute bags at Nyanza

Damage Category	Moisture Content					
	8.8%		12.1%		14.4%	
	0 Months	2 Months	0 Months	2 Months	0 Months	2 Months
Wrinkled	11[a)]	15	21	12	13	14
Shriveled	8	7	13	9	12	6
Discolored	1	6	-	6	-	7
Insect Damage	1	1	2	2	2	-
Dented	13	11	7	8	5	7
Torn Pericarp	11	-	9	-	6	-
Broken	1	2	-	1	1	-
Germinated	-	-	-	-	-	-
Visible Mold	-	-	1	-	-	-
Rodent Damage	-	-	-	-	-	-
Test Weight, g	826.5[b)]	-[c)]	830.6	-	841.4	-

a)Number of beans damaged in a 100 g sample (mean of three determinations)

b)Single determination

c)Insufficient sample

Table 37. Effect of time on damage levels in beans stored at three moisture contents in unlined jute bags at Kibungo

Damage Category	Moisture Content					
	8.8%		12.1%		14.4%	
	0 Months	2 Months	0 Months	2 Months	0 Months	2 Months
Wrinkled	11[a]	14	21	11	13	13
Shriveled	8	7	13	6	12	8
Discolored	1	10	-	10	-	8
Insect Damage	1	1	2	1	2	2
Dented	13	7	7	8	5	6
Torn Pericarp	11	1	9	1	6	-
Broken	1	-	-	1	1	1
Germinated	-	-	-	-	-	-
Visible Mold	-	-	1	-	-	-
Rodent Damage	-	-	-	-	-	-
Test Weight, g	826.5[b]	-[c]	830.6	-	841.4	-

a) Number of beans damaged in a 100 g sample (mean of three determinations)

b) Single determination

c) Insufficient sample

Table 38. Effect of time on damage levels in beans stored at three moisture contents in plastic-lined bags at Kora

Damage Category	Moisture Content					
	8.8%		12.1%		14.4%	
	0 Months	2 Months	0 Months	2 Months	0 Months	2 Months
Wrinkled	11[a)]	16	21	11	13	12
Shriveled	8	9	13	7	12	12
Discolored	1	7	-	8	-	8
Insect Damage	1	1	2	1	2	-
Dented	13	8	7	7	5	11
Torn Pericarp	11	-	9	1	6	-
Broken	1	-	-	-	1	2
Germinated	-	-	-	-	7	-
Visible Mold	-	-	1	-	-	-
Rodent Damage	-	-	-	-	-	-
Test Weight, g	826.5[b)]	825.0	830.6	818.1	841.4	792.7

a)Number of beans damaged in a 100 g sample (mean of three determinations)

b)Single determination

c)Insufficient sample

Table 39. Effect of time on damage levels in beans stored at three moisture contents in plastic-lined bags at Nyanza

Damage Category	Moisture Content					
	8.8%		12.1%		14.4%	
	0 Months	2 Months	0 Months	2 Months	0 Months	2 Months
Wrinkled	11[a)]	17	21	14	13	19
Shriveled	8	6	13	9	12	10
Discolored	1	7	-	7	-	5
Insect Damage	1	2	2	2	2	2
Dented	13	8	7	8	5	7
Torn Pericarp	11	2	9	-	6	2
Broken	1	2	-	-	1	1
Germinated	-	-	-	1	-	-
Visible Mold	-	2	1	-	-	-
Rodent Damage	-	-	-	-	-	-
Test Weight, g	826.5[b)]	821.1	830.6	814.9	841.4	813.3

a)Number of beans damaged in a 100 g sample (mean of three determinations)

b)Single determination

c)Insufficient sample

Table 40. Effect of time on damage levels in beans stored at three moisture contents in plastic-lined bags at Kibungo

Damage Category	Moisture Content					
	8.8%		12.1%		14.4%	
	0 Months	2 Months	0 Months	2 Months	0 Months	2 Months
Wrinkled	11[a)]	11	21	18	13	16
Shriveled	8	14	13	9	12	10
Discolored	1	6	-	5	-	4
Insect Damage	1	-	2	-	2	1
Dented	13	5	7	9	5	5
Torn Pericarp	11	1	9	-	6	-
Broken	1	1	-	1	1	1
Germinated	-	-	-	-	-	-
Visible Mold	-	-	1	-	-	-
Rodent Damage	-	-	-	-	-	-
Test Weight, g	826.5[b)]	831.5	830.6	815.0	841.4	812.8

a)Number of beans damaged in a 100 g sample (mean of three determinations)

b)Single determination

c)Insufficient sample

Table 41. Hardness of Water from the Kicukiro Lab

Sample	Hardness (mg/L as $CaCO_3$)	
	Ca Hardness	Total Hardness
Tap water, Sample 1 1/23/87	110.0	110.0
Tap water, Sample 2 1/26/87	110.0	120.0
Boiled water, Sample 1 1/23/87	100.0	150.0
Boiled water, Sample 2 1/26/87	180.0	200.0
Boiled water (15 min.) 1/24/87	*	80.0
Boiled water (40 min.) 1/24/87	70.0	100.0

* Insufficient sample for Ca hardness. Most of the sample leaked from the vial during transport here from Rwanda; the cap was not on tight.

3/6/87 Analyses by: Ingman Laboratories, Inc.
2945 34th Avenue South
Minneapolis, MN 55406

SECTION V

LAB STORAGE STUDIES

ABSTRACT

Two separate studies were conducted. In each study beans were stored at three temperatures and three water activities (Study I) or three moisture levels (Study II) for a period of two years. Instrumental measures of hardness were made using a puncture test on beans cooked for three hours. The Munsell color system was used to describe changes in seedcoat color that occurred during storage. Both hardness and color were measured at four-month intervals. Storage temperature and water activity affected both the hardness and color of the beans. Beans stored at the higher temperatures and the higher relative humidities were harder and showed greater color changes. Most color changes involved darkening; if the hue shifted it was typically towards a more yellow or orange color.

INTRODUCTION

A considerable body of literature exists that deals with loss of cookability in legumes and the influence of storage conditions on this loss of cookability. Beans stored at high moisture contents and high temperatures become hard to cook more readily than beans stored at lower moisture contents and lower temperatures. However, no studies of this type have been conducted on Rwandan beans. One purpose of the studies reported here was to determine whether Rwandan beans respond to temperatures and water activities of storage in a manner similar to other beans that have been studied. Another goal of this

study was to provide supplementary data to the large scale bag study. In the large scale bag study the moisture content of the beans is set to three different levels, but the storage temperature is variable and dependent on the temperature at the three storage locations in different regions of Rwanda. In this laboratory study we have controlled both the moisture content of the beans and the storage temperature.

Two separate storage studies were conducted. The first study began in September 1984 and was not paralleled by a large scale bag study. In this first study the lowest storage temperature was 4°C, which was the only temperature lower than room temperature available at that time. Also in the first study the beans were stored in desiccators over different salt solutions. When the storage temperatures were altered, the water activities were also altered resulting in different moisture contents among beans stored over the same salt solutions but at different temperatures.

The second study began in February 1986 and parallels the large scale bag study. This second lab storage study used the bean mixture as it was prepared for the large scale bag study. Instead of storing the beans over saturated salt solutions, beans for this second lab storage study were placed in sealed bags and stored at three different temperatures. The lab storage conditions differ from the storage conditions of the large scale bag study in that the storage temperature is held constant in the lab storage test. The primary objective of these laboratory storage tests is to determine the effect of the factors storage temperature and moisture content on the cookability and color of beans as they are stored for a two year period.

MATERIALS AND METHODS - STUDY I

A. Beans

Approximately 20 kg of a Rwandan bean mixture were harvested on 8/27/84 from fields in low-lying areas of Kigali prefecture, commune Mbogo, secteur Ruhanga. After harvest the pods were removed and the beans were transferred to a jute bag for delivery to OPROVIA. Upon arrival on the following day, the beans were tested for moisture content (wet basis) using a Motomco moisture meter (Model 919, Motomco Inc., 267 Vreeland Ave., Box 300, Paterson, NJ 07543). Three replicate Motomco readings were taken using the same 250 g sample. The mean of these three readings was substituted into the following calibration curve:

$$\% \text{ moisture content} = 7.95 + 0.17 \text{ (Motomco reading)}$$

This preliminary calibration curve was developed in the OPROVIA laboratory in April 1984 using a Rwandan bean mixture and a pure variety.

B. Drying Procedure

Since the moisture content of the beans was too high to be read from the Motomco scale, they were dried to a level which would register on the scale. Approximately 12 kg of the original 20 kg were dried in six 2-kg batches in a mechanical convection oven (Blue M Stabil-Therm, Model OV500C-2Y, Blue Island, IL 60406) at 40°C. The beans were spread out in thin layers on metal trays and placed on the upper 2 shelves in the oven. Moisture content was roughly monitored by measuring moisture content with the Motomco at approximately 60 min. intervals until it had dropped to a measureable level.

After drying, the batches were combined and stored for approximately two days in a closed plastic container in the laboratory until drying was completed. The final moisture content of this mixture by the Motomco was 18.3%. The beans were then divided into three parts each of which was dried further using the procedure described above to one of the following moisture contents: 9%, 12% and 15%. After drying, they were allowed to cool in the laboratory for two hr before being transferred to plastic bags for temporary storage (not more than five days) in a refrigerator at 6°C.

C. Storage

Beans at each moisture content were further divided into three lots (1300 g each) and placed on a thin layer of glass wool in desiccators (Nalge #5310, 250 mm, Fisher Scientific Co., 6990 Shady Oak Rd., Eden Prairie, MN 55344) over saturated salt solutions under different water activity (a_w) and temperature conditions. The saturated salt solutions were chosen to maintain water activities in approximate equilibrium with the moisture contents of the beans (Greenspan, 1977; Weston and Morris, 1954). The 9% moisture beans were stored over a saturated solution of magnesium chloride (a_w = about 0.33); the 12% moisture beans were stored over a saturated solution of magnesium nitrate (a_w = about 0.53); and the 15% moisture beans were stored over a saturated solution of postassium iodide (a_w = about 0.69). A desiccator containing beans at each moisture content was stored at each of the following temperatures: 4, 23 and 30°C (39, 73, and 86°F, respectively). The 4°C storage temperature was maintained in a refrigerator (Model D 13-M Frigidaire Co., P.O. Box WC 4900, 3555 S. Kettering Blvd.,

Dayton, OH 45449). The 23°C (ambient air) storage temperature was maintained in a closed metal cabinet in the laboratory. The 30°C temperature was maintained in an incubator (Precision Model 815, Precision Scientific Group, 3737 West Cortland St., Chicago, IL 60647).

D. Laboratory Tests

Both instrumental hardness and color analysis tests were conducted on the samples at four month intervals beginning with 0 months storage.

1. Instrumental hardness

A 1/3 cup sample (approximately 150 beans) from each treatment was cooked and tested for instrumental hardness (mean grams force, % > 450 g) according to the standard cooking and hardness testing procedure described in Section I of this final report.

2. Color analyses

Six bean types from the mixture were chosen for seedcoat color analysis according to their predominance in the mixture or how well they might be expected to show color changes over time (i.e. light-colored types were chosen rather than dark-colored types). These types were described according to the system developed by Lamb and Hardman (1986) (see Table 42). The beans were not described by shininess or size. The Munsell color system was used to describe seedcoat color (see Section VII of this final report).

Table 42. Description of bean types used for color analysis

Variety #	Seed Shape[a)]	Color Pattern[b)]	Color[c)]
1	ro	mc	n
2	ro	mc	j
3	rp	mc	rg
4	ro	mc	rs
5	ro	mc	jbr
6	lo	mc	rgpr

a) ro = rounded oval
rp = rounded flat
lo = elongate oval

b) mc = single color

c) n = black
j = yellow
rg = red
rs = pink
jbr = yellow/brown
rgpr = red/purple

In some cases one or more of the bean types could not be found in the samples used for color analysis. In these cases, the types were listed as "data not available" in the color change tables. In addition, beans of the same type frequently differed noticeably in color within a sample. When this occurred, the different colors of not more than four beans of the same type were listed in the color change tables.

MATERIALS AND METHODS - STUDY II

A. Beans

Bean mixtures purchased in different regions of Rwanda were mixed together to form a 'master' mixture which was used in this study and also in the Large Scale Bagged Study (Section IV of this final report). The mixture was divided into three parts and dried to three different moisture contents, 8.8, 12.1, and 14.4%, using the methodology reported for the Large Scale Bagged Study. Descriptions of the mixing and drying procedures used to prepare the beans for storage and the varietal characteristics of the mixtures are given in Section IV of this final report.

B. Storage

A 4 kg portion of beans from each of the three moisture classes was divided into three subportions (about 1.3 kg each); one of the subportions was stored at each of three temperatures: 15, 23, and 30°C (59, 73, and 86°F respectively) for a total of nine treatments. The beans were put into plastic bags such that the bags were completely filled. The bags were

sealed with adhesive tape. Each plastic bag was marked with the initial sample moisture content and storage temperature. The 15 and 30°C storage temperatures were maintained in incubators (Precision model 815, Precision Scientific Group, 3737 W. Cortland St., Chicago, IL 60617); the 23°C storage temperature (ambient air) was maintained in a closed metal cabinet in the laboratory.

This Laboratory Storage Study differs from the first in the bean mixture used, the time of harvest, the sealed storage (beans were not placed in sealed bags in Lab Storage Test I), and the lowest storage temperature (15° in this study vs 4° in Lab Study I).

C. Laboratory tests

1. Instrumental hardness

Beginning with zero months storage and at four month intervals through 24 months storage, a 1/3 cup portion (approximately 150 beans) of each treatment was removed from storage and evaluated for instrumental hardness (mean grams force; % $\geq$ 450 g) using the cooking and instrumental hardness procedures described in Section I of this final report.

2. Color analysis

Six bean types were chosen for seedcoat color analysis according to their predominance in the mixture and/or how well they might be expected to show color changes over time. Color analyses were done at four month intervals. The types chosen for color analysis were the same as those used for color analysis in Section 4 of this final report.

3. Oven-dry moisture content determinations

At four month intervals, the moisture contents of three 10 g replicates of each treatement were determined using AACC method 44-15A for whole beans.

RESULTS

Lab Storage Study I

Instrumental Hardness

Instrumental hardness data are shown in Table 43. Plots of the data collected through 20 months storage are shown in Figures 45-60.

The results in terms of percentages of hard-to-cook (HTC) beans gave rise to the following conclusions. The newly harvested beans (at zero storage time) had a baseline percentage HTC of 11 to 14%. We can assume that this level of HTC beans is quite acceptable and may only reflect a difference in firmness of fully cooked individual beans. This could be a reflection of the large number of bean types in these Rwandan bean mixtures. Most of the literature reports on bean hardness and the hard-to-cook problem have dealt with lots of beans of a single type, for example, navy beans, black beans, kidney beans, pinto beans, etc.

At the 4°C storage temperature, regardless of water activity (a_w), there was no change in cookability after two years storage. Percentage HTC ranged from 3 to 30%. There was no trend to indicate that a_w influenced cookability; ranges of % HTC at 0.33, 0.53 and 0.69 a_w levels were 10-28%, 3-23% and 4-30%, respectively. Despite the fact that moisture content increased from an initial

Table 43. Influence of Water Activity (a_w), Temperature and Storage Time on Instrumental Hardness.

I. Percent Hard-to-Cook Beans ($\geq$ 450 g)

Temp. °C	a_w	Storage Time, Months 0	4	8	12	16	20	24
4	0.33	11	14	10	21	28	15	15
	0.53	11	8	5	3	19	23	7
	0.69	14	22	12	4	15	30	26
23	0.33	11	32	23	9	27	30	29
	0.53	11	19	23	16	21	42	41
	0.69	14	17	31	27	35	79	80
30	0.33	11	29	18	17	26	33	41
	0.53	11	31	11	19	35	53	57
	0.69	14	29	37	35	28	100	100

II. Mean Grams Force[a]

4	0.33	285	332	294	357	360	303	333
	0.53	334	319	295	266	340	351	331
	0.69	330	359	323	278	344	367	343
23	0.33	285	359	357	312	371	387	369
	0.53	334	341	366	317	325	399	379
	0.69	330	349	379	314	350	466	456
30	0.33	285	354	344	325	360	385	382
	0.53	334	349	312	309	349	439	411
	0.69	330	325	354	320	346	494	>500

[a] values are means of 100 determinations on randomly selected individual beans

14.6% in the 4°C, 0.69 a_w storage condition to 17-18% after one year of storage, this apparently did not affect cookability. The moisture increase was probably caused by periodic electricity outages and resulting temperature fluctuations in the refrigerated storage cabinet, which could have caused moisture to condense on the beans. Bean moisture content remained fairly constant at the 23°C and 30°C conditions. Thus, for storage of Rwandan mixed beans for up to 24 months at 4°C, a_w appeared not to affect cookability.

At the 23°C storage condition, there was only a slightly higher percentage of HTC beans after two years when the a_w was low (0.33); the % HTC ranged from 9 to 32%. Even at the 0.53 level, no appreciable increase in HTC was observed until 20 months storage, when % HTC reached about 40. However, at 0.69 a_w, there was a definite increase in hardness at 18 months (75% HTC) and little further change up to 24 months (80% HTC).

At the 30°C storage condition, hardness did not essentially change over 16 to 20 months at 0.33 a_w (11-33% HTC), but edged upward at 24 months (41% HTC). There was the beginning of a trend toward increased hardness after 16 months at 0.53 a_w (35% HTC) and a definite increase in hardness at 20 months (53% HTC) and 24 months (57% HTC). At 0.69 a_w, the results were less clear; it appeared that the beans began to increase in hardness after 8 to 12 months storage but the 16 month data seemed to indicate a leveling off or reversal of this trend. However, it was very clear that after 18, 20, and 24 months the beans were uncookable (84, 100 and 100% HTC, respectively).

Color

The extent of the color changes appeared to increase as both temperature and relative humidity increased. Color analysis data are shown in Tables 44-52 for

fresh beans (0 months storage) and beans stored for 20 months. (The 24 month data was not available at the time this report was prepared.) The color changes that occurred can be summarized as follows:

The purple beans become darker.

The yellow-brown beans changed to a more yellow hue and also darkened.

The pink beans changed to a more orange hue and also darkened.

The dark red beans changed to a more orange hue and also browned, darkened or faded.

The yellow green beans tended to darken and become more yellow or orange. However color data on these beans was often not available due to absence of beans in the mixture.

Lab Storage Study II

At the time this manuscript was prepared only the 0 to 8 month instrumental hardness data was available for this study (Table 53). Data will be added to the table as the study progresses.

CONCLUSION

Lab Storage Study I

In summary, Rwandan mixed beans can be expected to remain cookable for at least 24 months if they are stored at 4°C and in the range of 11.0 to 14.6% moisture which corresponds with 0.33 to 0.69 a_w. As storage temperature increases, moisture content becomes more important. The beans can be safely stored for 24 months at 23°C if the a_w/moisture condition is sufficiently low (a_w 0.33, 11%). The expected maximum time of storage drops, however, to 16 months at the two higher a_w conditions (0.53 and 0.69).

Lab Storage Study #1

Table 44. Munsell Color Change Data

Storage Temperature: 4°C Storage Water Activity: 0.33%

Bean Type Color	4 months	20 months	Change Noted
black	N 0.5/0.6% R, and N 1/1.2% R	N 0.5/0.6% R	no change
yellow/ green	-	-	data not available
dark red	10R $\frac{2}{6}$ 5R $\frac{2}{8}$, $\frac{3}{8}$, $\frac{3}{10}$	5R $\frac{2}{8}$	slight browning
pink	5R $\frac{6}{6}$, $\frac{7}{4}$	10R $\frac{5}{4}$ and 7.5R $\frac{5}{4}$	slight darkening
yellow/ brown	10YR $\frac{5}{10}$, $\frac{6}{12}$	10YR $\frac{5}{10}$	no change
purple	10RP $\frac{2}{4}$, $\frac{2}{6}$, $\frac{4}{4}$	10RP $\frac{2}{2}$	color less saturated, grayer

Guide to Abbreviations

% R = percent reflectance
N = black
R = red
YR = yellow/red
RP = red/purple
Y = yellow

Example:

1) 10R - Hue (red)
$\frac{2}{6}$ - degree of lightness (value)
$\frac{2}{6}$ - degree of saturation (chroma)

As value scores increase, color is lighter.
As chroma scores increase, color is more saturated.

2) N 0.5/0.6% R = number designation of black color/percentage reflectance

Lab Storage Study #1

Table 45. Munsell Color Change Data

Storage Temperature: 4°C Storage Water Activity: 0.53%

Bean Type Color	4 months	20 months	Change Noted
black	N 0.5/0.6% R, and N 1.5/2.0% R	N 0.5/0.6% R, and N 0.75/0.9% R	no change
yellow/ green	-	-	data not available
dark red	2.5R $\frac{2}{4}$, $\frac{2}{6}$, $\frac{2}{8}$	2.5R $\frac{2}{4}$ and 5R $\frac{2}{4}$	slight change of hue towards orange
pink	2.5R $\frac{6}{6}$, $\frac{7}{4}$	7.5R $\frac{6}{4}$ and 10R $\frac{5}{4}$	change of hue towards orange
yellow/ brown	10YR $\frac{6}{8}$, $\frac{5}{10}$, $\frac{6}{12}$	10YR $\frac{5}{10}$	no change
purple	10RP $\frac{2}{1}$, $\frac{2}{4}$, $\frac{2}{6}$	10RP $\frac{2}{2}$	no change

Guide to Abbreviations

% R = percent reflectance
N = black
R = red
YR = yellow/red
RP = red/purple
Y = yellow

Example:

1) 10R - Hue (red)
$\frac{2}{6}$ - degree of lightness (value)
- degree of saturation (chroma)

As value scores increase, color is lighter.
As chroma scores increase, color is more saturated.

2) N 0.5/0.6% R = number designation of black color/percentage reflectance

Lab Storage Study #1

Table 46. Munsell Color Change Data

Storage Temperature: 4°C Storage Water Activity: 0.69%

Bean Type Color	4 months	20 months	Change Noted
black	N 0.5/0.6% R, and N 1.5/2.0 R	N 0.5/0.6% R	no change
yellow/ green	-	-	data not available
dark red	7.5R $\frac{2}{4}$, $\frac{2}{8}$ and 5R $\frac{3}{10}$	5R $\frac{3}{4}$	fading
pink	5R $\frac{6}{6}$, $\frac{6}{6}$, $\frac{5}{6}$	7.5R $\frac{5}{4}$ and 5R $\frac{8}{6}$	change of hue towards orange; darkening
yellow/ brown	7.5YR $\frac{6}{12}$, $\frac{7}{10}$	10YR $\frac{5}{10}$, $\frac{6}{12}$, $\frac{7}{10}$	change of hue towards yellow; slight browning
purple	10RP $\frac{2}{6}$, $\frac{2}{2}$	10RP $\frac{2}{2}$	no change

Guide to Abbreviations

% R = percent reflectance
N = black
R = red
YR = yellow/red
RP = red/purple
Y = yellow

Example:

1) 10R - Hue (red)
$\frac{2}{6}$ - degree of lightness (value)
- degree of saturation (chroma)

As value scores increase, color is lighter.
As chroma scores increase, color is more saturated.

2) N 0.5/0.6% R = number designation of black color/percentage reflectance

Lab Storage Study #1
Table 47. Munsell Color Change Data
Storage Temperature: 23°C Storage Water Activity: 0.33%

Bean Type Color	4 months	20 months	Change Noted
black	N 0.5/0.6% R, and N 1.5/2.0% R	N 0.5/0.6% R	no change
yellow/ green	7.5Y $\frac{5}{10}$, $\frac{8}{8}$	7.5Y $\frac{7}{12}$ and 5Y[a] $\frac{6}{8}$	change of hue towards yellow, darkening
dark red	7.5R $\frac{2}{6}$, $\frac{3}{6}$ and 5R[b] $\frac{4}{4}$	10R $\frac{2}{8}$, $\frac{4}{4}$	change of hue towards oranges, darkening
pink	7.5R $\frac{7}{4}$ and 10R $\frac{6}{4}$	10R $\frac{5}{4}$	darkening
yellow/ brown	10YR[b] $\frac{5}{10}$, $\frac{6}{8}$	10YR $\frac{5}{8}$	no change
purple	10RP $\frac{2}{1}$, $\frac{2}{4}$, $\frac{3}{2}$	10RP $\frac{2}{4}$	no change

a)16 mo. data - unable to find variety in 20 mo. sample.
b)8 mo. data - 4 mo. data in error.

Guide to Abbreviations
% R = percent reflectance
N = black
R = red
YR = yellow/red
RP = red/purple
Y = yellow

Example:

1) 10R - Hue (red)
$\frac{2}{6}$ - degree of lightness (value)
- degree of saturation (chroma)
As value scores increase, color is lighter.
As chroma scores increase, color is more saturated.

2) N 0.5/0.6% R = number designation of black color/percentage reflectance

Lab Storage Study #1

Table 48. Munsell Color Change Data

Storage Temperature: 23°C Storage Water Activity: 0.53%

Bean Type Color	4 months	20 months	Change Noted
black	N 0.5/0.6% R, and N 1.25/1.6% R	-	at 20 mo. no good match with color charts
yellow/green	-	-	data not available
dark red	7.5R $\frac{2}{8}$, $\frac{2}{6}$	2.5R $\frac{2}{6}$	slight browning
pink	7.5R $\frac{6}{6}$, $\frac{5}{4}$	10R[a] $\frac{6}{4}$	variability in color ID between 4 and 16 mo. no overall change
yellow/brown	10YR[b] $\frac{5}{8}$, $\frac{5}{10}$, $\frac{6}{8}$	10YR $\frac{4}{8}$	browning, darkening
purple	10RP $\frac{2}{2}$, $\frac{3}{4}$	10RP $\frac{2}{2}$	variability in color ID between 4 and 20 mo. no overall change

a) 16 mo. data - unable to find variety in 20 mo. sample.
b) 8 mo. data - 4 mo. data in error.

Guide to Abbreviations

% R = percent reflectance
N = black
R = red
YR = yellow/red
RP = red/purple
Y = yellow

Example:

1) 10R - Hue (red)
$\frac{2}{6}$ - degree of lightness (value)
$\frac{2}{6}$ - degree of saturation (chroma)

As value scores increase, color is lighter.
As chroma scores increase, color is more saturated.

2) N 0.5/0.6% R = number designation of black color/percentage reflectance

Lab Storage Study #1

Table 49. Munsell Color Change Data

Storage Temperature: 23°C Storage Water Activity: 0.69%

Bean Type Color	4 months	20 months	Change Noted
black	N 0.5/0.6% R, and N 2/3.1% R	-	at 20 mo. no good match with color charts
yellow/green	7.5Y $\frac{8}{8}$, $\frac{8}{10}$	-	data not available at 20 mo.
dark red	2.5R $\frac{3}{6}$ and 7.5R[a] $\frac{2}{6}$, $\frac{2}{8}$	7.5R $\frac{2}{4}$ and 10R $\frac{2}{4}$	change of hue towards orange, darkening
pink	7.5R $\frac{6}{4}$, $\frac{6}{6}$	-	color at 20 mo. too dark - no good match with charts
yellow/brown	10YR $\frac{5}{10}$, $\frac{6}{12}$	7.5YR $\frac{4}{8}$ and 10YR $\frac{4}{8}$	no change
purple	10RP $\frac{2}{4}$	-	color at 20 mo. too dark - no good match with charts

a) 8 mo. data - 4 mo. data in error.

Guide to Abbreviations

% R = percent reflectance
N = black
R = red
YR = yellow/red
RP = red/purple
Y = yellow

Example:

1) 10R - Hue (red)
$\frac{2}{6}$ - degree of lightness (value)
- degree of saturation (chroma)
As value scores increase, color is lighter.
As chroma scores increase, color is more saturated.

2) N 0.5/0.6% R = number designation of black color/percentage reflectance

Lab Storage Study #1

Table 50. Munsell Color Change Data

Storage Temperature: 30°C Storage Water Activity: 0.33%

Bean Type Color	4 months	20 months	Change Noted
black	N 0.5/0.6% R, and N 1.75/2.5% R	-	at 20 mo. no good match with color charts
yellow/green	$\frac{5Y}{7}$[1], $\frac{8}{4}$[2]	$\frac{2.5Y}{7}$[1], and $\frac{5Y}{7}$[2] a)	[1]darkening [2]change of hue towards orange; color less saturated
dark red	$\frac{7.5R}{3}$, $\frac{2}{4}$	$\frac{7.5R}{2}$	variability in color ID - no overall change
pink	$\frac{7.5R}{5}$, $\frac{5}{4}$	$\frac{10R}{6}$ b)	change of hue towards orange; darkening
yellow/brown	$\frac{7.5YR}{5}$, $\frac{6}{10}$	$\frac{10YR}{4}$	darkening
purple	$\frac{10RP}{2}$, $\frac{4}{4}$	$\frac{10RP}{2}$	slight darkening

a) 16 mo. data - unable to find variety in 20 mo. sample.

b) 16 mo. data - unable to find variety in 20 mo. sample.

Guide to Abbreviations

% R = percent reflectance
N = black
R = red
YR = yellow/red
RP = red/purple
Y = yellow

Example:

1) 10R - Hue (red)
$\frac{2}{6}$ - degree of lightness (value)
- degree of saturation (chroma)
As value scores increase, color is lighter.
As chroma scores increase, color is more saturated.

2) N 0.5/0.6% R = number designation of black color/percentage reflectance

Lab Storage Study #1

Table 51. Munsell Color Change Data

Storage Temperature: 30°C Storage Water Activity: 0.53%

Bean Type	4 months	20 months	Change Noted
black	N 0.5/0.6% R, and N 1/1.2% R	-	at 20 mo. no good match with color charts
yellow/green	-	-	data not available
dark red	7.5R $\frac{2}{8}$, $\frac{3}{8}$	7.5R $\frac{2}{6}$	darkening
pink	7.5R $\frac{6}{6}$, $\frac{5}{6}$, $\frac{5}{8}$	-a)	color too dark to find good match with charts
yellow/brown	7.5YR $\frac{5}{8}$, $\frac{6}{10}$ and 10YR $\frac{6}{12}$	-	at 20 mo. color too dark to find good match with charts
purple	10RP $\frac{2}{6}$, $\frac{2}{4}$	-	at 20 mo. color too dark to find good match with charts

a) 16 mo. data - unable to find variety in 20 mo. sample.

Guide to Abbreviations

% R = percent reflectance
N = black
R = red
YR = yellow/red
RP = red/purple
Y = yellow

Example:

1) 10R - Hue (red)
$\frac{2}{6}$ - degree of lightness (value)
- degree of saturation (chroma)

As value scores increase, color is lighter.
As chroma scores increase, color is more saturated.

2) N 0.5/0.6% R = number designation of black color/percentage reflectance

Lab Storage Study #1

Table 52. Munsell Color Change Data

Storage Temperature: 30°C Storage Water Activity: 0.69%

Bean Type Color	4 months	20 months	Change Noted
black	N 0.5/0.6% R, and N 1/1.2% R	-	at 20 mo. no good match with color charts
yellow/green	-	-	data not available
dark red	7.5R $\frac{2}{4}$, $\frac{3}{6}$, $\frac{3}{8}$	7.5R[a] $\frac{2}{6}$	fading
pink	7.5R $\frac{6}{4}$, $\frac{6}{6}$	-[b]	color too dark to find good match with charts
yellow/brown	7.5YR $\frac{8}{2}$ and 10YR $\frac{5}{10}$, $\frac{6}{12}$	5YR -	change of hue towards yellow; browning, darkening
purple	10RP $\frac{2}{4}$, $\frac{2}{6}$, $\frac{3}{6}$	-[c]	color too dark to find good match with charts

a) 16 mo. data - unable to find variety in 20 mo. sample.
b) 16 mo. data - unable to find variety in 20 mo. sample.
c) 16 mo. data - unable to find vareity in 20 mo. sample.

Guide to Abbreviations

% R = percent reflectance
N = black
R = red
YR = yellow/red
RP = red/purple
Y = yellow

Example:

1) 10R - Hue (red)
$\frac{2}{6}$ - degree of lightness (value)
- degree of saturation (chroma)
As value scores increase, color is lighter.
As chroma scores increase, color is more saturated.

2) N 0.5/0.6% R = number designation of black color/percentage reflectance

Figure 45. Effect of storage time on instrumental hardness (mean grams force) averaged over relative humidities by temperature

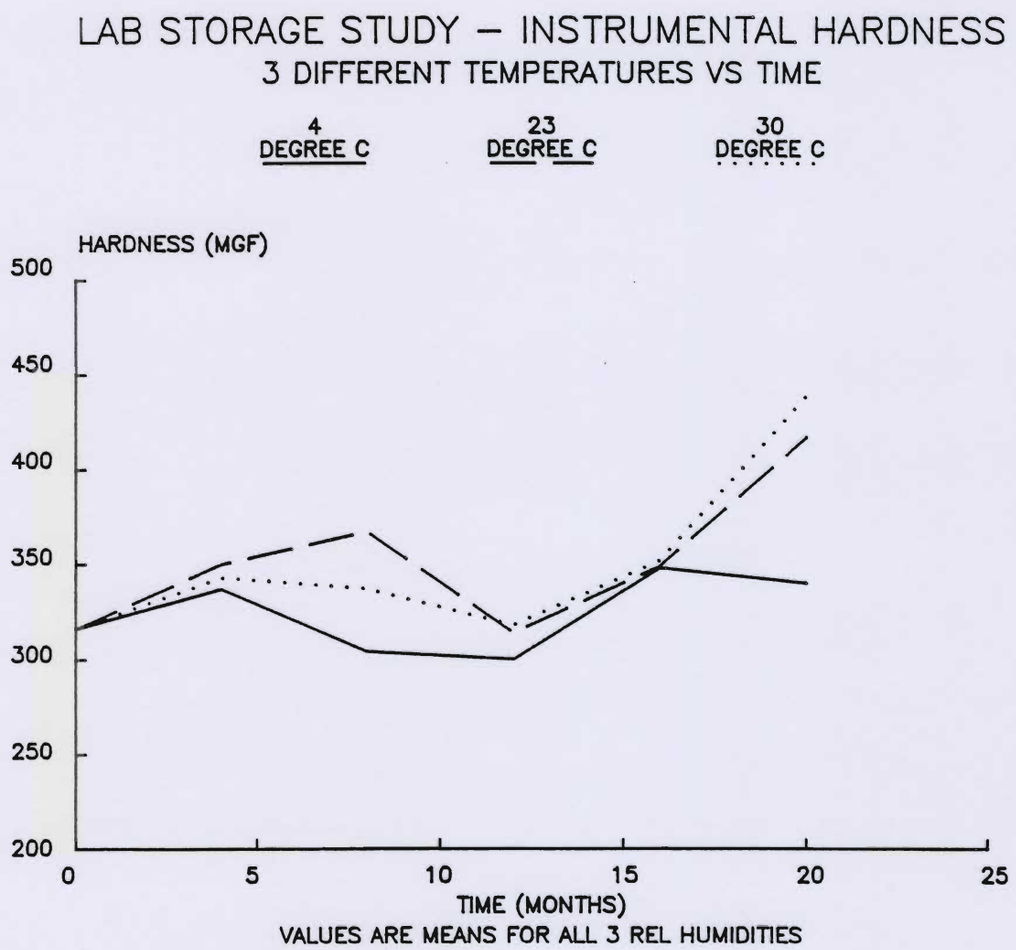


Figure 46. Effect of storage time on instrumental hardness (percentage hard-to-cook) averaged over relative humidities by temperature

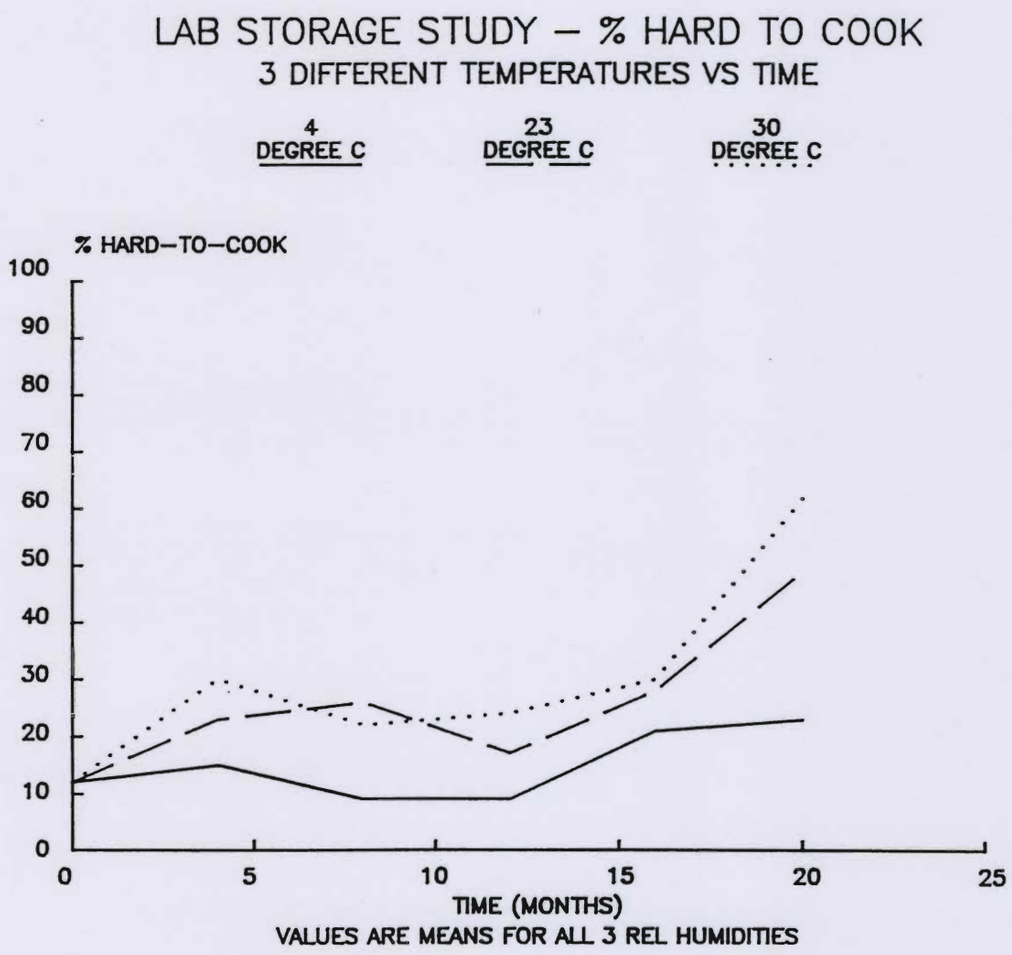


Figure 47. Effect of storage time on instrumental hardness (mean grams force) of beans at 4°C by relative humidity

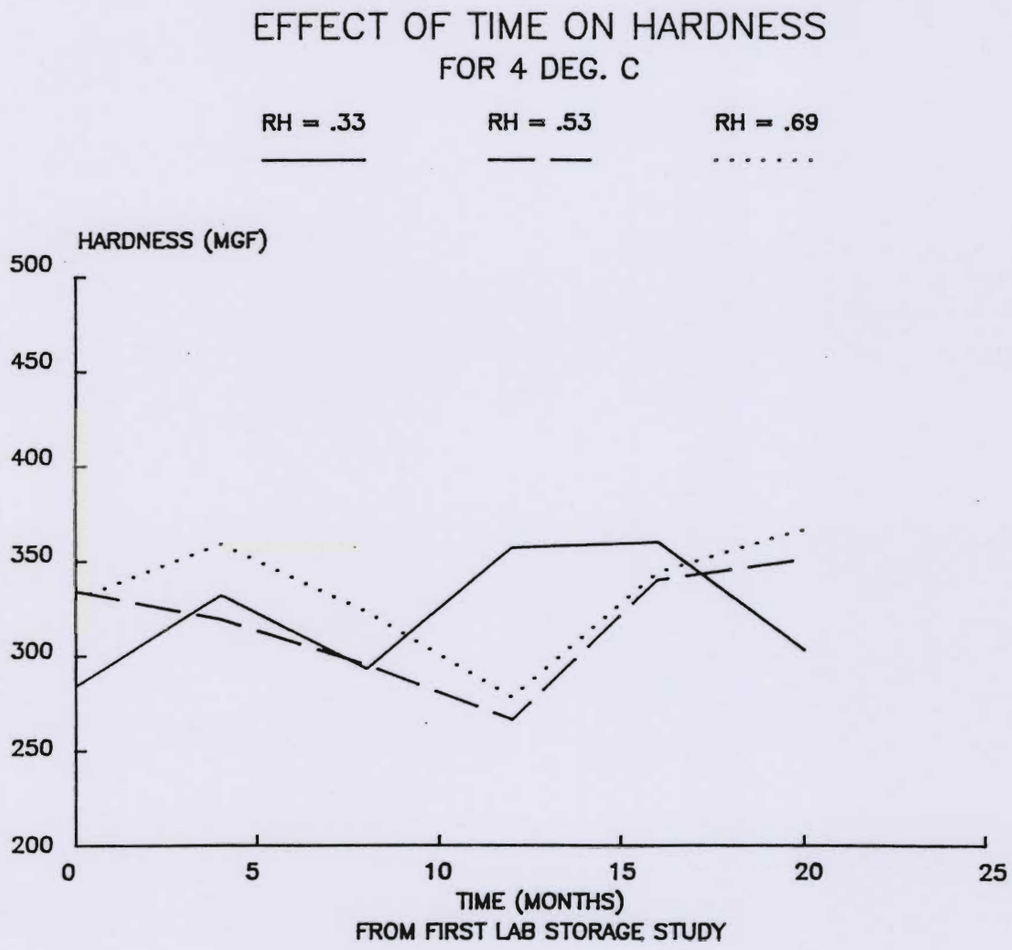


Figure 48. Effect of storage time on instrumental hardness (percentage hard-to-cook) of beans at 4°C by relative humidity

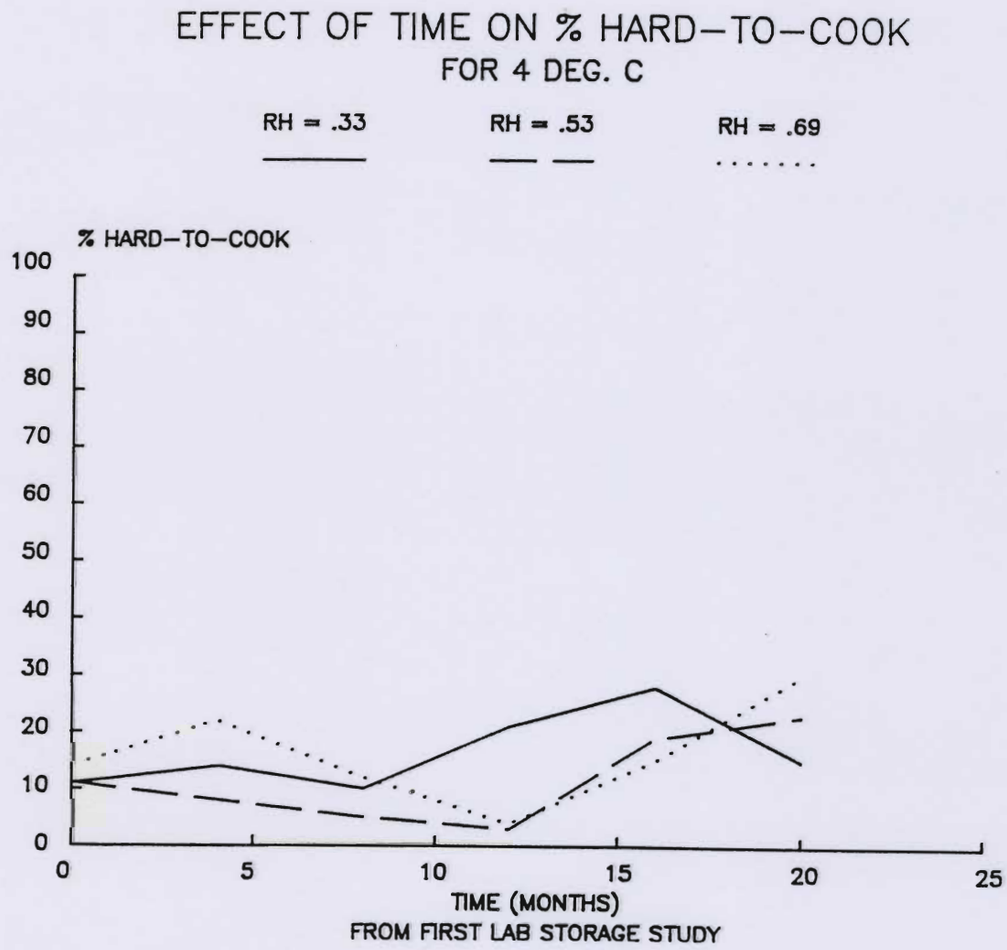


Figure 49. Effect of storage time on instrumental hardness (mean grams force) of beans at 23°C by relative humidity

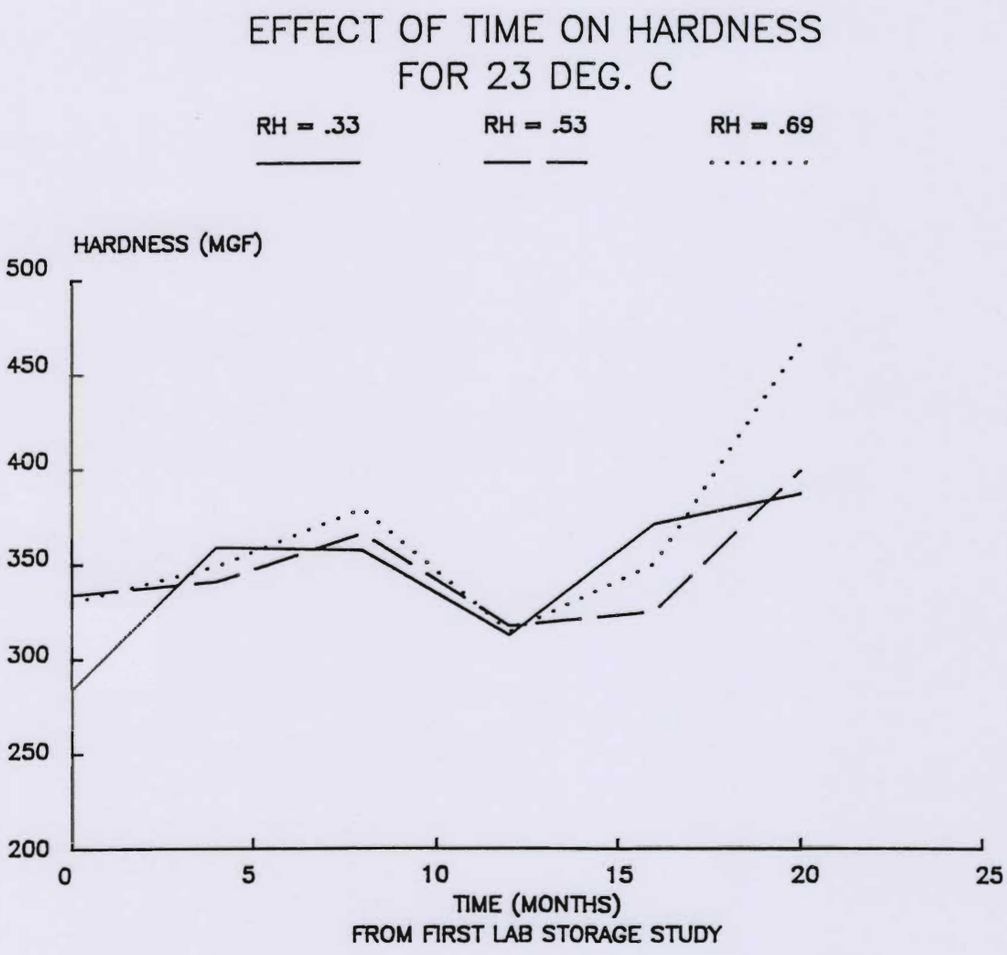


Figure 50. Effect of storage time on instrumental hardness (percentage hard-to-cook) of beans at 23°C by relative humidity

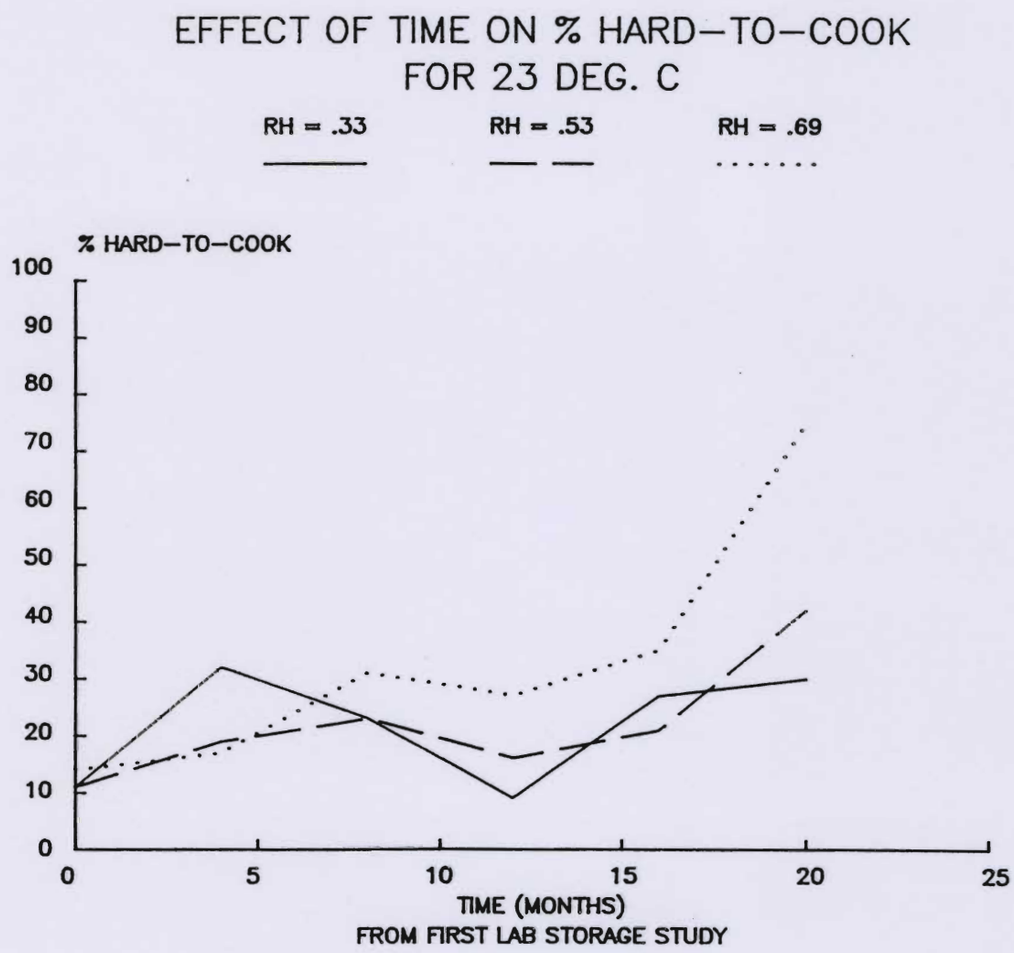


Figure 51. Effect of storage time on instrumental hardness (mean grams force) of beans at 30°C by relative humidity

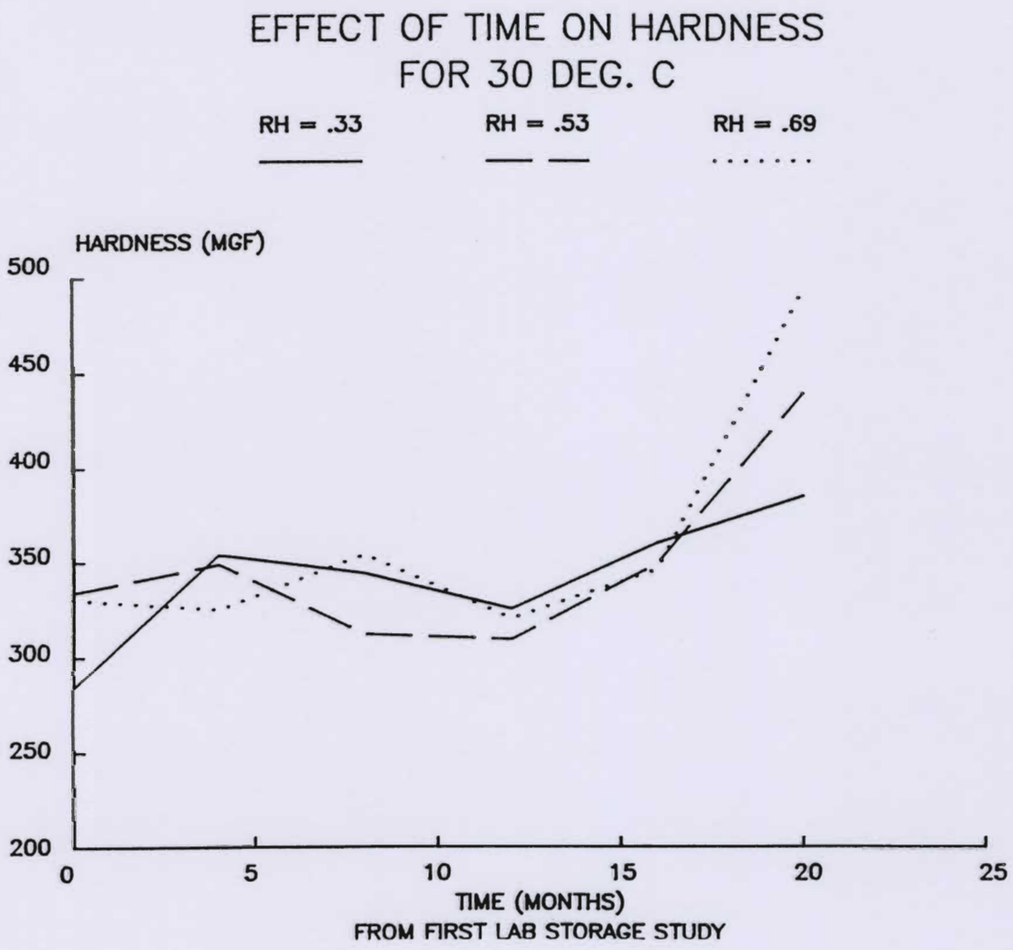


Figure 52. Effect of storage time on instrumental hardness (percentage hard-to-cook) of beans at 30°C by relative humidity

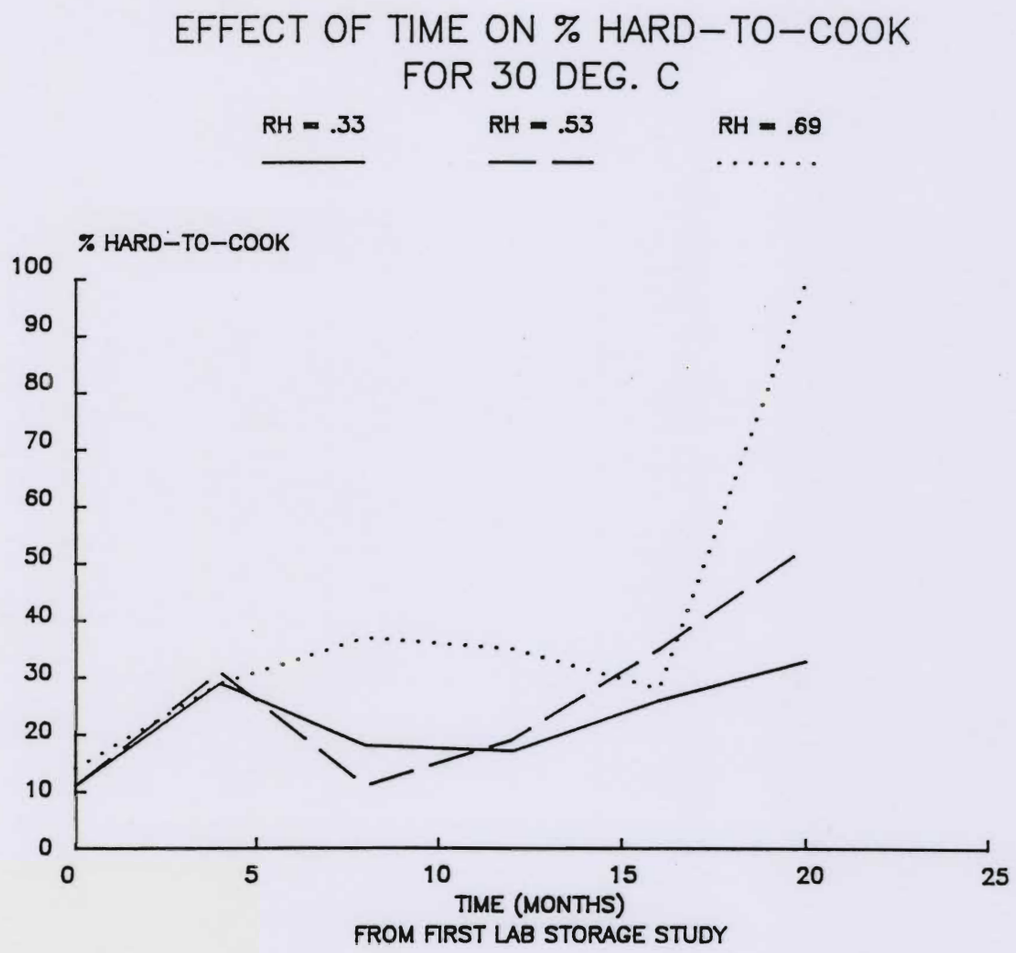


Figure 53. Effect of storage time on instrumental hardness (mean grams force) averaged over temperatures by relative humidity

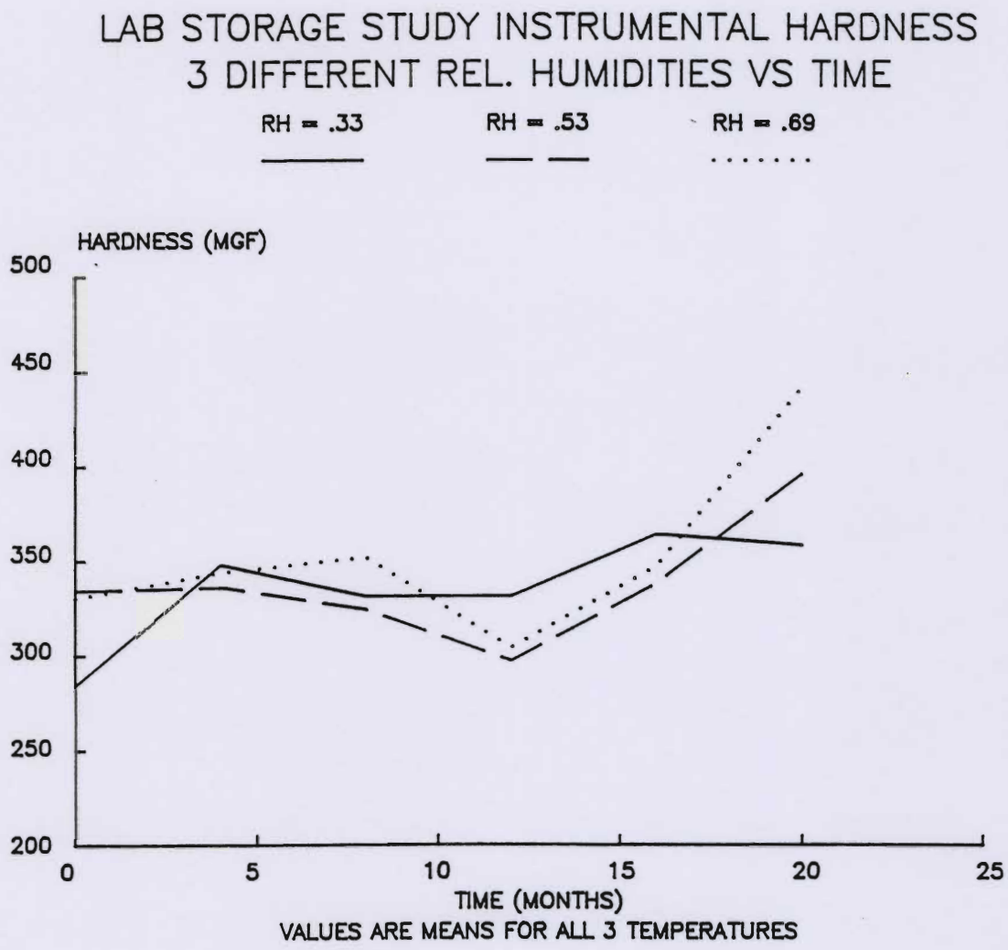


Figure 54. Effect of storage time on instrumental hardness (percentage hard-to-cook) averaged over temperatures by relative humidity

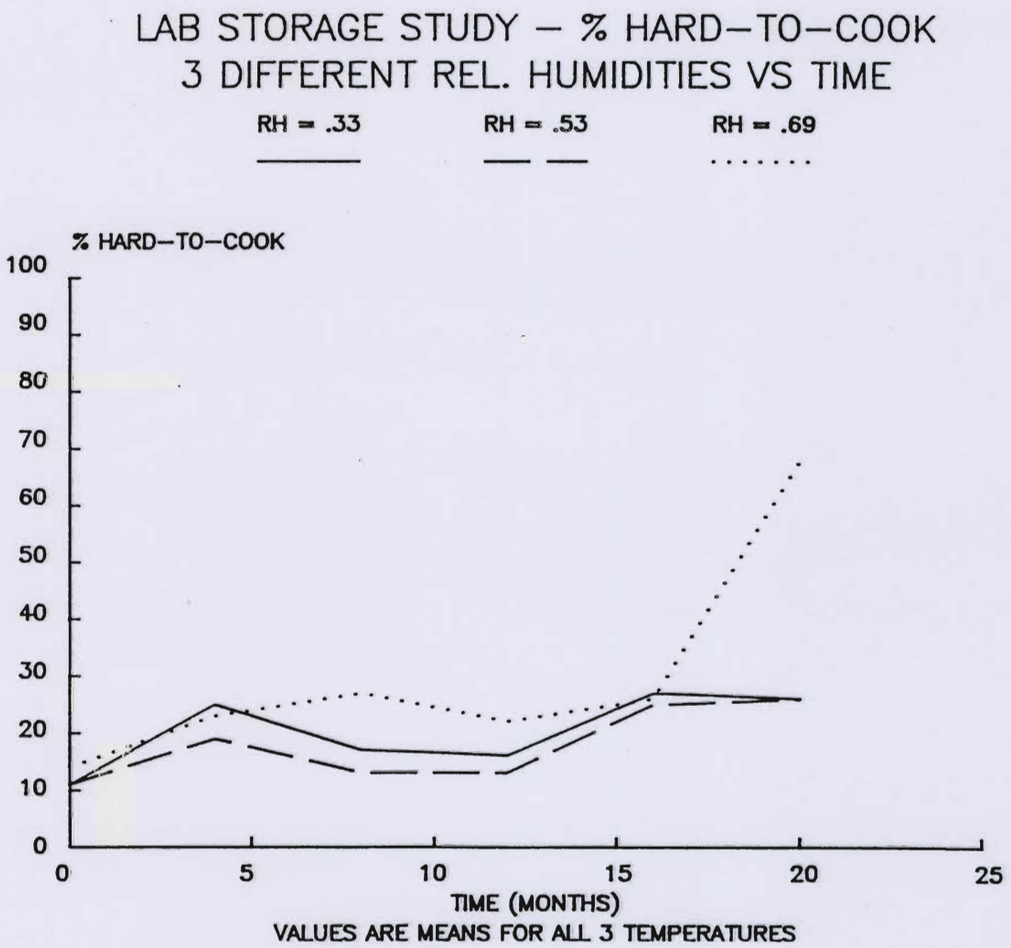


Figure 55. Effect of storage time on instrumental hardness (mean grams force) of beans at 33% relative humidity by temperature

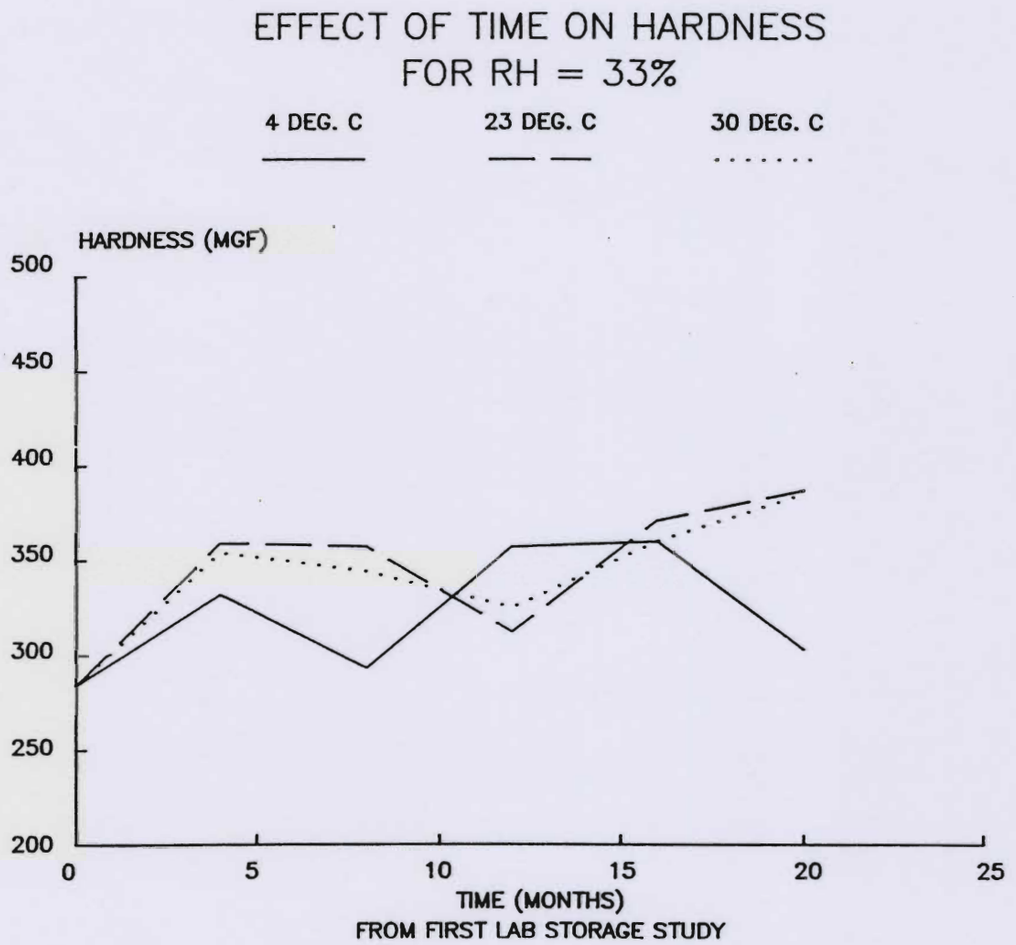


Figure 56. Effect of storage time on instrumental hardness (percentage hard-to-cook) on beans at 33% relative humidity by temperature

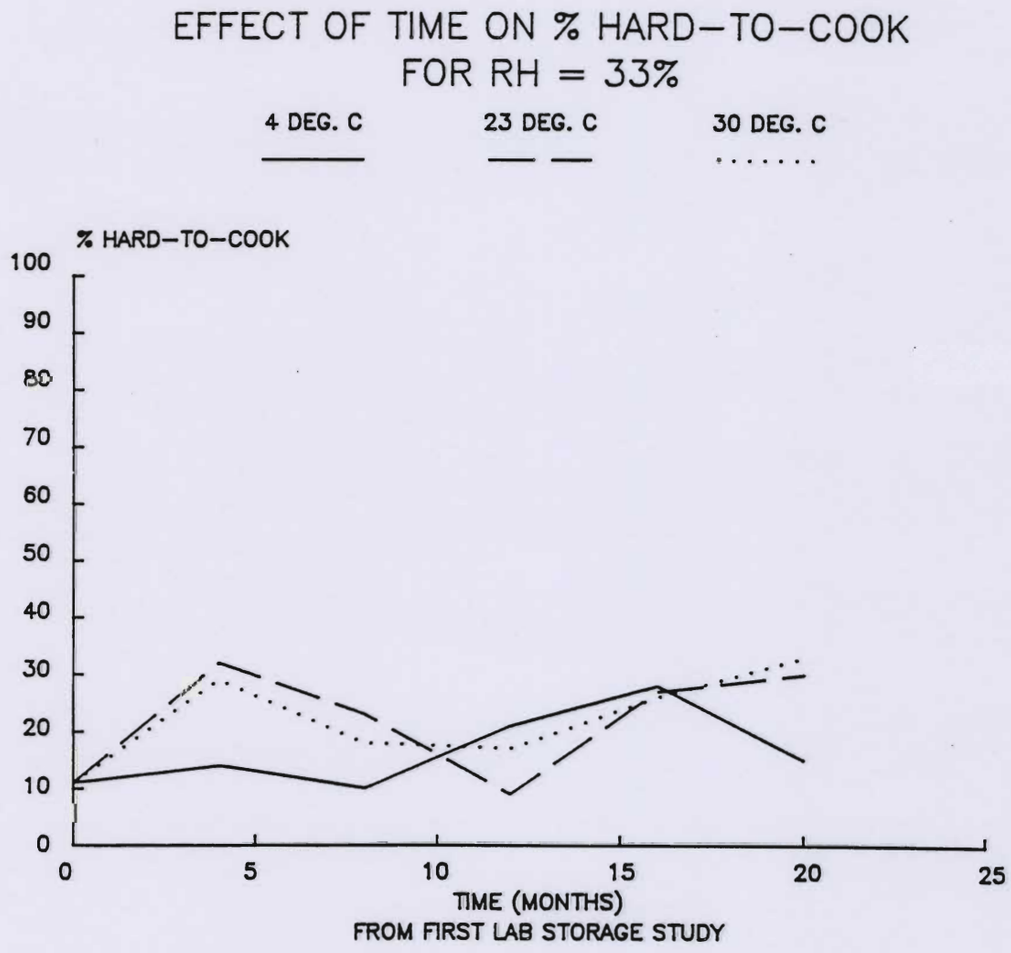


Figure 57. Effect of storage time on instrumental hardness (mean grams force) of beans at 53% relative humidity by temperature

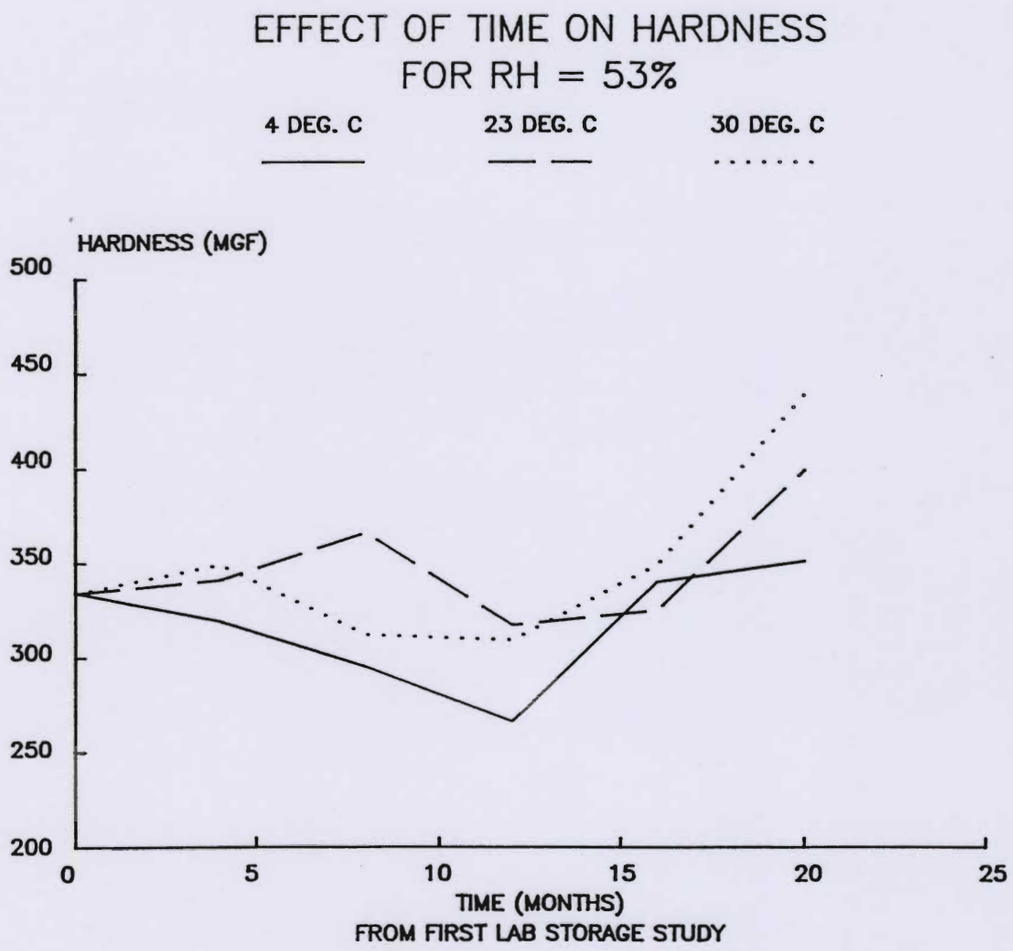


Figure 58. Effect of storage time on instrumental hardness (percentage hard-to-cook) of beans at 53% relative humidity by temperature

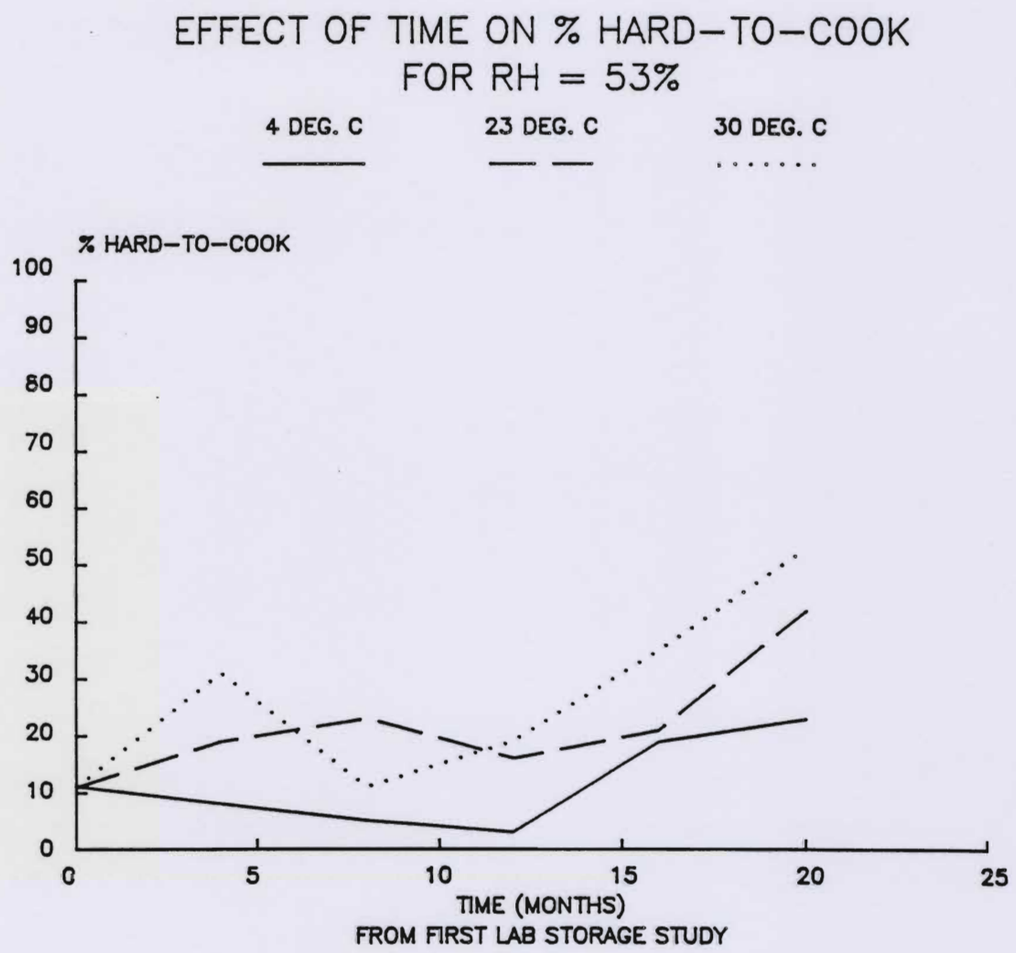


Figure 59. Effect of storage time on instrumental hardness (mean grams force) of beans at 69% relative humidity by temperature

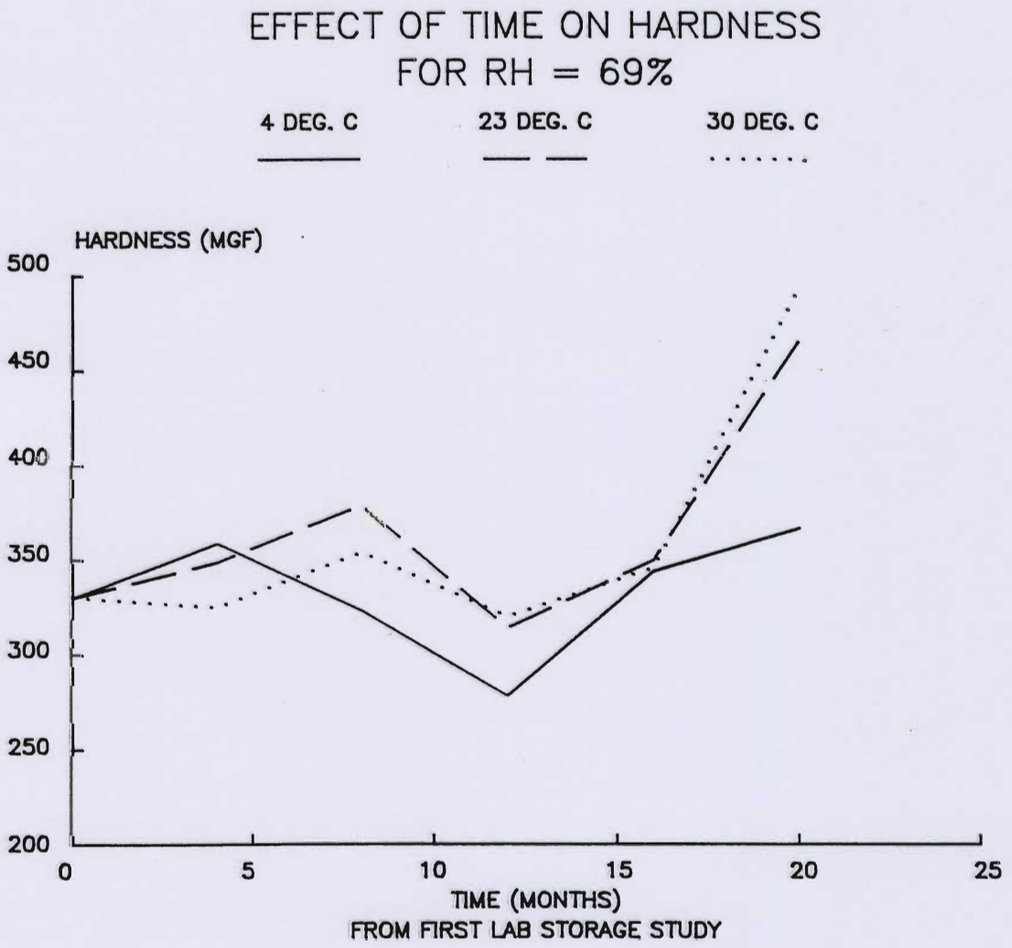


Figure 60. Effect of storage time on instrumental hardness (percentage hard-to-cook) of beans at 69% relative humidity by temperature

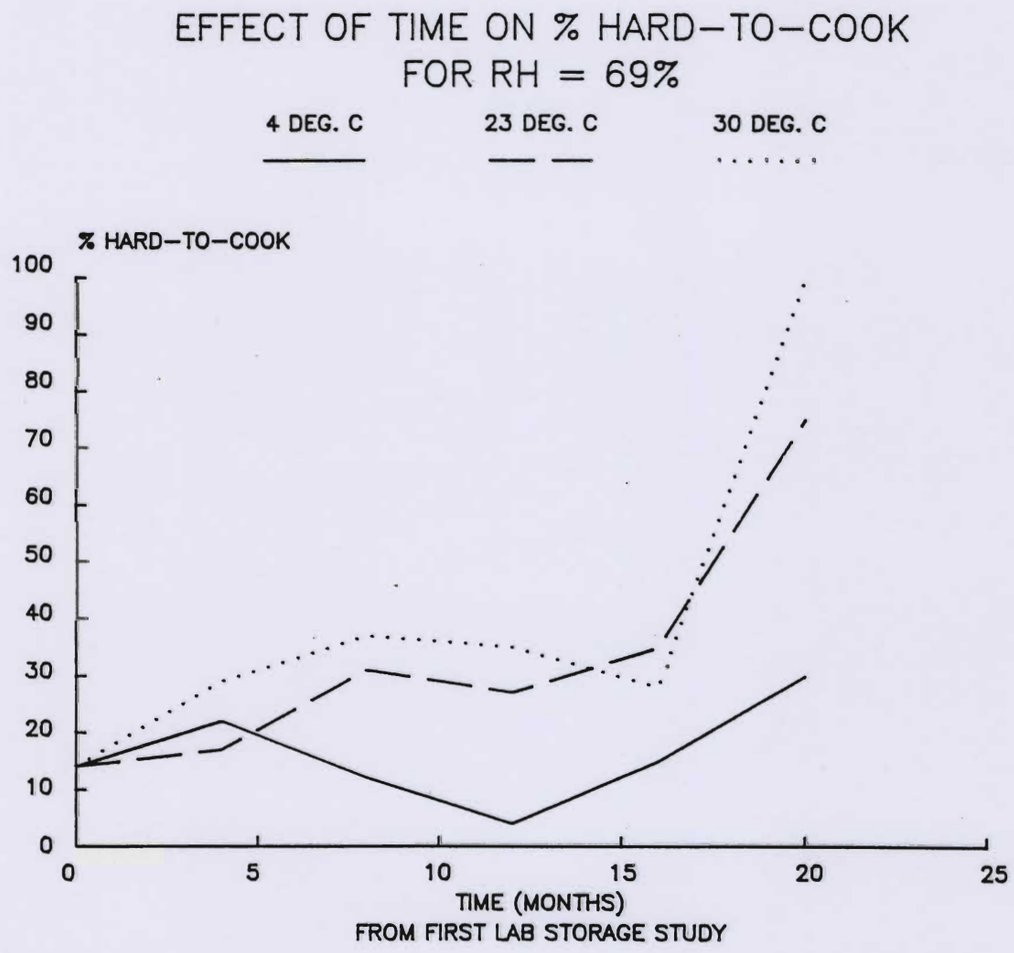


Table 53. Influence of Initial Moisture Content, Temperature and Storage Time on Instrumental Hardness.

Study II

I. Percent Hard-to-Cook Beans ($\geq$ 450 g)

Temp. °C	% Moisture	Storage Time, Months 0	4	8	12	16	20	24
15	8.8	19	17	24	20	28	55	43
	12.1	24	22	30	24	34	43	40
	14.4	18	11	25	30	40	47	56
23	8.8	19	7	14	30	46	49	53
	12.1	24	1	12	41	58	75	56
	14.4	18	9	21	52	64	86	78
30	8.8	19	18	22	35	49	65	47
	12.1	24	14	25	41	57	82	87
	14.4	18	25	40	54	66	--	--

II. Mean Grams Force[a]

15	8.8	311	328	335	358	360	435	403
	12.1	317	340	366	366	392	396	384
	14.4	312	308	343	379	409	409	428
23	8.8	311	284	329	387	432	419	423
	12.1	317	267	326	415	456	460	407
	14.4	312	320	354	435	459	482	481
30	8.8	311	337	326	385	433	445	421
	12.1	317	310	344	411	438	472	479
	14.4	312	348	403	435	457	---	---

[a] values are means of 100 determinations on randomly selected individual beans

SECTION VI

ALTERNATIVE PRESERVATION OF GREEN AND DRY BEANS (*Phaseolus vulgaris*) IN RWANDA

ABSTRACT

Several alternative methods for the preservation of green and dry beans were evaluated for potential use in Rwanda:

1. Dry beans (uncooked) were stored under controlled atmosphere conditions at moisture contents ranging from 10% to 16%.
2. Dry beans were precooked and dried for storage, and then rehydrated and heated before serving.
3. Precooked and dried beans were ground, stored as flour and used as a thickener in vegetable soup.
4. Green and dry beans were canned under pressure at 15 psi, stored and reheated before serving.

The pleasantness and acceptability of these products was evaluated at 6-month intervals during 30 months storage by an untrained panel of 40-50 Rwandan consumers. Controlled atmosphere, precooked and dried, and canned dried beans were also evaluated for cookability (instrumental hardness).

This study is still in progress. However, data after 18 months storage show that canned dry beans and beans at 10% moisture in controlled atmospheres are the best liked. Beans at the higher moisture levels in controlled atmosphere storage and precooked and dried beans were clearly inferior after storage. The soup thickened with bean flour and the canned green beans were both acceptable products to Rwandans.

Table 54. Alternative Preservation Processes for Legumes Reported in the Literature

Process	Legume (x= *Phaseolus vulgaris*)	Product	Authors
Milling	Navy beans - hulls (x)	Spice-flavored layer cakes	DeFouw et al., 1982
	Navy and Pinto beans - protein isolates (x)	Macaroni	Seyam et al., 1983
	Navy beans - protein fractions (x)	Wheat bread (yeast)	Zabik et al., 1983
	Navy beans (x)	Soups, crepes, cookies, cakes fritters, doughnuts, crackers, tortillas, chips, pie crust	Nymon et al., 1982
	Great Northern beans - flour and protein concentrates (x)	Sugar cookies	Sathe et al., 1981
	Cowpeas - meal and flour	Ground beef patties, quick breads, doughnuts, sugar cookies	McWatters, 1985
	Cowpeas, soybeans and cereals	Yeast bread	Nout and Nout-van der Hoeft, 1979
	Yellow pea, lentil, Faba bean (germinated and ungerminated) flours and starches	Yeast bread	Morad et al., 1980
Protein coagulation	Field peas	Protein curd	Gebre-Egziabher and Sumner, 1983
	Winged beans, winged beans/soybeans	Protein curd	Sri Kantha et al., 1983

Table 54 continued

Process	Legume	Product	Authors
Hydration in inorganic salt solution	Lima, small white,(x) pinto (x), kidney (x) and soybeans, peas	"Quick-cooking" beans	Rockland and Metzler, 1967
	Winged beans	"Quick-cooking" beans	Rockland et al., 1979
	Broad beans	"Quick-cooking" beans	Al-Nouri and Siddigi, 1982
Extrusion cooking	Cowpea meal	Snacks	Phillips et al., 1985
	Navy beans - high protein and high starch fractions (x)	Textured vegetable protein	Aguilera et al., 1984
Heat treatment under steam (121°C)	Black beans (x)	Dry beans for storage	Molina et al., 1976
Irradiation	Phaseolus vulgaris variety Tortola Diane	Dry beans for storage	Aguilera and Steinsapir, 1985
Roasting	Phaseolus vulgaris variety Tortola Diane	Dry beans for storage	Aguilera and Steinsapir, 1985
	Navy beans (x)	Dry beans for storage	Aguilera et al., 1982

INTRODUCTION

Dunkel et al. (1986) conducted a comprehensive survey of dry bean storage methods in Rwanda at the farm, cooperative, and national levels. The survey indicated that beans were always stored in dry form: in containers (baskets, granaries) at the farm level, in bulk at the cooperative level, and in woven sacks stacked in piles on pallets at the national level. However, there is also considerable interest in the development of alternative methods of dry bean preservation in Rwanda. Such methods could be useful to preserve excess bean stocks during times of high production for times of low production or famine; to add variety to the diet by the introduction of new products high in protein and acceptable to Rwandan consumers; and to reduce cooking energy expenditure at the consumer level.

LITERATURE REVIEW

A partial list of alternative processing methods and products developed from legumes is shown in Table 52. This review will be limited to discussions of research concerning the three of the alternative methods used in the present study: 1) "quick-cooking" legumes (pre-cooked and dried), 2) legume flour, and 3) controlled atmosphere storage. Pressure canning, the fourth alternative method used in the study, will not be discussed here as canning methods are standard techniques found in many Food Technology texts. The reader is referred to Jackson and Shinn (1979) for in-depth discussions of canning techniques.

"Quick-Cooking" Legumes

A process has been developed for preparing quick-cooking dry legumes whereby the legumes are prehydrated in special salt solutions, dried for storage, and rehydrated during cooking. Cooking time is significantly reduced in comparison to that for legumes prepared by normal methods.

Rockland and Metzler (1969) developed such a process for lima and other dry beans. The first step was an intermittent vacuum treatment (Hydravac process) during which the beans were hydrated in an inorganic salt solution (25% sodium chloride, 1.0% sodium tripolyphosphate, 0.75% sodium bicarbonate, and 0.25% sodium carbonate) for 30-60 min at 70-75°F (21-24°C). The receptacle holding the beans and hydration solution was evacuated to a pressure of 50 to 80 mm Hg for 5 min after which the vacuum was released for 5 min. This process constituted one cycle. The pressure was established at 30 mm instead of the previous level for the remaining cycles which were repeated 3-6 times.

Rockland and Metzler stated that the vacuum treatment facilitated uptake of the salt solution through the hilum and fissures in the outer layer of the seedcoat. The seedcoat inner membrane hydrated and the seedcoats expanded completely within several minutes. The cotyledons were surrounded by the hydration solution and imbibed it rapidly to fill out the already expanded seedcoats. They stated that the vacuum process minimized "fishmouth" and "butterfly" beans in the dry product and disintegration during cooking by minimizing extension of seedcoat fissures which normally occur during hydration without vacuum.

Next, the beans were soaked in the same solution for six hours or more at 70°F (21°C). The soaking time depended on the bean variety. Lima beans were

soaked for six hours; soaking times for Phaseolus vulgaris varieties varied from 6-24 hours. After a distilled water rinse, the hydrated beans were dried in a force-draft oven. The beans were spread in single layers on polypropylene mesh-covered perforated stainless steel trays and dried at 7-20% relative humidity at 140°F (60°C) or less and air velocities of 30 ft/min (9 m/min) for 24 hours. Air velocities of 30 ft/min (9 m/min) or less reduced seedcoat weakening and the production of "fishmouth" or "butterfly" beans, and temperatures of 140°F (60°C) or less minimized darkening and "burned" off-flavor. Moisture contents of the dried product varied from 8.5 to 10.5%.

The "subjective cooking time" of the dried product was evaluated by placing them in six times their weight of boiling distilled water. Samples were removed at five minute intervals during boiling and evaluated. The beans were said to be cooked when three or more "trained" persons agreed that the beans were cooked and uniform in texture.

Obvious reductions in cooking time were achieved with the quick-cooking process. Processed lima beans took 26 minutes to cook, while lima beans soaked in distilled water for 16 hours at 70°F and then boiled, took about 31 minutes to cook (time for cotyledons). They were also similar in Protein Efficiency Ratio to unprocessed cooked beans. Cooking time increased from 26 to 35 minutes after six months storage in glass jars at 60-80°F (16-27°C) and ambient light (fluorescent light and daylight).

Rockland et al. (1979) used a simplified version of the above process to prepare quick-cooking winged beans (Psophocarpus tetragonolobus). The intermittent vacuum treatment was eliminated and replaced by 2 min blanching in boiling water. The blanched beans were soaked for 24 hrs in a solution of 2% sodium chloride, 1% sodium tripolyphosphate, 0.75% sodium bicarbonate, and 0.25%

cooked immediately for 15-20 min in water for evaluation of subjective cooking time or dried in a forced draft oven as described above. The subjective cooking times of the dried quick cooking and hydrated standard beans (soaked in distilled water for 24 hrs at 20°C) were also evaluated.

Significant reductions in cooking time were achieved with this quick-cooking process. Hydrated quick cooking beans cooked about 20 minutes compared to 210 minutes for the hydrated standard beans and about 45 minutes for the dried rehydrated beans. Protein content (N x 6.25) and riboflavin and niacin contents of standard hydrated cooked beans were almost identical to those of the quick-cooking beans; however, the quick-cooking beans contained only half as much thiamin as the standard beans.

Al-Nouri and Siddigi (1982) modified the process developed by Rockland et al. (1979) for use with broad beans (feves des marais). The blanching step was increased to 7 min to inactivate lipoxygenase to avoid production of off-flavors during soaking. The concentrations of the inorganic salts in the soaking solutions were reduced to 0.2% sodium bicarbonate, 0.1% sodium carbonate, and 0.1% sodium phosphate. Since sodium chloride was found to decrease the cooking time for seedcoats and increase the cooking time slightly for lima beans (Rockland 1968), it was not used in the soaking solution but added during cooking at a concentration of 2.5%. (Al-Nouri and Siddigi also experimented with higher concentrations of salts in the soaking solutions alone and in combination with each other, up to levels used by Rockland et al. (1979). However, lowering the concentrations resulted in more favorable evaluations of cooked bean flavor and appearance with no apparent effect on cooking time). The beans were soaked in this solution for 6 hrs at room temperature. No

information was given on bean cooking procedure or determination of cooking time; these are assumed to be similar to those described by Rockland and Metzler (1979).

Al Nouri and Siddigi compared quick-cooked beans to beans soaked overnight and cooked for about 2 hrs for cooking time and acceptability by a panel of 50 consumers (no information was given concerning the sex ratio, age group, or nationality of the panel). The quick-cooking process reduced cooking time from 110 minutes to 20 minutes with no significant difference in acceptability.

The results of these studies suggest that quick-cooking processes can significantly reduce cooking times of legumes without a severe loss of nutrient value or consumer acceptability; however, acceptability may be influenced to some extent by the concentration of salts used in the soaking solution. Simplified processes such as those described by Rockland et al. (1979) and Al-Nouri and Siddigi (1982) may be of particular interest in developing countries.

Flours

It is clear from Table 54 that considerable research has been done on processing legumes for flour and the development of products from these flours. Generally they are used in baked goods at low levels, combined with wheat flour to obtain products with baking and sensory characteristics similar to those of products made with wheat flour alone. Legume flours and meal have also been used in soups (Nymon et al., 1982) and as meat extenders (McWatters, 1985).

Either the entire legume can be processed and ground into flour, or various fractions of the legume can be isolated and used. For example, Nout and Nout-van der Hooft (1979) apparently used whole cowpeas, soybeans, and

groundnuts to produce protein-rich flours for yeast breads, however the processing methods for preparing the flours were not described. The cowpea and soybean flours were added at levels of 15.4 and 6.7% (wheat flour basis) respectively, to replace 30% of the protein supplied by the wheat flour. Thirty-five judges evaluated samples of wheat bread (control) and breads made with the legume and groundnut flours with hedonic scales and paired preference, triangle, and ranking tests. Results indicated that the yeast bread containing wheat and partially defatted groundnut flours was the most preferred, followed by the wheat bread (control) and then by bread containing wheat and soybean flours. The least preferred breads contained wheat and cowpea flours and wheat and fully defatted groundnut flour.

McWatters (1985) used cowpea flour to replace wheat flour at levels of 0 (control), 10, 20, and 30% (flour weight basis) in sugar cookies. A sensory panel rated samples for quality of appearance, color, aroma, texture and flavor on a 9-point scale (9 = excellent, 1 = very poor). The addition of cowpea flour had no effect on the appearance scores, and little effect on the other sensory scores except at the 30% level, where the flavor and aroma scores were decreased due to a beany flavor.

In Zabik et al.'s (1983) study, Navy beans were roasted at 240°C for 1 min and dehulled. Dehulled beans were then pin-milled and air-classified to yield a high protein fraction. This high protein fraction was used at different levels in combination with wheat flour in yeast-raised doughnut holes (0 and 25% of flour weight), white pan bread (0,5 and 10% of flour weight), and peanut butter cookies (0 and 30% of flour weight). Ten trained adult judges evaluated the doughnut holes and pan bread, and 300 consumers (adults and children) evaluated the peanut butter cookies.

Sensory evaluation of doughnut holes with 0 and 25% high protein bean flour for tenderness, texture, fat absorption, flavor, and crumb color were almost identical. Sensory evaluation of white pan bread for texture, tenderness and flavor were also unaffected by the addition of 5 or 10% high protein flour. There was also little difference in acceptability between 0 and 30% high protein flour peanut butter cookies. Thus the addition of high protein bean flours to these baked products can increase the protein value of these products without seriously affecting consumer preferences.

Controlled Atmosphere Storage

The storage life of fresh fruits and vegetables and grains may be considerably extended by modifying or controlling the storage atmosphere to reduce available oxygen (O_2) and increase available carbon dioxide (CO_2). Normal plant respiration, which involves the enzymatic oxidation of sugars to Co_2 and water accompanied by a release of energy, requires a certain amount of atmospheric oxygen to occur. Thus plant respiration rates can be decreased by reducing the amount of oxygen available for respiration. Air contains about 21% oxygen, 78% nitrogen, 0.9% argon, 0.03% carbon dioxide, and trace amounts of other gases and water vapor (Ryall and Pentzer, 1972). The oxygen level must normally be reduced to less than 10% for a reduction in plant respiration rate to occur (Wills et al., 1981). For apples stored at 5°C, the oxygen level must be reduced to about 2.5% to obtain a 50% reduction in respiration rate (Wills et al., 1981). However, the oxygen level which effectively reduces respiration rate varies with the commodity and storage temperature; the reduction of oxygen concentration necessary decreases with increasing temperature. At the same time, oxygen levels must be kept sufficiently high to prevent the occurrence of

anaerobic respiration which produces off-flavors. The critical oxygen level producing anaerobic respiration increases with the respiration rate of the commodity, and is therefore higher at elevated temperatures than at low temperatures (Wills et al., 1981). In addition to the influence of reduced oxygen level on respiration rate, it may also retard the activity of microorganisms (Wills et al., 1981) and storage insects (Jay and D'Orazio, 1984).

Carbon dioxide levels in controlled atmosphere storage are also critical; the addition of just a few percent of this gas has a marked effect on respiration. If the carbon dioxide level is too high, off-flavors may develop. Commodities' response to carbon dioxide levels vary even more widely than to oxygen. For example, most apple cultivars are stored at levels of 2-5% carbon dioxide (at 32-38°F)(Ryall and Pentzer, 1972), while grains such as rice, wheat, sorghum, and maize can be stored at 60-80% carbon dioxide (Qianyu, 1984).

There are several common methods for altering storage atmosphere:

1. restricted venting of the storage container, room, conveyance, box, or individual wrapper (Ryall and Pentzer, 1972);
2. removal or 'scrubbing' carbon dioxide or oxygen from the atmosphere;
3. partial vacuum or subatmosphere pressure storage (also called hypobaric storage) to reduce pressure exerted on the stored product (Salunkhe and Wu, 1974);
4. addition of a blend of gases specially formulated for different commodities (Salunkhe and Wu, 1974);
5. product controlled or modified atmosphere storage (Salunkhe and Wu, 1974), in which no attempt is made to change the storage atmosphere by artificial

means. The commodity is placed in a sealed airtight room or container, and normal respiration increases carbon dioxide and decreases oxygen levels which results in a modified atmosphere.

This last method is of particular interest for grain storage in developing countries, as little sophisticated equipment is needed and modification of storage to produce airtight conditions could be achieved. Qianyu (1984) described some simple techniques for maintaining airtight enclosures for modified and controlled atmosphere storage of grains (rice, peanuts, "green grain", red beans, and sesame seed) in China. Hermetic storage was provided for bulk grain by covering the grain surface with polyethylene sheeting fixed with wax to the walls of the storage enclosure, which had been previously treated with asphalt. Grain stored in bags was completely enclosed in PVC sheeting. Small quantities of grain (2-20 kg) were sealed in polyethylene/polyester laminated film. In the latter case, either a vacuum, natural reduction of oxygen level, or a carbon dioxide exchange method was used to provide the controlled atmosphere. Peanuts, "green grain", red beans and sesame seed were stored in this way for up to a year without apparent quality loss.

Qianyu (1984) also studied the rate of natural reduction of oxygen levels in non-glutinous long-grain rice stored under airtight conditions. He found that the rate of change and the variation in oxygen level depended to a large extent on the moisture content of the rice. The oxygen content of rice stored at 12.7% moisture decreased from approximately 20% to 17.5% after 50 days of storage, while rice stored at 14.7% moisture for the same length of time decreased to almost 2% oxygen. Rice stored at 17.4% moisture decreased to 2% oxygen after only about 7 days storage. These results suggest that it is necessary to be

aware of critical oxygen levels for anaerobic respiration and associate quality loss. As moisture contents increase, oxygen levels may descend to those levels during storage.

In summary the alternative preservation methods for legumes and grains discussed above all have potential for use in Rwanda and other developing countries as ways of extending the storage life of dry beans. Whether these methods can be applied satisfactorily and whether Rwandan consumers would find beans stored by these methods acceptable are unknown. The objectives of this study were to 1) adapt several of these methods (precooked and dried, flour, controlled atmosphere storage, and canning) for use with Rwandan beans, 2) evaluate the acceptability of these products to Rwandan consumers, and 3) monitor changes in the sensory quality and cookability of these products during storage.

MATERIALS AND METHODS

I. Precooked dried and rehydrated beans; bean flour

A. Beans

Beans (25 kg) from the June 1985 harvest were a mixture typically found in the northern region of Rwanda (Ruhengeri). A portion of them were used in another study (Influence of drying on cookability). The initial moisture content was approximately 20.4% (AACC oven-dry method 44-15A, 2 stage). The beans were stored in a tightly closed plastic-lined bag at room temperature (23°C) for several days, screened to remove damaged seeds and foreign material, washed three times in tap water and drained.

B. Cooking

Ten cups of beans and five teaspoons of table salt (iodized) in excess tap water in a covered 17-quart stainless steel pot were boiled for three hours, on a preheated laboratory hotplate (Thermolyne model HPA 2230M, Thermolyne Corporation, 2555 Kerper Blvd., Dubuque, IA 52001). The hotplate was regulated to maintain a moderate boiling rate throughout the cooking time. Boiling water was added as necessary throughout cooking so that there was always excess liquid, and in such a way that the boiling rate did not change appreciably.

The cooked beans were immediately drained in a stainless steel colander for approximately 1 hr. The drained beans were divided into three portions and spread in 2-inch layers in metal sorghum sieves (14 in diameter x 3 in deep). The perforations in the bottom of the sieves allowed air circulation through the bean mass during the drying process.

C. Drying

The sieves containing the beans were placed in a mechanical convection oven (Blue M Stabiltherm Model OV500C-2Y, Blue Island, IL 60406) preheated to 140°F (60°C). Two of the sieves were placed on evenly spaced shelves; the other one rested on the floor of the oven. During the approximately 10 hour drying period the beans were stirred and the sieves were rotated at 2½ hour intervals. The beans on the top shelf dried fastest; those on the floor of the oven dried slowest. The dried beans were crisp when bitten and disintegrated into small fragments when crushed between the thumb and index finger. After cooling to room temperature (approximately 3 hours) they were transferred to 8-qt plastic containers with tightly fitting lids and stored at room temperature (23°C).

Four 10-cup batches of beans were cooked and dried in this manner. Forty cups of raw beans yielded about 11.25 kg of precooked and dried beans. Approximately one-third of the final product was then ground into flour using an ultra-centrifugal mill (Quartztech Microjet 10J, # QT-80141; Quartz Technology Inc., New York, NY) set at 10,000 rpm. The beans were ground in 250 g batches, first using the 5 mm screen and finally, the 1 mm screen. The flour was stored at room temperature in plastic containers.

Moisture contents (AACC method 44-15A, one stage, for ground sample) of the precooked, dried beans and flour were 11.7% and 10.3%, respectively. The moisture contents of these products were redetermined at 6 month intervals along with consumer acceptability and instrumental tests.

D. Rehydration Procedure - precooked, dried beans

Six cups of precooked, dried beans were added to 1.75 liters of boiling water in a 2 liter stainless steel saucepan. When the beans came to a boil, they were simmered over moderate heat (with the pan covered) for 15-20 min until completely rehydrated and tender. This quantity of beans/liquid was sufficient for a 50 consumer sensory acceptance test and for the instrumental hardness test.

E. Preparation of vegetable soup using bean flour

The following formulation was used to prepare vegetable soup using bean flour as a thickener (50-1/3 c servings).

Leeks, chopped (upper 2/3 of green leaves removed):520 g

Cabbage, chopped:470 g

Carrots, pared and chopped into small pieces:340 g

Celery leaves, chopped:80 g

Salt:4 tsp

Bean flour:310 g

Boiled tap water, unfiltered: about 5 liters for the soup and 1 liter to dilute the bean flour

The vegetables were cleaned thoroughly, chopped and simmered in excess water for 1 hour. The drained vegetables (the cooking liquid was saved and added back to the soup as part of the 5 liters of boiled tap water) were puréed in a manually operated food mill using the medium grind attachment. The purée was combined with the cooking liquid and enough water to make 5 liters. The bean flour was diluted in 1 liter of water and heated separately until it formed a thick paste. The puréed vegetables and liquid

were then combined with the salt and the bean flour paste and heated to boiling. The soup was served as soon as possible to consumers.

II. Controlled Atmosphere Storage

A. Beans

Approximately 40 kg of a bean mixture harvested in June 1985 were purchased in the northern region of the country (Ruhengeri). This was a different mixture than was used for the precooked and dried beans and the bean flour. The initial moisture content of the bean mixture approximated 19% as determined using a Motomco moisture meter (Model 919, Motomco Inc., Box 300, 267 Vreeland Ave., Paterson, NJ 07543) and a calibration curve developed in the laboratory in April 1985: % moisture = 8.31 + 0.13 (Motomco reading).

The beans were kept in a tightly closed plastic lined polyethylene bag at room temperature (23°C) in the laboratory until they were dried.

B. Drying Procedure

After screening to remove damaged beans and foreign material, four 10-kg lots of mixed beans were dried to different moisture contents (10.7, 12.1, 13.9 and 16.0%) in the mechanical convection oven preheated to 40°C. Each 10-kg lot was divided equally among three of the perforated sorghum sieves (about 3-inch deep) which were then all placed in the oven for drying to the desired final moisture content. The drying time varied from seven to 48 hours for the four lots. Each lot of dried beans was allowed to cool at room temperature for 30 min and was then transferred to an 8-qt plastic container for cooling overnight.

C. Storage

After cooling overnight, the beans at each moisture content were transferred from the plastic containers to ten to twelve 1-qt wide-mouth Mason canning jars (Ball Corporation, Muncie, IN 47302), which were filled as full as possible and closed tightly with dome lids and bands (Ball Corporation, Muncie, IN). Each jar was labelled with the final moisture content (AACC oven dry method 44-15A, 2 stage) and date that it was placed storage at room temperature (23°C) in a metal cabinet in the laboratory. Moisture contents were redetermined at each 6-month interval when the consumer acceptability and instrumental tests were conducted.

III. Thermal Processing - Green and Dry Beans

A. Determination of appropriate thermal processing times

Thermal processes (time/temperature) for low-acid foods including green and dry beans, must be sufficient to inactivate spores of Clostridium botulinum which can grow and produce toxin in foods in the absence of oxygen and at pH levels above 4.5. Thermal processing times which reduce the probability of spoilage from surviving C. botulinum spores to an acceptable level have been determined for many vegetables. However, the time projections for thermal processing at high altitudes are still subject to debate. Therefore, thermal process times were verified in Kigali (altitude 1500 m, 4900 ft).

Different combinations of time-temperature conditions can achieve the same lethal effect on micro-organisms. For example, long-time processes at lower temperatures can be as lethal to specific organisms as short-time very

high temperature processes. The lethality of a process can be calculated by integrating the lethal rates corresponding to the temperatures occurring in the process over the processing time. Usually, lethal rates are determined as the processing time at 250°F (121°C) that is equivalent to 1 minute of processing at the recorded temperature. The integration of these lethal rates over time is equivalent to plotting the lethal rates as a function of process time and measuring the area under the curve. This area or integral is called the F-value for the process. The F-value represents the equivalent number of minutes of processing at 250°F to have the same lethality as the real process for which temperatures were recorded.

The lethal rate corresponding to any temperature depends on the temperature sensitivity of the organism. For C. botulinum spores, the lethal rate is assumed to decrease 90% for a 10°C (18°F) drop in temperature. This logarithmic temperature dependence is different for vegetative cells, other processes and may be different for other types of spores. Thus the F-value is only valid for organisms having the thermal characteristics assumed in the calculation of the lethal rates.

The calculated or process F-value can be compared to a target F-value to determine whether the process time is adequate. The calculated F-value should be sufficiently large so that there is a 99.999% probability that it is greater than the target F-value. This is calculated by substracting the appropriate number of standard deviation values from the calculated F-value and comparing this reduced calculated value with the target F-value. The target values for green beans and dry beans were 5 and 15 minutes, respectively.

1. Determination of slowest heating points in containers

The determination of lethalities in containers of green and dry beans during thermal processing was based on the slowest heating point in the container. If the slowest heating point has been processed sufficiently (time/temperature) to be considered commercially sterile, then all other points in the jar will also have been sufficiently processed.

In order to find the slowest heating points in jars of green and dry beans, a series of calibrated thermocouple needles (O. F. Ecklund Co., P.O. Box 279, Cape Coral, FL 33910) were placed in specially modified 1-qt glass canning jars (Ball Corporation, Muncie, IN 47302). The thermocouple needles were of 2 different lengths in order to detect temperatures at the center of the jar (8.25 cm) and at 1 cm from the bottom of the jar (14.5 cm) during the thermal process. The metal lids of the jars were punched in the center using a can punch (Cat # C-11, O. F. Ecklund Co.) to allow placement of thermocouple mountings (Cat # C-5, O. F. Ecklund Co.) and attached thermocouple needles.

Two Presto Pressure Cooker Canners (21-qt, Model 21B, National Presto Industries, Inc. Eau Claire, WI 54701) were modified to allow recording of temperatures in jars throughout the thermal process (Figure 61). A metal pipe approximately 2 cm in diameter and 5 cm long was soldered into a hole drilled in the body of the canner approximately 1.5 cm below the lid base. One end of the pipe was flush with the inside wall of the canner and the other end was soldered to a metal washer approximately 2 cm in diameter to form a flange. A metal disk

Figure 61. Modifications made in a pressure canner for recording temperatures inside the canner during processing (Wallace, 1977)

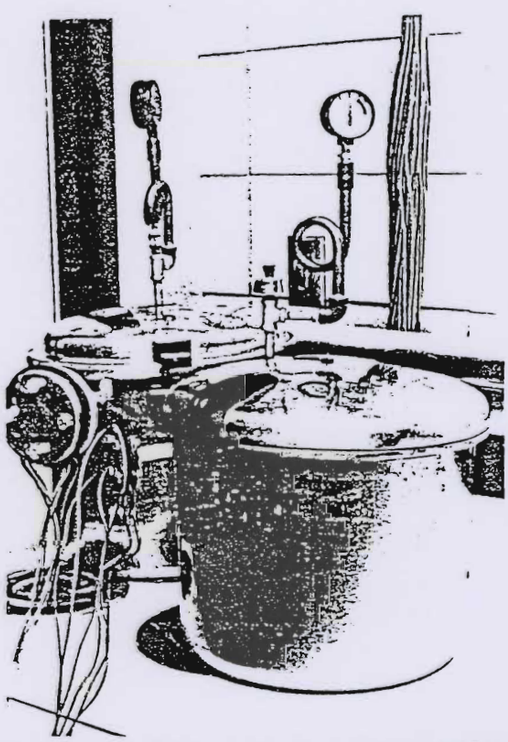


Illustration 1. Mirro 22 qt (left) and Presto 21 qt (right) pressure canners showing the stuffing box and thermocouple leads.

Illustration 2. Ecklund thermocouple (right) thermocouple receptacle through a canning jar lid (center) and thermocouple connector (left).

was attached to the flange by 4 screws. Two rubber gaskets between the disk and the flange prevented loss of pressure from this outlet during processing.

Thermocouple wire (copper-constantan, duplex, insulated, Cat # GG-T-24, Omega Engineering Inc., 1 Omega Dr., Stanford, CT 06907) was threaded between the rubber gaskets, through the pipe and into the cooker and attached to the filled jars using male connectors (Cat # C-6, O. F. Ecklund, Co.). Temperatures were recorded using a monitor (Omega Model CL6503, Omega Engineering Inc., Stanford, CT 06907) via a multipoint switch (Sterm # C-25, 11 points, O. F. Ecklund, Co.).

Six jars each of green and dry beans were processed during two separate canning runs for each product to determine the slowest heating points. In each run, three jars were equipped with the long (14.5 cm) thermocouple needles and three were equipped with the short (8.25 cm) needles. A seventh jar was filled with water and placed in the canner to fill it up; temperatures in this jar were not monitored. This dummy jar was placed in a different position in each run. An additional thermocouple lead was extended into the headspace above the jars to measure the temperature; after it reached 203°F (95°C) temperatures were recorded at 2 min intervals throughout the come-up time, the process period and until cooling down to 212°F (100°C). Headspace temperatures during the actual process at 15 psi varied from 242.6°F (117°C) to 246.2°F (119°C).

a) Green Beans

Approximately 30 kg of green beans from the January 1985 harvest purchased at the Kigali market were washed, trimmed to remove

strings, tips and stems, cut or snapped into 4 cm pieces, and packed into clean 1-qt glass canning jars, leaving about 1.25 cm headspace above the beans. One teaspoon of salt (iodized) was added to each jar, and the jars were filled with room temperature tap water, leaving about 2.5 cm headspace above the brine. The lids equipped with thermocouple needles were placed on the jars and the lid bands were tightened firmly.

Tap water about 5-7 cm deep in the bottom of the canner was brought to a boil on an electric hotplate. The jars were put in and the cooker was closed. The canner was heated over high heat until the water returned to the boil. After venting for 5 min, the pressure regulator was put on the vent pipe and heating was continued until the gauge pressure reached 15 psi and the pressure regulator began to rock gently. The heat was regulated to maintain gauge pressure at or slightly above 15 psi for 30 min after which time the cooker was removed from the hot plate. Gauge pressure was allowed to return to zero of its own accord. The slowest heating point was determined by finding the point in the jar which had the smallest F value. This point was 1 cm from the bottom of the container. This determination agrees with the hypothesis that heat is transferred inside containers primarily by convection when heating products where there is free fluid motion.

b) Dry Beans

Determination of the slowest heating point for canning mixed dry beans was conducted in two canning runs instrumented similarily to

the one already described. Beans that had been stored for 6-12 months at 23°C and 70% R.H. were picked over to remove obviously damaged beans, rinsed and drained. One-half cup of beans and one teaspoon of salt (iodized) were added to each of 6 1-qt glass canning jars which were then filled to approximately 2.5 cm from the top with boiling tap water. The lids equipped with the long and short thermocouple needles (three 8.25 cm, three 14.5 cm) were placed on the containers and the lid bands were tightened firmly.

The filled jars were placed in the cooker as described above. A seventh jar was filled with water, closed, and placed in the canner with the other jars. The process time at 15 psi was 60 min. Temperatures inside the jars were recorded every 2 min after the temperature in the headspace had reached 203°F (95°C). At the end of the process, jar temperatures were recorded during cooling until the cooker headspace temperature dropped below 212°F (100°C).

Initially the beans heated rapidly but near the process temperature, the heating rate decreased dramatically, creating a break in the heating curve. The break did not consistently occur at the same temperature, which may reflect a difference between bean samples. The failure of the break to occur at a consistent temperature also increased the variability in the measured results. The broken heating curve is significant since the slowest heating point would be expected to be at the center of the container if there was no convective heat transfer inside the container. The center is the point at which the heat must traverse the greatest

distance through the solid mass. Although this point cools most slowly it does not receive nearly as much lethality during the heating part of the process and the slower cooling is not adequate to offset the low lethality during heating. The results of our canning runs showed that there was little difference in slowest heating points between the center and the point 1 cm from the bottom of the container. F-values were slightly smaller at the point 1 cm from the bottom of the container than at the center. This is logical because the dry beans and brine initially heated by convection due to free fluid movement around the bean, making the lowest point in the jar the slowest heating point. As the process temperature was approached the beans absorbed the brine and became hydrated and swollen, thus converting the product to conduction heating and shifting the slowest heating point upward toward the center. The small proportion of processing that was characterized by conduction heating was more than offset by the faster cooling by conduction near the bottom than at the center of the jar, thus the bottom of the jar remained the slowest heating point.

2. Determination of process lethalities

a) Green Beans

After the slowest heating point was determined, the process lethalities at the slowest heating point were measured in three additional canning runs. Green beans were prepared for canning in the same manner as described previously. All 6 jars of beans in

each load were fitted with long (14.5 cm) thermocouple needles to monitor temperatures at the slowest heating point and processed for 30 min at 15 psi. Temperatures were recorded every 2 min from the time the temperature in the headspace above the containers reached 203°F (95°C) until it dropped to below 212°F (100°C) after the cooker was removed from the heat. Seventeen jars were successfully monitored during the process.

Lethalities were calculated for each recorded temperature for each container and these lethalities were integrated to an F value for the process according to the formula: $F = 2 \Sigma L$, where 2 represents the two minute interval between the temperatures recorded and L = lethality. The mean F value for the 17 jars was 12.43 with a standard deviation of 1.22. The minimum mean F value which could be expected from the process with a confidence level of 99.999% was calculated according to the formula:

$$F = \bar{X} - (t_{.001,\ 16dF})\ SD$$

where

$\bar{X}$ = the mean F value of the 17 jars

$t_{.001,\ 16dF}$ = the t value from student's t distribution with 16 degrees of freedom

SD = standard deviation of $\bar{X}$

Solving the formula resulted in an F value of 7.52. The target F value for the process was 5. Since the target value for the process was less than the calculated value, it was assumed that process delivered the target F value with a confidence level of 99.999%. Furthermore, the lethality of the highest temperature at the slowest

heating point in the jars during the process (244°F, 117.8°C) was such that the process time could be reduced from 30 min to 25 min and still deliver the target F value. The decision to reduce the process time by 5 min was based on two assumptions: 1) temperatures plotted during the heating intervals reached essentially steady terminal values at or slightly below the temperature in the headspace of the canner and 2) the lethal rate at the peak temperature, 244°F, was less than 0.5 (since we did not want to substract more than 2.5 units from the F value). This assumption was satisfied as long as the peak temperature did not exceed the 244°F which had a lethal rate of slightly less than 0.5.

b) Dry Beans

Three additional canning runs were conducted to determine the lethalities of temperatures at the slowest heating point in jars of dry beans during thermal processing. The beans were prepared for canning as described previously. All six jars in each canning run were equipped with long (14.5 cm) thermocouple needles to monitor temperatures at the slowest heating point. These temperatures were monitored as described previously for green beans.

Twenty-three jars of dry beans were successfully monitored during processing. The mean F value of the processes was 35.69 with a standard deviation of 5.16. To find the minimum mean expected F value of the processes at a confidence level of 99.999%, the formula

$$F = \overline{X} - (t_{.001,\ 22dF})SD$$ was used.

Solving this formula resulted in an F value of 16.13, which exceeded the target F value of 15. Thus a thermal process time of

60 min at 15 psi was adopted for dry beans.

B. Canning green and dry beans for consumer acceptability tests

1. Green Beans

Twenty-one quarts of green beans (purchased in Byumba, January 1985) were thermally processed for 25 min at 15 psi. The beans were prepared for processing and packed into 1-qt glass canning jars with 1 teaspoon salt as described above and covered with boiling tap water, leaving 1.25 cm headspace. Jar rims were wiped clean and the lids were placed on the jars with the lid bands tightened down firmly. Tap water to a depth of about 7.5 cm in a 17-qt Presto cooker/canner (Model 0175002; National Presto Industries, Inc., Eau Claire, WI 54701) was brought to a boil. A seven jar lot was placed in the canner and the lid was attached. The canner was heated on high until the water had boiled for about 5 min and enough steam had escaped from the vent pipe to flush any air from the canner. The pressure regulator was then placed on the vent pipe and the canner was heated until the gauge pressure reached 15 psi and the pressure regulator began to rock gently. The heat was adjusted to maintain a gentle rocking motion of the pressure regulator and the gauge pressure at or slightly above 15 psi.

At the end of the process time, the canner was removed from the hot plate and allowed to cool until the gauge pressure had dropped to zero and the pressure relief lock had dropped. The jars were removed from the canner and allowed to cool further. Each jar was examined to make sure that it had sealed properly. The jars were stored at room

temperature (23°C) on open metal shelves in the laboratory. The lid bands were left on the jars during storage.

Within approximately one month of canning, one jar of beans had become unsealed, and a chalky white deposit had formed on the bottom of the jar. Approximately five months later, another jar had become unsealed in the same way. It is not clear why the jar lids became unsealed.

The same canning experiment was repeated in June, 1985 using 15 kg of beans purchased in Byumba. The canning procedure was the same as that described above; again, 21 quart jars of beans were processed. This time the lid bands were removed from the jars before storage. Three of these jars of beans were used in the consumer acceptability tests conducted on the following day.

Five of the remaining 18 jars became unsealed approximately one month later. A chalky white deposit was noted in the bottom of some of the unsealed jars; however, this deposit was also noted at the bottom of the sealed jars. A sample of liquid from spoiled beans canned in June, 1985 was transferred to a sterile vial and hand-carried to the University of Minnesota for microbial analysis at the Food Science and Nutrition department. A jar of unspoiled beans was also taken for comparison. The decision was made not to can any more green beans until the reason for the spoilage had been determined. In late September 1985, another jar of beans canned in January, 1985 became unsealed and was sent to the University for analysis.

Analyses of the spoiled bean liquid were inconclusive. There was no evidence of any spore forming bacteria in the liquid. The jar of beans

(from June, 1985) was kept at 38°C; it was still properly sealed in August 1986. The jar of unsealed beans (from January 1985) was found to contain a variety of microorganisms none of which would survive the canning proces and which therefore must have been present due to contamination after the jar became unsealed.

2. Dry Beans

Twenty-one jars of dry beans were canned in July, 1985 using a bean mixture (predominantly large red and beige types) purchased at the Kigali market and containing 12.0% moisture as determined using a Motomco moisture meter (Model 919) and the calibration curve:% moisture = 8.31 + .13 (Motomco reading).

The beans were screened, rinsed, processed and cooled as described above in the slowest heating point determinations. The cooled jars were examined individually for proper seal and stored at room temperature (23°C) on open metal shelves in the laboratory after removal of the lid bands.

Three quarts of these beans were sampled for consumer acceptability and instrumental hardness three days after canning; this was designated as zero storage time data. Three jars became unsealed during the following week. The most plausible cause for the failure of seals is defective lids. Two canning lids - one from a jar that had sealed properly and one from a jar that became unsealed - were sent to the Quality Control Department at Kerr Company (Kerr Glass Manufacturing Corp., Sand Springs, OK 74063.

Technical advisors in the Food Science and Nutrition department

recommended that in further canning trials, the beans be preheated to boiling, drained, and a small quantity of cooking oil added to each jar before closing.

Beans from the first three canner loads were discarded. Therefore, one and one-half cup lots of dry beans were sorted, washed, placed in excess tap water, brought to a boil, and immediately removed from the heat. The beans were rinsed again and measured. The volume of each lot of beans had increased to slightly more than two cups. Two cup portions of these preheated, rinsed beans were placed in each of 21 quart jars. One teaspoon each of salt and soybean oil were added to each jar. Jars were processed for 60 min at 15 psi as described above. Only one jar was unsealed after processing.

Three jars of these beans were sampled for consumer acceptability and instrumental hardness the following day. The brine in two of the jars became discolored (reddish brown to gray) within six months, but their seals remained intact. These two jars were discarded.

IV. Consumer Acceptability and Instrumental Tests

The following sensory and instrumental tests were conducted on the various alternatively preserved products at 6-month intervals.

A. Moisture Determinations

Samples to be stored in controlled atmosphere and bean flour samples, were analyzed for percent moisture using AACC Method 44-15A. Beans were ground for 90 sec in the micromill (Belart Technilab Model 500). Five 2- to 3-g replicates were dried for 1 hr at 130°C. Moisture in the precooked

and dried beans was determined by the same procedure except that the product was ground in the Quartztech mill (see I.C above) using the 5 mm screen attachment. After six months of storage percent moisture was determined using 3- to 5-g replicates of whole beans which were dried for 72 hrs at 130°C (AACC Method 44-15A).

B. Instrumental Hardness Tests

The procedure for these tests and for analysis of data is given in Section I of this final report entitled "Development of Standard Laboratory Sensory and Cookability Tests".

C. Consumer Acceptability Tests

The general procedures for the consumer acceptability tests and analysis of data are outlined in Section I of this final report entitled "Development of Standard Laboratory Sensory and Cookability Tests". The following discussion summarizes cooking and testing methods particular to each alternatively preserved product.

1. Canned green beans

a) Cooking procedure

Three jars of beans were used for each consumer acceptability test. Each jar was checked for seal integrity, opened, and checked for off-odors. All questionable jars were discarded. The beans and brine were boiled for 15 min in a 2-qt stainless steel saucepan on an electric hotplate before tasting/serving to consumers. If

off-odors were noted during or after cooking, the beans were discarded.

b) Test procedure

A single sample of beans was served to 50 panelists at OPROVIA. They were asked (in Kinyariwanda) to taste the beans and to complete a written questionnaire. The questions were: 1) how many times a week do you eat green beans during the seasons when green beans are available; 2) Would you eat the green beans you have just tasted on a normal basis; and 3) Indicate your level of preference for the green beans by marking a point along a line. This line was approximately 18 cm in length and was anchored at the left end with a frowning face, under which was written "I don't like these green beans at all", and at the right end with a smiling face, under which was written "I like these green beans very much".

c) Analysis of results

The mean number of times per week that green beans were consumed was calculated in order to estimate the frequency of green bean consumption during the seasons when they are available.

The mean percentage of consumers who were willing to eat the beans on a normal basis and the mean levels of preference (expressed as % of the scale length) were calculated in order to estimate the overall acceptability of canned green beans during storage. In these experiments the tests were concluded at 18 months storage simply because the experimental stock had all been consumed.

2. Precooked and dried, controlled atmosphere, and canned dry beans

a) Cooking procedures

Precooked and dried beans were rehydrated before serving by combining 6 cups of dry beans and 1.75 l of tap water previously boiled, and at boiling, and simmering the mixture for 15-20 min until beans were tender and completely rehydrated. Beans from controlled atmosphere storage were boiled in excess tap water for 3 hrs (4 cups dry beans/2 tsp salt) as described in Section I of this final report mentioned above. Canned dry beans were prepared using three 1-qt jars of acceptable beans having intact seals and no off-color or off-odors. Beans and brine were boiled for 15 min in a 2-qt stainless steel saucepan on an electric hotplate before serving to consumers. If off-odors were noticed during or after cooking, the beans were discarded.

b) Consumer acceptability tests

Six samples, one of precooked and dried beans, four from the controlled atmosphere experiments, and one of canned dry beans were served to 50 panelists at OPROVIA in a single test session. Samples were served in random order. Acceptability testing of canned dry beans was concluded at 24 months of storage due to exhaustion of the samples.

3. Bean flour

a) Cooking procedure

A puréed vegetable soup was prepared using bean flour as a thickener as described earlier.

b) Consumer acceptability test

A single sample of soup was served to 50 panelists at OPROVIA. Panelists were asked to indicate their level of preference for the soup by the 18 cm smiling-frowning face line procedure described earlier.

RESULTS AND DISCUSSION

Tables 55 and 56 show the effects of storage time on the sensory preferences and instrumental hardness of the alternatively preserved products. Sensory data on precooked, dried and rehydrated beans after 6 months storage and on controlled atmosphere beans stored at 14% and 16% moisture after 12 months storage were not obtained because of consumers' unwillingness to taste these samples due to the development of off-flavors, off-odors and off-colors. Plots of some of the data collected from 0 to 12 months storage are shown in Figures 62-70.

Table 55. Effect of storage time on consumer preference responses

a. Percentage of consumers willing to each the product on a normal basis:

Product	0 months	6 months	12 months	18 months
controlled atmosphere				
10%	68	50	77	62
12%	68	50	70	57
14%	73	58	35	-
16%	88	50	25	-
precooked, dried, and rehydrated	29	30	-	-
canned dry beans	92	67	71	64
canned green beans	80	72	71	79

b. Mean preference level (percentage of scale length):

controlled atmosphere				
10%	60	59	63	60
12%	59	63	56	53
14%	62	61	44	-
16%	69	57	42	-
precooked, dried, and rehydrated	46	37	-	-
canned dry beans	83	60	67	64
vegetable soup - added bean flour	85	75	58	77
canned green beans	78	68	63	69

c. How many times a week do you eat green beans when they are available?

canned green beans	11	3	3	2

d. market value ($\frac{\text{price consumer willing to pay for product}}{\text{price of bean mixture at local market}} \times 100$)

controlled atmosphere				
10%	89	86	97	85
12%	88	88	94	88
14%	85	86	81	-
16%	93	86	81	-
precooked, dried, and rehydrated	82	71	-	-
canned dry beans	100	87	101	89

Table 56. Effect of storage time on insturmental hardness

Mean grams force/percent hard-to-cook ($\geq$ 450 gf)

Product	0 months	6 months	12 months	18 months
controlled atmosphere				
10%	213/0	329/21	371/27	400/36
12%	220/0	356/27	367/33	418/45
14%	225/1	361/42	441/59	474/81
16%	207/0	326/25	334/29	500/100
precooked, dried, and rehydrated	215/3	261/12	-	-
canned dry beans	209/0	188/2	141/0	128/1

Controlled Atmosphere Beans

Before storage, consumers preferred the highest moisture beans (16%). This was more evident in the acceptability scores (percentage of consumers willing to eat the beans on a normal basis, Table 55a; Figure 62) than in the preference scores (Table 55b; Figure 63). After six months storage, acceptability scores for all controlled atmosphere beans had decreased although preference scores and market values remained fairly constant. By 12 months of storage the beans with higher moisture contents had decreased on all measures of sensory preference while beans with the lower moisture contents showed little or no change from 0 months. After 18 months of storage the 10% and 12% beans were about equally well-liked although both acceptance and preference scores had decreased somewhat from 12 months.

Instrumental hardness values were low before storage, from 207 to 225 MGF and 0 to 1% HTC (Table 56; Figures 64 and 65). There was no difference in hardness between moisture contents at 0 months. Hardness increased at all moisture contents during storage, but the increase was most dramatic for the 14% and 16% moisture beans.

Precooked, Dried, and Rehydrated Beans

Consumer preferences for this product were low before storage and remained low after six months storage (Table 55a, b, d; Figure 66). These precooked beans had a burnt, rancid flavor, were dark in color and puree-like in texture. Rockland and Metzler (1967) attributed burnt flavor and dark color of precooked and dried lima beans to elevated drying temperatures; acceptable flavor and color were maintained if temperatures were kept to 140°F (60°C) and below. It

is likely that such changes occur to some extent even at 140°F, the temperature used in this study.

Figure 62. Effect of storage time on sensory acceptability of beans stored under controlled atmosphere

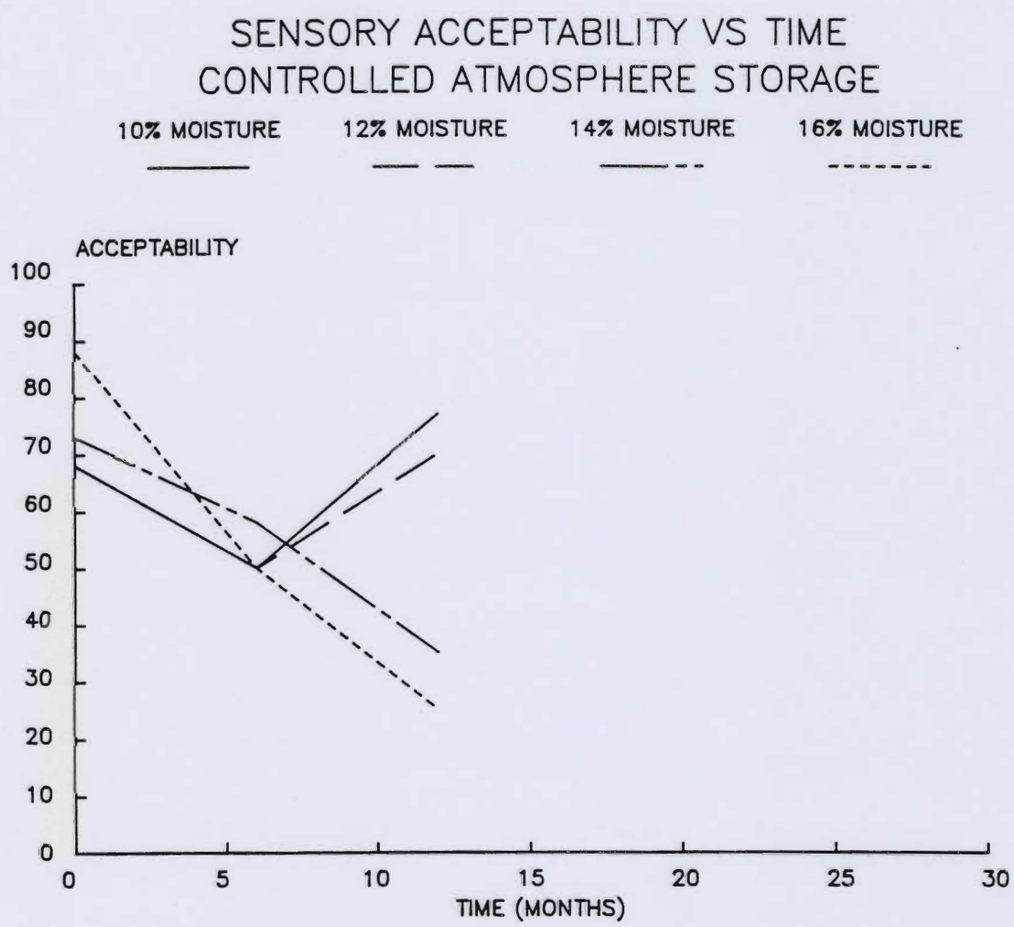


Figure 63. Effect of storage time on sensory preference for beans stored under controlled atmosphere

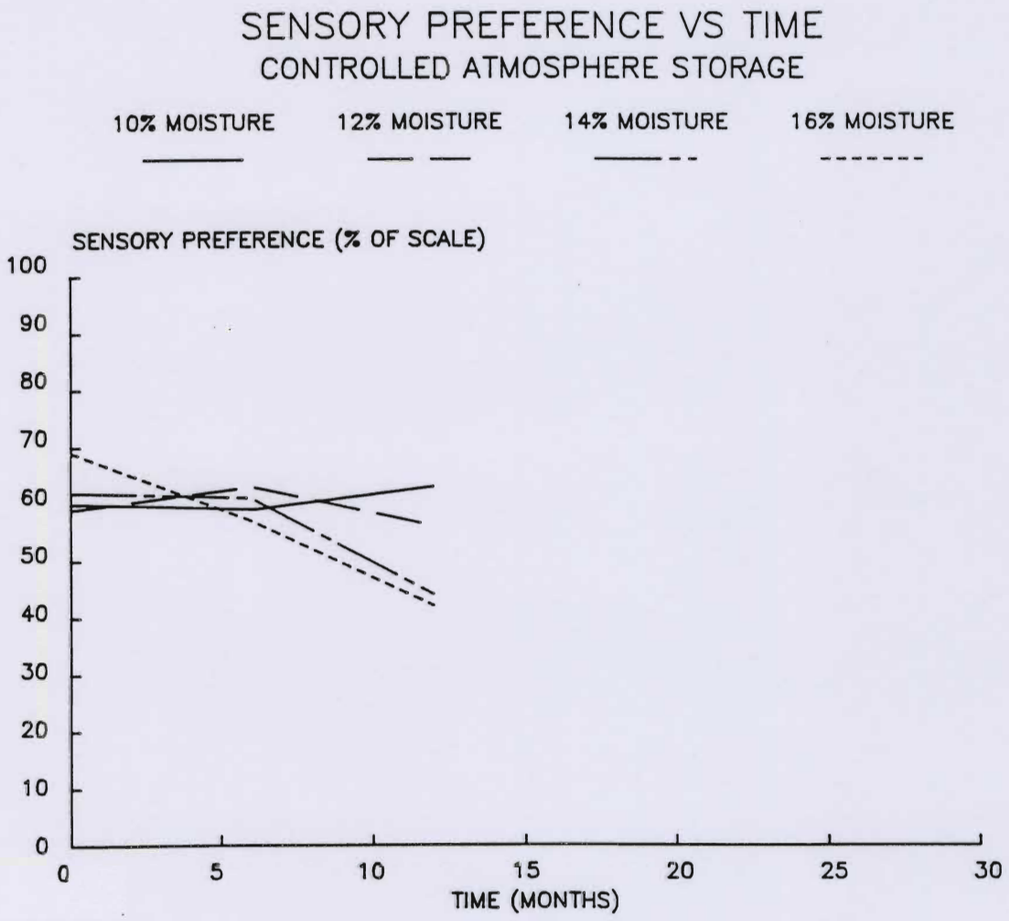


Figure 64. Effect of time on instrumental hardness (mean grams force) of beans stored under controlled atmosphere

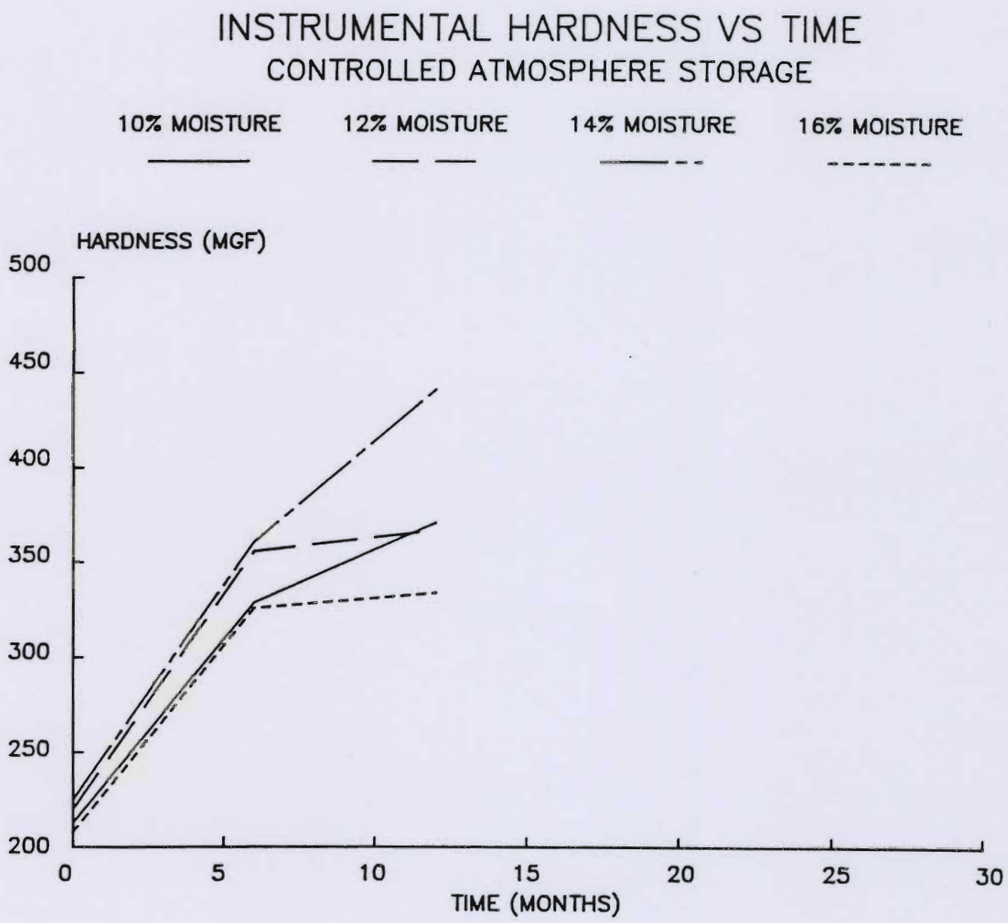


Figure 65. Effect of time on instrumental hardness (percentage hard-to-cook) of beans stored under controlled atmosphere

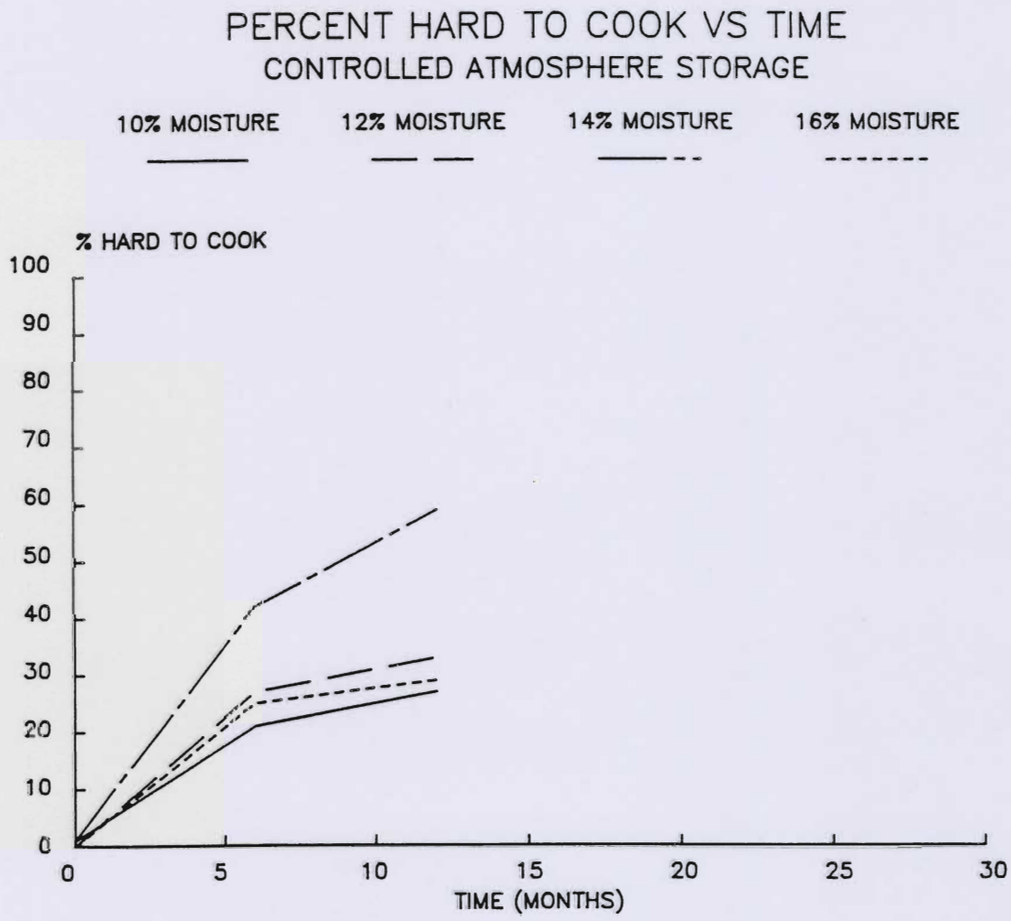
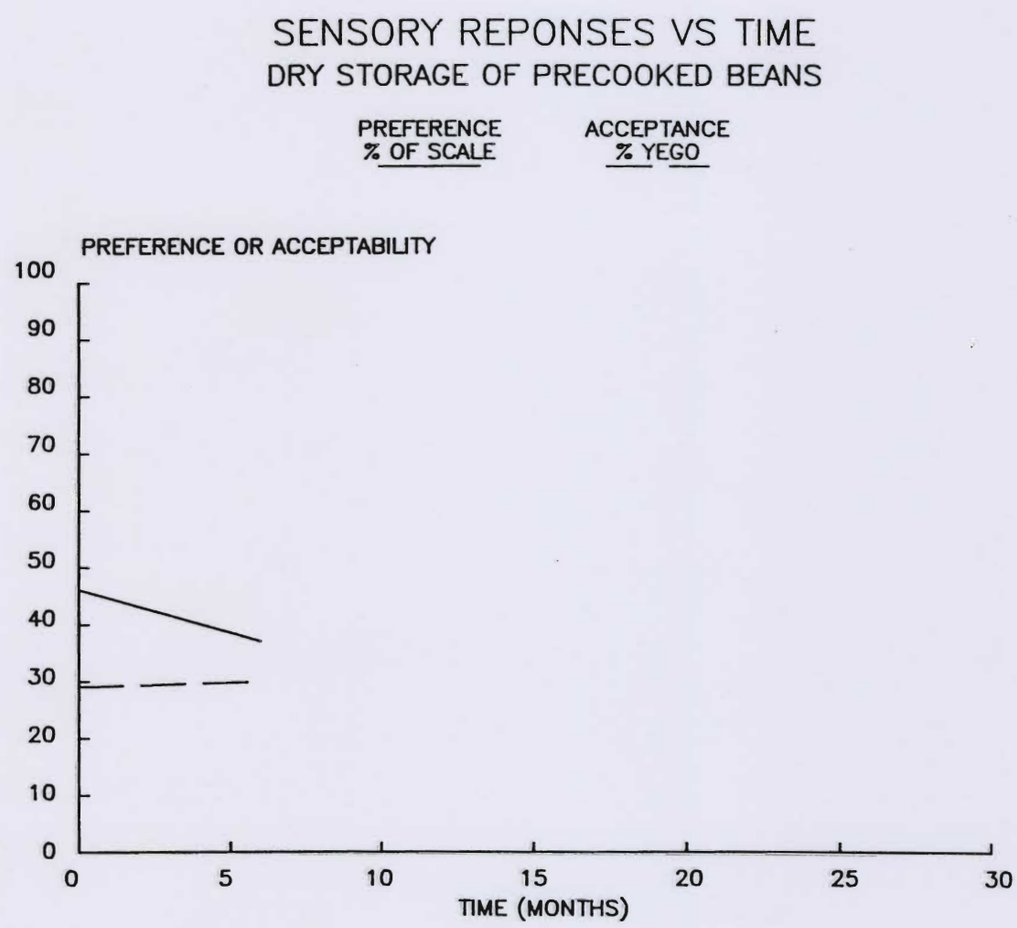


Figure 66. Effect of time on sensory responses (preference and acceptability) for precooked, dried, and rehydrated beans



Instrumental hardness values were low before storage and did not change during storage (Table 56). These low values were undoubtedly caused by destruction of bean integrity during cooking, drying, and rehydrating.

Vegetable Soup With Added Bean Flour

The vegetable soup was generally well-accepted by consumers at all test times (Table 55b) although preferences at 12 months storage had decreased.

Canned Dry Beans

Canned dry beans were well-accepted before storage (Table 55a, b, d; Figure 67); sensory preference and acceptability decreased noticeably after six months but the market values of these beans remained relatively high. Decreased preferences at 6 months storage were unrelated to changes in instrumental hardness. Mean grams force (Figure 68) and percent hard-to-cook values (Figure 69) were low before storage and appeared to decrease during storage.

Canned Green Beans

This product was well-accepted at all test times (Table 55a, b; Figure 70) although preferences did decrease slightly after 6 to 18 months storage. In June 1985 (0 months), consumers reported that they ate green beans on average of 11 times a week during the seasons when they were available (Table 55c); in December 1985, this figure dropped to 3 times a week and remained at this level after 12 and 18 months storage. Reasons for the large decrease are unclear.

Figure 67. Effect of time on sensory responses (preference and acceptability) for canned dry beans

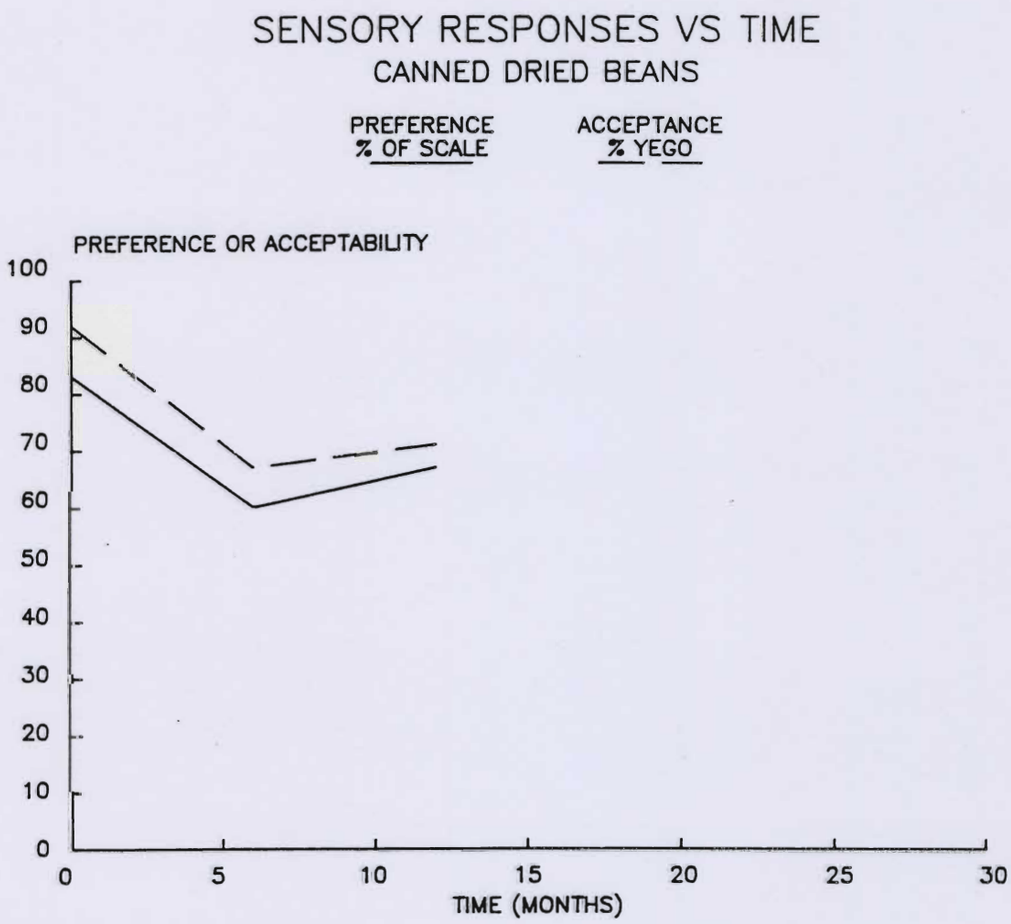


Figure 68. Effect of time on instrumental hardness (mean grams force) of canned dry beans

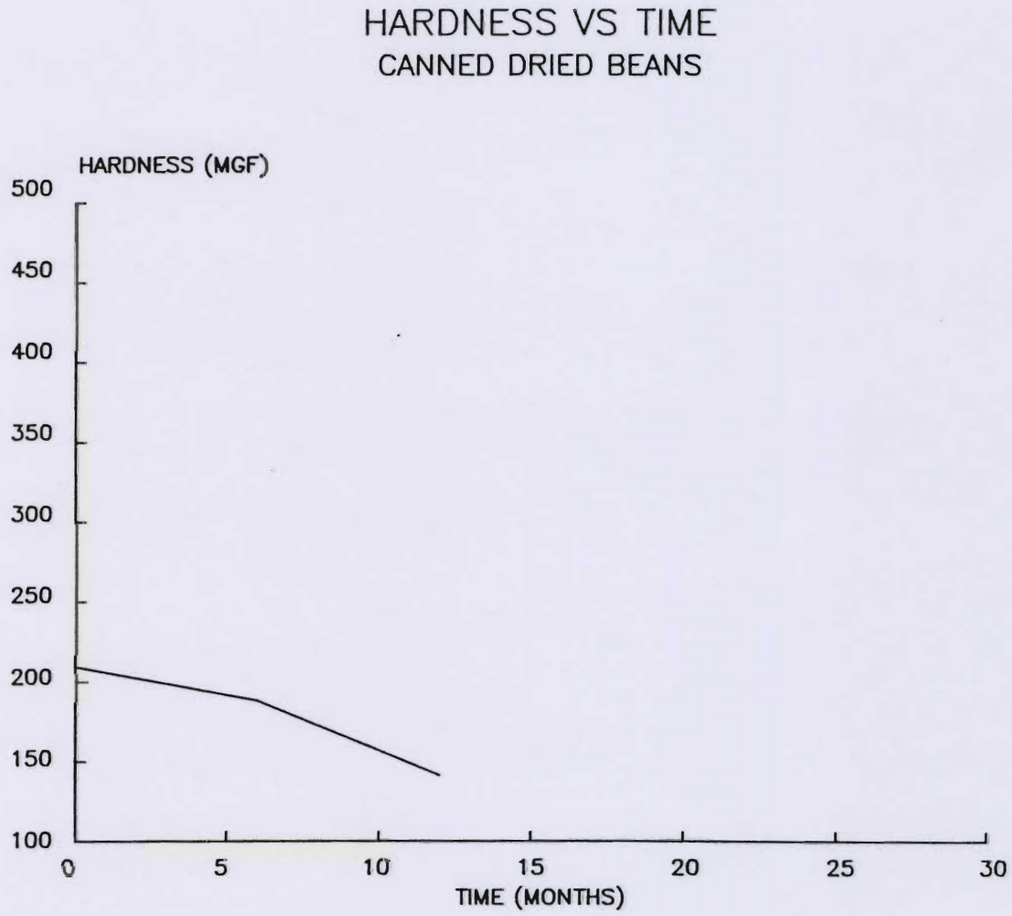


Figure 69. Effect of time on instrumental hardness (percentage hard-to-cook) of canned dry beans

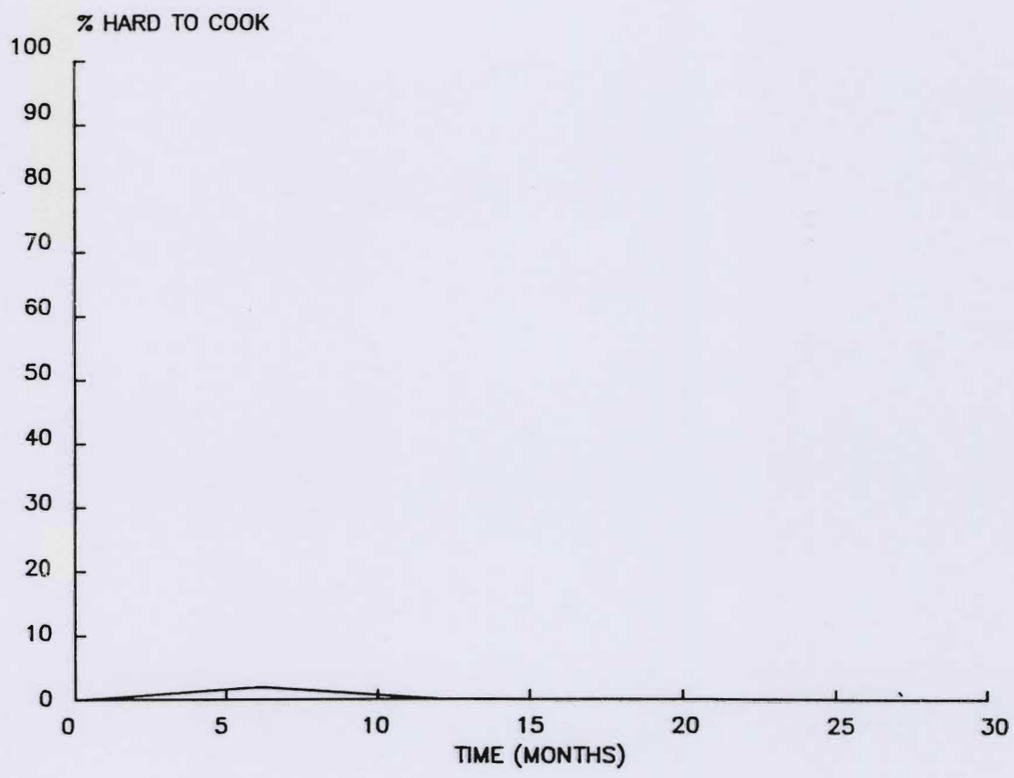
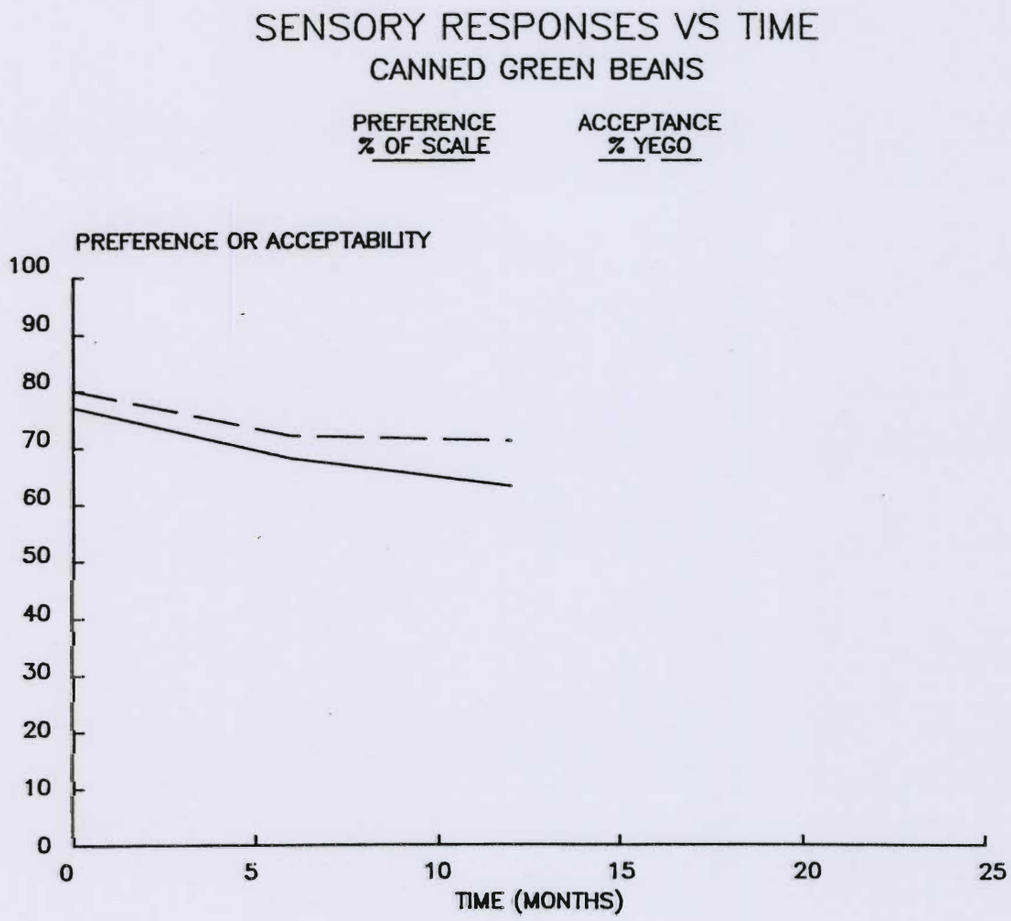


Figure 70. Effect of time on sensory responses (preference and acceptability) for canned green beans



The lower figure seems more reasonable, however, since many Rwandans report that they normally do not eat green beans very frequently since harvesting green beans reduces their dry bean harvest.

Comparison of Alternative Preservation Methods

The best preservation methods studied were canned dried beans and beans dried to 10% moisture and stored in a controlled atmosphere. Both products had relatively high preference and acceptability scores at market values after 18 months storage. Of these two methods the 10% moisture controlled atmosphere is clearly preferable in that it is immediately implementable and does not require the large capital investment needed to can on a large scale.

The canned green beans and soup prepared from bean flour were also acceptable preservation methods. Both products were new to Rwandans and results from this study indicate that either would be an acceptable food. However, both would require extensive capital investments to prepare on a large scale.

The precooked and dried beans and the beans with 14% and 16% moisture stored in controlled atmosphere were clearly inferior.

The differences in preference observed among beans preserved by different methods do not appear closely related to differences in hardness.

CONCLUSIONS

All products were initially acceptable to Rwandan consumers. Canned dry beans and beans dried to 10% moisture and stored in controlled atmosphere were preferred overall at 18 months storage to beans preserved by the other methods. The precooked dried beans and the higher moisture beans stored in a controlled

atmosphere were unacceptable at 6 and 12 months storage, respectively. Both canned dried beans and precooked and dried beans did not increase in hardness when stored, in fact the hardness of the canned beans actually decreased. The hardness of the controlled atmosphere storage beans increased with time - most dramatically for the 14% moisture beans.

Canned green beans and vegetable soup made with added bean flour were both well-accepted by consumers even though they likely had no previous experience with them.

REFERENCES

Aguilera, J.M., Crisafulli, E.B., Lusas, E.W., Uebersax, M.A., and Zabik, M.E. 1984. Air classification of Navy bean fractions. J. Food Sci. 49:543-546.

Aguilera, J.M., Lusas, E.W., Uebersax, M.A, and Zabik, M.E. 1982. Roasting of Navy beans (Phaseolus vulgaris) by particle-to-particle heat transfer. J. Food Sci. 47:996-1000,1005.

Aguilera, J.M., and Steinsapir, A. 1985. Dry processes to retard quality losses of beans (Phaseolus vulgaris) during storage. Can. Inst. Food Sci. Technol. J. 18(1):72-78.

Al-Nouri, F.F., and Siddigi, A.M. 1982. A quick cooking method for broad beans. Can. Inst. Food Sci. Technol. J. 15(1):75-77.

Anzaldua-Morales, A., and Brennan, J.G. 1982. Relationship between the physical properties of dried beans and their textural characteristics after processing. J. Texture Studies. 13:229-240.

DeFouw, C., Zabik, M.E., Uebersax, M.A., Aguilera, J.M., and Lusas, E.W. 1982. Use of untreated and heat-treated Navy bean hulls as a source of dietary fiber in spice-flavored layer cakes. Cereal Chem. 59(3):229-230.

Dunkel, F.D., Wittenberger, T., and Read, N. 1986. Final Report. Bean and Sorghum Storage Survey in Rwanda. USAID-Rwanda Local Crop Storage Cooperative Research, LCS/FSMII (Research component). University of Minnesota.

Gebre-Egziabher, A., and Sumner, A.K. 1983. Preparation of high protein curd from field peas. J. Food Sci. 48:375-377, 388.

Jackson, J.M., and Shinn, B.M. 1979. "Fundamentals of Food Canning Technology". Avi Publishing Co., Inc., Westport, CT.

McCurdy, S.M., Drake, S.R., Swanson, B.G., Leung, H.K., and Powers, J.R. 1983. Influence of cultivars, soak solution, blanch method, and brine composition on canned dry pea quality. J. Food Sci. 48:394-399.

McWatters, K.H. 1985. Functionality of cowpea meal and flour in selected foods. In "Cowpea Research, Production and Utilization" (ed. S.R. Singh and K.O. Rachie), John Wiley and Sons, Ltd. pp 361-366.

Molina, M.R., Baten, M.A., Gomez-Brenes, R.A., King, K.W., and Bressani, R. 1976. Heat treatment: A process to control the development of the hard-to-cook phenomenon in black beans (Phaseolus vulgaris). J. Food Sci. 41:661-666.

Morad, M.M., Leung, H.K., Hsu, D.L., and Finney, P.L. 1980. Effect of germination on physicochemical and bread-baking properties of yellow pea, lentil, and Faba bean flours and starches. Cereal Chem. 57(6):390-396.

Nout, M.J.R., and Nout-van der Hooft, C.F.S. 1979. Composite flour bread in Nigeria. Voeding - 40e Jaargang. 10:363-365.

Nymon, M.C., Salami, L., and Subramanian, K. 1982. Food uses of North Dakota dry edible beans. ND Farm Res. 40(2):25-27, 31.

Phillips, R.D., Kennedy, M.B., Baker, E.A., Chhinnan, S., and Rao, V.N.M. 1985. Novel foods from cowpeas by extrusion cooking. In "Cowpea Research, Production, and Utilization" (eds. S.R. Singh and K.O. Rachie), John Wiley and Sons, Ltd. pp. 367-373.

Qianyu, L. 1984. An Overview of the Present State of Controlled Atmosphere Storage of Grain in China. In "Controlled Atmosphere and Fumigation in Grain Storage" (eds. B.P. Ripp, H.J. Branks, E.J. Bond, D.J. Calverley, E.G. Jay, and S. Navarro), Elsevier, Amsterdam. pp. 15-29.

Rockland, L.B. 1968. New quick-cooking dry lima beans. Proceedings of the Eighth Dry Bean Research Conference, Bellaire, MI, ARS-74-41.

Rockland, L.B., and Metzler, E.A. 1967. Quick-cooking lima and other dry beans. Food Technol. 21:344-348.

Rockland, L.B. Zaragosa, E.M., and Oracca-Tetteh, R. 1979. Quick-cooking winged beans (Psophocarpus tetragonolobus). J. Food Sci. 44:1004-1007.

Ryall, A.L., and Lipton, W.J. 1972. Controlled Atmosphere Storage. In "Handling, Transportation and Storage of Fruits and Vegetables. Volume I: Vegetables and Melons". Avi Publishing Co., Inc., Westport, CT. pp. 240-242.

Ryall, A.L., and Pentzer, W.T. 1972. Controlled Atmosphere Storage of Apples and Pears. In "Handling, Transportation, and Storage of Fruits and Vegetables. Volume II: Fruits and Tree Nuts". Avi Publishing Co., Inc., Westport, CT. pp. 340-360.

Salunkhe, D.K. and Wu, M.T. 1974. Developments in Technology of Storage and Handling of Fresh Fruits and Vegetables. In "Storage, Processing and Nutritional Quality of Fruits and Vegetables" (eds. D.K. Salunkhe, J.Y. Do, M.T. Wu, H.R. Bolin, S.K. Pao, and G.G. Dull). CRC Press, Inc., Cleveland, OH. pp. 121-160.

Sathe, S.K., Iyer, V., and Salunkhe, D.K. 1981. Functional properties of the Great Northern bean (Phaseolus vulgaris) proteins, amino acid composition, in vitro digestibility, and application to cookies. J. Food Sci. 47:8-11, 15.

Seyam, A.A., Banasik, O.J., and Breen, M.D. 1983. Protein isolates from Navy and Pinto beans: Their uses in macaroni products. J. Agric. Food Chem. 31(3):499-502.

Sri Kantha, S., Hettiarachchy, N.S., and Erdman, J.R. Jr. 1983. Laboratory scale production of winged bean curd. J. Food Sci. 48:441-444, 447.

Uebersax, M.A., and Bedford, C.L. 1980. Navy bean processing: Effect of storage and soaking methods on quality of canned beans. Agricultural Business Research Report #410. Michigan State University Agricultural Experiment Station, East Lansing.

Wallace, M.J. 1977. Thermal inactivation of Clostridium sporogenes PA 3679 and Bacillus stearothermophilus in low acid canned foods. M.S. Thesis. University of Minnesota, St. Paul.

Wills, R.H.H., Lee, T.H., Graham, P., McGlasson, W.B., and Hall, E.G. 1981. Storage Atmosphere. In "Postharvest: An Introduction to the Physiology and Handling of Fruits and Vegetables". Avi Publishing Co, Inc., Westport, CT. pp. 60-70.

Zabik, M.E., Uebersax, M.A., Lee, J.P., Aguilera, J.M., and Lusas, E.W. 1983. Characteristics and utiliztion of dry-roasted air-classitied Navy bean protein fraction. JAOCS. 60(7):1303-1308.

SECTION VII

INFLUENCE OF DRYING ON COOKABILITY, COLOR, VIABILITY AND GERMINABILITY OF RWANDAN BEANS (*Phaseolus vulgaris*)

ABSTRACT

Samples of a Rwandan bean mixture were dried to moisture contents ranging from 8.8 to 16.6% at 86, 104, and 122°F (30, 40, and 50°C), and subjected to cookability (instrumental hardness), color, viability and germinability tests at time 0 and after 10 months storage at 30°C. The drying parameter having the most important influence on bean quality was the final moisture content to which the beans were dried. Beans having the highest moisture contents after drying were harder after cooking and showed increased color changes. Dryer temperature had no effect on instrumental hardness, viability or germinability.

INTRODUCTION

The importance of dry beans as a source of protein and calories in the Rwandan diet has been documented (Vis et al., 1975; Aykroyd and Doughty, 1982). Methods of improving the storability of beans are of great importance in Rwanda and other developing countries, as quality loss during storage may significantly affect the amount and value of beans available at certain times of the year. Some quality loss during storage may be induced by poor drying practices; drying temperature and moisture content after drying have been linked to reduced viability/germination, and to changes in some physical characteristics of grains. Moisture content after drying has also been linked to changes in cookability and seedcoat color during storage.

Drying-related changes in viability/germinability during storage are documented for some grains; however, there is no published research on such changes in dry beans. There is also no published research on the effects of drying temperature on the cookability and color of dry beans during storage. Thus the present study was undertaken to determine to what extent drying conditions affect the cookability (instrumental hardness), viability, germinability, and color of a Rwandan bean mixture during storage.

LITERATURE REVIEW

This review will be limited to a discussion of some of the existing research concerning the influence of drying conditions (temperature, moisture content after drying) on seed vigor (viability/germinability of legumes) before and/or during storage. The influence of moisture content and storage temperature on cookability and color changes during storage has been discussed elsewhere in this final report.

Influence of Drying Conditions on Seed Vigor of Legumes

Viability Tests

In many studies on seed quality, viability and germinability are used interchangeably to define seed vigor. Henceforth, in this review the term "seed vigor" will be used when referring to viability/germinability. Germination testing is commonly used to measure seed vigor. This measures the percentage of seeds in a sample failing to germinate and in some cases, the percentage of seeds germinating abnormally, after a given length of time under controlled conditions (Assoc. Official Seed Analysts, 1970). Another test which

is sometimes used to measure viability is the Tetrazolium Chloride Test (Tetrazolium Testing Handbook for Agricultural Seeds, 1970). This test measures the oxidation of tetrazolium chloride by viable cells of seeds after soaking in dilute solutions of this chemical. Viable portions of seeds stain pink, and viability is evaluated according to the staining patterns exhibited in comparison to standard staining patterns found in the Tetrazolium Testing Handbook. The procedures used for both germination and tetrazolium chloride tests vary with grain type; detailed procedures are found in the references mentioned above.

Effect of Drying Conditions on Viability/Germinability

Temperature

There is considerable evidence in the literature to suggest that elevated grain drying temperatures cause reduced seed vigor. The temperatures injurious to seed vigor apparently vary with the moisture content of the seed, with higher moisture seed being more susceptible to reduced vigor at elevated temperatures than lower moisture seed. Harrington (1959) recommended the following temperatures as guidelines for drying grains of different moisture contents:

Seed Moisture Range	Drying Temperatures	
	°F	°C
over 18%	90	32
10 - 18%	100	38
under 10%	110	43

The deleterious effects of elevated drying temperatures on seed vigor have been linked to physical changes occuring at these temperatures. 'Case

hardening' occurs when seeds are dried rapidly. Seedcoats shrink and become impervious to further moisture movement until the seedcoat takes up more moisture. This condition can produce dormant seeds (Harrington, 1959).

A far more serious condition is seedcoat cracking, which also occurs at elevated drying temperatures. It may increase seed susceptibility to disease and mold attack and result in abnormal seedlings or seed death (Harrington, 1959; McKenzie, 1972; Walker, 1972).

Theories of seedcoat cracking have been reviewed by Mensah et al. (1985). The "Pressure Build-Up" theory is based on the hypothesis that seedcoats exhibit a higher resistance to moisture transfer than cotyledons, resulting in a build-up of moisture and pressure behind the seedcoat during drying which eventually cause the seedcoat to rupture. The "shrinkage" theory is based on the hypothesis that seedcoats shrink faster than cotyledons during drying. The cotyledons prevent free shrinkage of the seedcoat, and the resulting tension causes the seedcoat to crack.

Mensah et al. (1985) used the latter theory to develop a mathematical model to predict stress development within soybean seedcoats resulting in cracking during drying. Predicted stress development was compared to experimentally determined stress development during thin-layer drying of soybeans (15% initial moisture, dry basis) at 35°C and 32, 45, and 55% relative humidity, and at 45°C and 25, 45, and 55% RH. Samples were dried for 5, 30, 60, and 90 min. Cracking only occurred during drying at 45°C and 25% RH, and then only at fairly low levels in comparison to other published data. Mensah et al. suggested that the low levels of cracking they observed may have been partially due to the low initial moisture content of their samples. This suggestion was based on Pfost's (1975) observation that the extent of soybean seedcoat cracking decreased with

decreased initial moisture content.

The mathematical model underestimated shrinkage stress by about 40% at 45°C, 25% RH and did not predict any stress development under the other drying conditions tested. However, the model was able to predict the seedcoat cracking trends observed experimentally. A trend of increased seedcoat cracking was observed during an initial critical drying period, when moisture content and shrinkage stress were changing rapidly. Cracking decreased as drying progressed. In addition, the extent of cracking increased as drying temperature increased from 35 to 45°C and as relative humidity of the dryer air decreased from 55% to 10% at 45°C. These last results support findings in other studies on soybeans and white beans (Walker, 1972; Pfost, 1975; Misra et al., 1978; Otten et al., 1984).

Drying temperature may have more of an effect on seed vigor after storage than immediately after drying. Harrington (1959) stated that the seed vigor of two lots of freshly harvested and washed onion seed (initial moisture = 25% wet basis) - one lot dried at 120°F (49°C) to 6% moisture and the other in stages at 90°F (32°C), 100°F (38°C), and 110°F (43°C) to the same moisture - will both exhibit high germinability initially. However, after six months storage Harrington suggested that the lot dried at 120°F will exhibit noticeably reduced germination in comparison to the lot dried in stages. No experimental data accompanied these statements and no explanation was given for the reduced vigor of the high temperature lot after storage. McKay (1972) has suggested that seed death is not an instantaneous process. Increased damage during drying at 120°F likely resulted in higher proportions of dead seeds after storage.

Mathematical equations have been used to predict safe drying temperatures of

seed grain. The reader is referred to Nellist (1980) for a detailed discussion of these equations.

Moisture Content After Drying

Seed moisture content is one of the two most important factors determining seed vigor during storage. The other factor, storage temperature, generally interacts with moisture content; maintenance of either factor at a low level helps to increase seed longevity (Toole and Toole, 1946). The influence of moisture content and storage temperature on seed vigor is documented. For example, Ellis et al. (1982a) studied the longevity of three cultivars of chickpea, cowpea, and soya bean during storage at moisture contents ranging from 5 to 25% (wet basis) and temperatures from -20 to 70°C. The seeds were conditioned to the different moisture contents by desiccation over silica gel or by humidification in an atmosphere of approximately 100% RH. Constant temperature environments were provided by a chest freezer (-20°C), cooled incubators (10-30°C), heated incubators (40-50°C), and heated water baths (60-70°C). Moisture contents were maintained during storage by sealing the beans in laminated foil packets. To determine the effect of storage conditions on longevity, germination tests were conducted at regular intervals up to 760 days storage. Longevity was defined as the time for viability (% germination) to be reduced to 50% (half-viability period). The half-viability period was plotted against moisture content on a logarithmic scale for each seed lot and cultivar at constant temperatures. Results indicated that there was a negative logarithmic relationship between half-viability period and seed moisture content at each temperature. That is, the time for viability to fall to 50% decreased logarithmically with moisture content. In addition, the effect of moisture

content on half-viability period decreased with decreasing temperature, and the relative effect of temperature on half-viability period was greater for higher temperatures than lower temperatures.

Ellis et al. also pointed out that there was no reversal of the negative logarithmic relationship between longevity and moisture contents at lower moisture contents: low moisture seed had longer half-viability periods than higher moisture seed. These results are important because they underscore the importance of rehumidification of low moisture seed before viability testing. In studies where low moisture seeds are not rehumidified before testing, viability is usually reduced because of excessive seedcoat desiccation. For example, in another study, Ellis et al. (1982b) showed that cowpea seeds dried from 12% to 4.4% moisture (wet basis) exhibited reduced vigor (germinability); moisture contents required to produce significant reductions varied from 10.2 to 6.2%. Rehumidification of these beans over water at 20°C for three days restored germination to expected levels. Tittel (1979) observed that soybean and French bean (Phaseolus vulgaris L.) seed exhibited reduced germination at moisture contents less than 4%. He also found that reduced germination could be avoided by rehumidification of the seed before testing. Thus it is clear that drying seed to low moisture contents for storage does not always assure high viability levels if appropriate rehumidification procedures are not used before testing.

Mathematical equations have been used in some studies to predict seed viability during storage at different moisture contents and temperatures. The reader is referred to Ellis and Roberts (1981) and Ellis et al. (1982a) for detailed discussions of these equations.

In summary it is clear that drying temperature and moisture content influence seed vigor. Elevated drying temperatures may cause seed dormancy due to case hardening, and abnormal seedlings or seed death due to seedcoat cracking. Seedcoat cracking occurs during an initial critical drying period and is dependent on initial seed moisture content and drying air relative humidity. Seed death is not an instantaneous process; seed damage caused by elevated drying temperatures may be more pronounced after storage than immediately after drying. Seed vigor decreases with increasing moisture content and temperature during storage. However, proper rehumidification of low moisture content seed is necessary before testing to assure that viability is high at low moisture levels.

Loss of seed vigor and concomitant changes in cookability and color of dry beans during storage are clearly of concern to consumers in Rwanda. Drying conditions affect seed vigor and may also affect cookability and color. Detailed information concerning the effects of drying conditions (temperature, final moisture content to which the beans are dried) on these qualities before and during storage are necessary to determine which drying procedures maximize storability. Thus the objectives of this study were to determine the influence of drying temperature and final moisture content on the germinability, viability, cookability and color of a mixture of Rwandan beans.

MATERIALS AND METHODS

I. Beans

Approximately 5 kg of a Rwandan bean mixture (Table 57) from the May-June, 1985 harvest were purchased at the Kigali market in June, 1985. The initial moisture content of the beans was 20.4% (AACC 2-stage method 44-15A). The beans were sorted and foreign material and damaged (cracked, shriveled, dented, insect-ridden) beans were removed. The sound beans were separated into 15 subsamples of 320 g each which were placed in tightly closed glass jars and stored for not more than three weeks at 6°C in a refrigerator to prevent changes in quality before testing. Subsamples were removed from the refrigerator the night before a test and left on the lab bench overnight to allow them to come to room temperature before drying.

II. Thin Layer Drying Apparatus

A laboratory scale thin layer dryer constructed at the University of Minnesota Department of Agricultural Engineering was used for the drying tests. The apparatus consisted of an air ventilation system to deliver air at a predetermined temperature and velocity, a weighing system to record the weight of bean samples at regular intervals during the drying process and a drying chamber (see Section 8, Thin Layer Drying Curves Figure 126 for a schematic drawing of the apparatus. The apparatus used in the present study had no controlled temperature water spray, air unit, valve, wet and dry bulb thermometers, or data logger.)

Table 57. Description of the three types of beans that were predominant in the mixture used for this study (Lamb and Hardman, 1986)

Seed Shape[a]	Seedcoat Color Pattern[b]	Color[c]	Color of Lines or Spots[c]	Size
ro	mc	jbr	-	medium
lo	zb	cr	n	large
ro	mc	rs	-	small

[a] ro = rounded oval
lo = elongated oval

[b] mc = monochromatic
zb = zebra striped

[c] jbr = yellow brown
cr = cream
rs = pink
n = black

Air was circulated using a Dayton Shaded Pole Blower (Model NC006B; Dayton Electric Mfg. Co., 5959 Howard St., Chicago, IL 60648), and was heated to the desired temperature using a system of resistance heaters. Temperature was controlled using a temperature control monitor (Paktronics Instrumental Measurement and Control Modules, 4044 N. Rockwell, Chicago, IL 60618). A copper-constantan thermocouple was located at the base of the sample tray in the plenum chamber to sense the drying temperature. A thermocouple leading to another temperature monitor (Model 8110-25, Cole Parmer Instruments, 7425 N. Park Ave. Chicago, IL 60618) was placed at the same level so that the drying temperature could be monitored independently of the internal control system throughout the drying process. The airflow delivered to the plenum chamber was measured ahead of the heaters with a differential head meter which consisted of a flat plate orifice (4.13 cm/1.65 in. diameter) and a micromanometer.

Air velocity was controlled using a series of orifice plates varying in diameter from 1.38 cm (0.55 in) to 4.13 cm (1.65 in) connected to the air ventilation system ahead of the resistance heaters. Air velocity could be increased from 5 cfm (cubic feet per min) to 27 cfm using this system.

The test chamber was a plywood column 40.5 x 40.5 x 76.5 cm (16.2 x 16.2 x 30.6 in) and was divided into two parts: a plenum chamber in the lower part and a test chamber in the upper part. The plenum chamber was insulated with 3 mm (0.12 in) thick expanded polystyrene to minimize heat loss to the surroundings. A door in the test chamber allowed insertion and removal of the sample.

The sample tray was suspended in the test chamber from a digital balance (Mettler Model PE 4000; Mettler Instrumental Corp., Box 71, Hightstown, NJ 08520) placed on top of the test chamber. A 2.5 cm (1 in) diameter hole drilled in the top of the test chamber allowed the sample tray to be hooked to the balance from

the inside of the test chamber.

The internal dimensions of the sample tray were 18 x 18 cm (7.2 x 7.2). The sides of the tray were made of sheet metal and the bottom was made of 1.6 mm (1/16 in) wire mesh. The sides of the tray extended approximately 10 cm (4 in) above and 5 cm (2 in) below the screen. When the sample tray was suspended from the balance, its bottom edges extended into a channel filled with soybean oil to form an air seal. This system allowed all the air from the plenum chamber to be forced through the sample tray and out through a 2 in circular hole drilled in the test chamber above and behind the tray.

III. Drying Procedure

Before a bean sample was placed on the sample tray, the drying apparatus was preheated for 30 minutes at the desired temperature with the tray suspended from the balance. The sample was placed on the tray with the blowers and heaters off and the balance tared. The beans were spread evenly across the bottom of the tray so that they would dry uniformly and the weight would be evenly distributed. The initial sample weight was recorded, and the balance was again tared before drying was started.

In order to prepare beans for the germination study, a 320 g sample was dried to approximately 13.6% moisture content at each of the following temperatures: 30, 40, and 50°C (86, 104 and 122°F) and at the maximum air velocity supplied by the blower (approximately 27 cfm). Subsamples were weighed at hourly intervals with the blower and heaters off until the desired moisture content was reached.

In order to prepare beans for the cookability tests and viability tests and color analyses, the remaining 12 subsamples of beans were dried at maximum air

velocity at the same three drying air temperatures. At each temperature, the subsamples were dried to three different moisture contents: approximately 15%, 13%, and the moisture content that was in equilibrium with the drying air after no weight change registered on the balance during a 1-hour interval. The 40°C, 13% moisture treatment was repeated four times. Subsamples were weighed at 30 min intervals until the desired moisture content was reached. The final moisture content of each lot was determined from its original moisture content and the total change in weight during drying.

After drying, subsamples were divided into two parts. One part was used immediately for baseline (zero time) germination, cookability, viability, and color analyses. The other part was stored in cotton or nylon mesh bags in desiccators containing saturated salt solutions providing a_w levels in approximate equilibrium with the final moisture contents of the subsamples. Table 58 shows the final moisture contents of samples after drying, the water activities of the saturated salt solutions used to maintain those moisture contents, and the saturated salt solutions employed in the instrumental analysis. After 10 months storage at 30°C in an incubator (Precision Model 815, Precision Scientific Group, 3737 West Courtland St., Chicago, IL 60647), all tests were repeated.

Table 58. Final moisture contents, water activities of the saturated salt solutions used to maintain those moisture contents and the saturated salt solutions employed in the cookability, germinability, viability and color analysis.

% moisture in sample after drying	water activity of saturated salt solution	saturated salt solution used to establish equilibrium moisture condition
8.8	0.33	$MgCl_2$
9, 11, 13.5, 13.6, 13.7, 13.8	0.53	$Mg(NO_3)_2$
15.1, 16.5, 16.6	0.69	KI

IV. Germination Tests

One hundred randomly chosen beans from each of the three subsamples were placed between two moistened sheets of brown paper toweling which were placed on a sheet of waxed paper. The beans and the two layers of paper were then rolled together into a single cylinder, which was secured at both ends with rubber bands. The cylinders were placed on end in separate closed plastic bags and stored in the dark for 6 days at room temperature (23°C/73°F). The bags were opened, the cylinders were removed, and water was poured over them twice daily to keep the paper toweling damp. Excess water was removed from the inside bottoms of the plastic bags so that the beans would not stand in it. The beans were considered to have germinated if the length of the hypocotyl was at least one-half the length of the seed. The numbers of beans that had germinated in 4 and 6 days were counted and used to calculate the percentage germination.

V. Cookability tests

A. Cooking procedure

A one-third cup portion of beans (about 150 beans) and one-half teaspoon salt were combined with excess tap water in a 2 qt. Farberware stainless steel saucepan. The mixture was brought to a boil over high heat on an electric hotplate and covered. When boiling began (at approximately 96°C, 205°F), the heat was regulated to maintain a moderate boil for three hours. Previous sensory tests had indicated that beans stored 1-2 months after harvest and cooked for 3 hr were at an acceptable level of doneness. Hot water was added as necessary during cooking to keep the beans completely immersed without cessation of boiling.

The cooked beans were drained and transferred to small enamel dishes or plastic trays for cooling. An inverted plate or tray was placed over the beans to avoid changes in hardness due to drying. The beans were allowed to cool to room temperature for approximately 2 hr before instrumental hardness testing.

B. Instrumental hardness tests

Bean hardness was tested with a Chatillon dial push/pull gauge (Model DPP-500G) and test stand (Model LTS: John Chatillon and Sons, Inc. 83-30 New Gardens Rd., New Gardens, NY 11415). See Section IX, Bean Varietal Study for a description of the Chatillon tester and hardness measurement.

VI. Viability tests

Percent viability of beans was determined using the tetrazolium test (Tetrazolium Testing Committee of the AOSA, 1970). One hundred beans from each sample were allowed to soften overnight between 2 pieces of moistened brown paper toweling. The following morning, the seedcoats were slit with a razor blade opposite and perpendicular to the hilum to facilitate imbibition during 6 hr soaking in a 1% tetrazolium chloride solution (2,3,5-triphenyl tetrazolium chloride, Fisher Scientific Co., No. T-413). The number of beans displaying red portions in specific regions of the cotyledons (interpreted according to tetrazolium staining patterns; Tetrazolium Testing Committee of the AOSA, 1970), indicating oxidation of tetrazolium by viable cells, was used as an estimate of percent viability.

VII. Color analyses

Six types of beans were chosen from the mixture for seedcoat color analysis according to their predominance in the mixture or how well they would show

changes in color over time (i.e., light-colored varieties were chosen over dark-colored varieties). The Munsell color system was used to determine seedcoat color. Two or three beans from each variety were compared to color chips arranged in charts according to hue, value (degree of lightness), and chroma (degree of saturation). The color charts were assembled at the Munsell Company specifically for use with Rwandan beans using samples taken from freshly harvested mixtures.

A typical Munsell color designation is as follows:

2.5R	(Hue)
6	(Value)
12	(Chroma)

Hue is designated by a number on a scale of 2.5 to 10 and by a letter (e.g., R=red; P=purple; YR=yellow/red). Value is designated by a number on a scale of 2 to 9; the higher the number, the lighter the color. Chroma is designated by a number on a scale of 1 to 20; the higher the number, the more saturated the color. Differences in color designations for a given type over time were used as indicators of the influence of drying and storage conditions on seedcoat color.

RESULTS AND DISCUSSION

Instrumental Hardness

All the beans showed a clear increase in hardness over the ten month storage period. However the beans dried to the higher final moisture contents (15-17% moisture) showed a much greater increase in hardness after ten months storage compared with beans dried to a lower moisture content (Figures 71 and 72). Drying temperature did not affect the instrumental hardness of the beans (Figures 73 and 74).

Figure 71. Effect of final moisture content on instrumental hardness (mean grams force) by drying temperature and storage time.

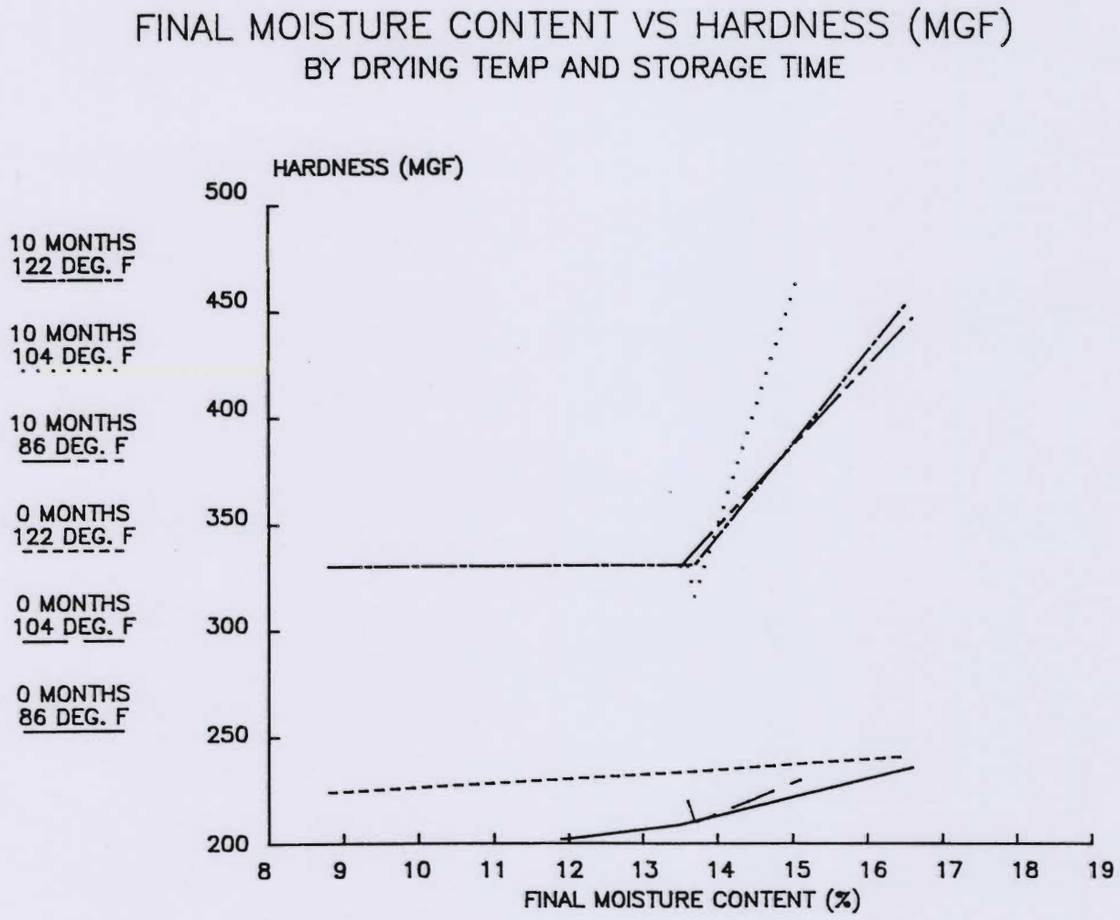


Figure 72. Effect of final moisture content on instrumental hardness (percentage hard-to-cook) by drying temperature and storage time.

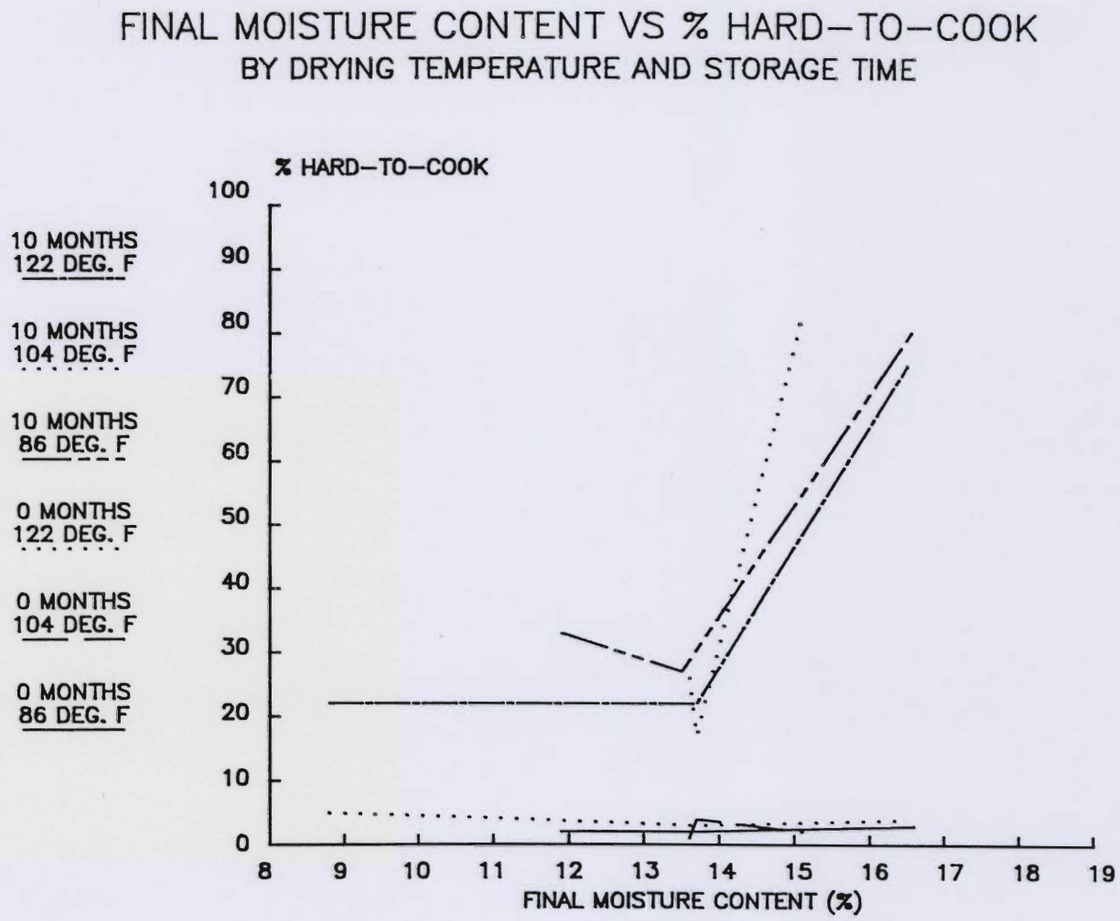


Figure 73. Effect of drying temperature on instrumental hardness (mean grams force) by storage time.

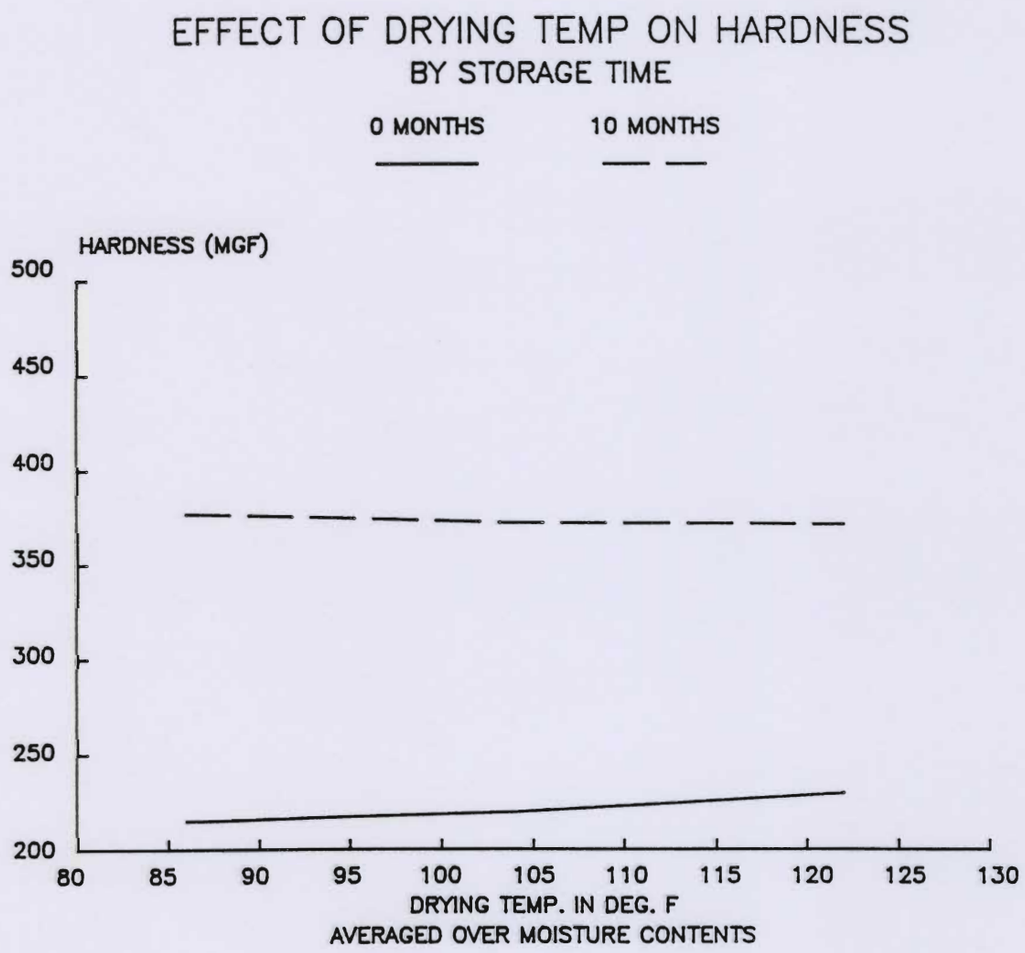
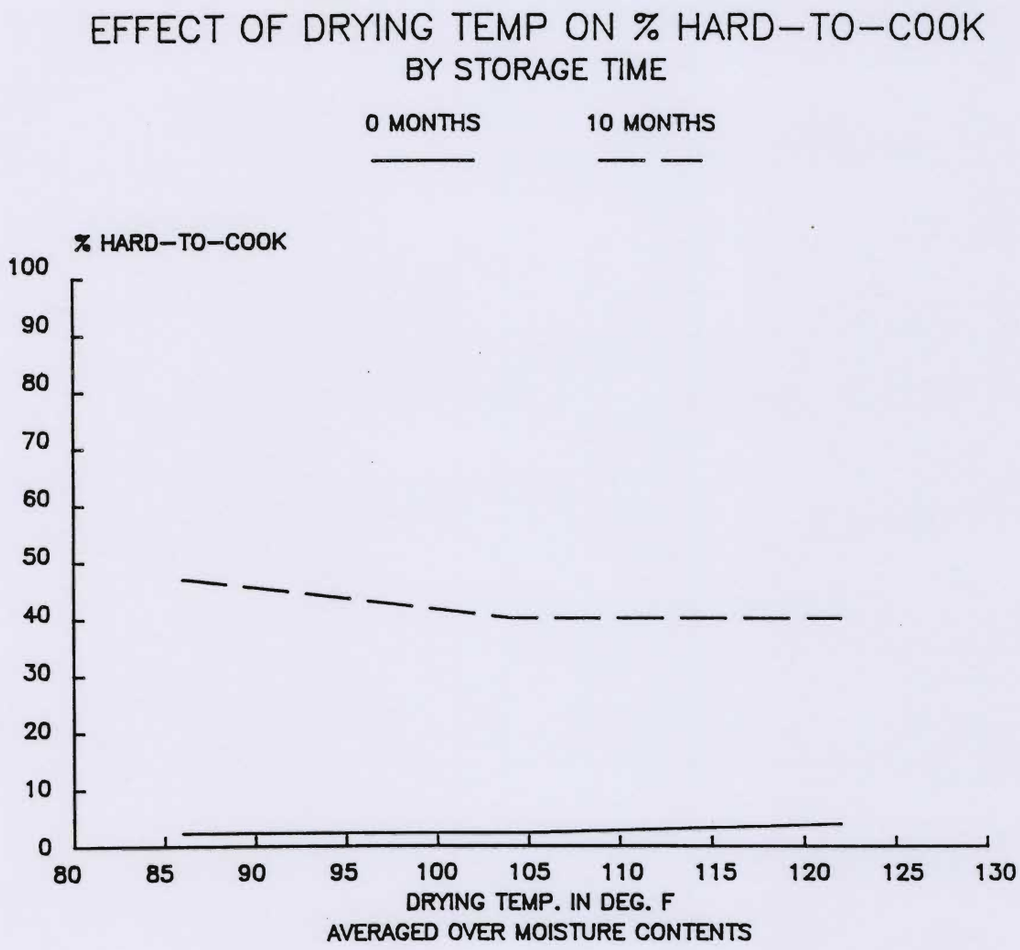


Figure 74. Effect of drying temperature on instrumental hardness (percentage hard-to-cook) by storage time.



Viability and Germinability

Viability scores decreased over the ten month storage period from a range of 67 to 82 at 0 time to a range of 30 to 75 at ten months (Figures 75 and 76). The viability scores at ten months were quite variable and did not show the decrease in viability with increasing drying temperature that was expected from the literature (Harrington 1959).

Drying temperature did not affect the germinability of the beans immediately after drying (Figure 77). After ten months storage the germinability of beans dried at the lowest temperture (86 F) had dropped considerably more than the germinability of beans dried at higher temperatures. This result was unexpected and opposite of the predictions of Harrington (1959) and McKay (1972).

Color Changes (Tables 59-65) generally increased with dryer air temperature and moisture content. In the 50°C, 16.5% moisture treatment, colors of four of the six bean types analyzed had darkened during storage to such an extent that they could no longer be matched to the Munsell color charts. Beans dried at 30°C to 11.9% moisture resisted color change more during storage than all the other treatments. (There is no color data for the 50°C, 8.8% moisture treatment.) The observed increases in color change with moisture content at each drying temperture in beans stored at 30°C are in accordance with those of Buri et al. (1968), who observed that pinto beans stored at temperatures as low as 21°C and 16.0% moisture darkened in color during up to 24 months storage, whereas those stored at 8.2% to 13.9% moisture did not. These color changes have been attributed to non-enzymatic browning reactions (Longe, 1980).

Figure 75. Effect of final moisture content on viability by drying temperature and storage time.

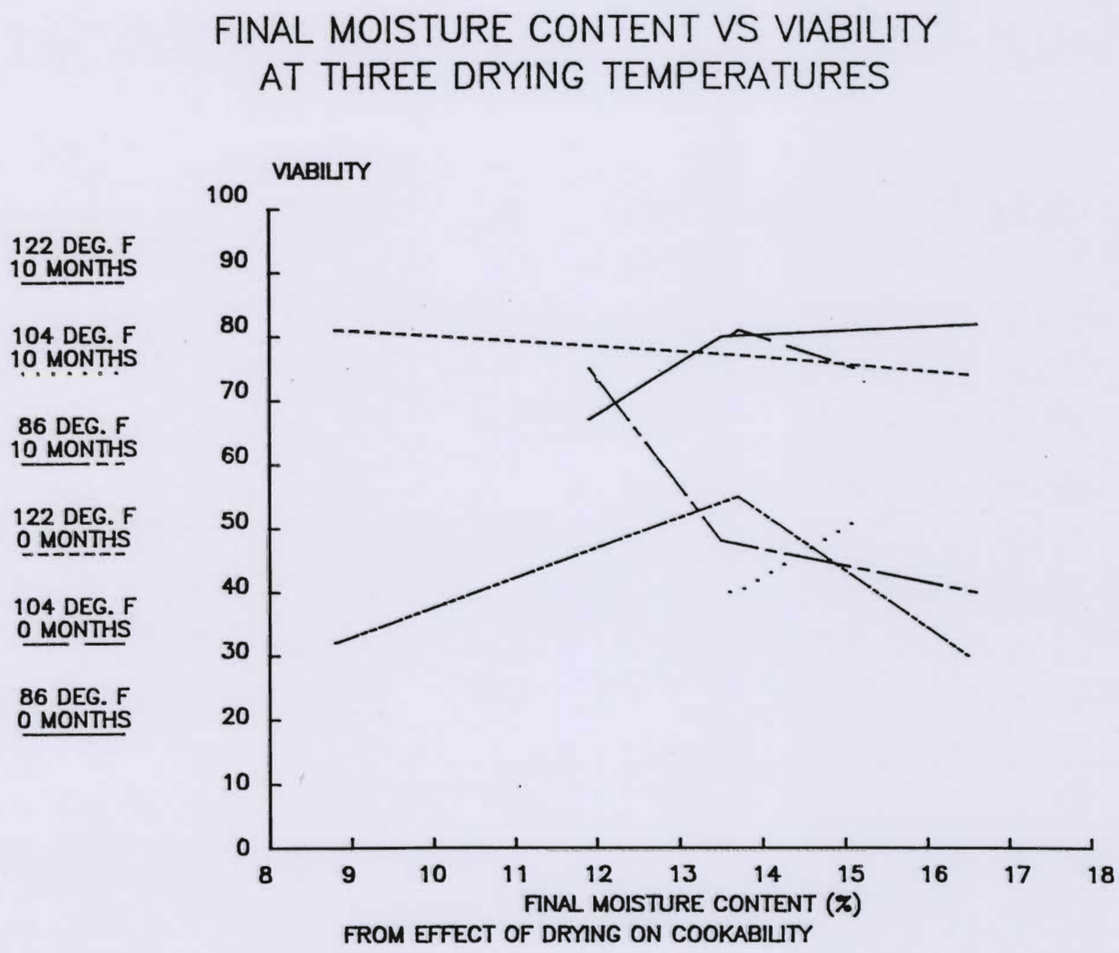


Figure 76. Effect of drying temperature on viability of beans in three moisture ranges (low - 8-12%; medium - 13-14%; and high - 15-17%) by storage time.

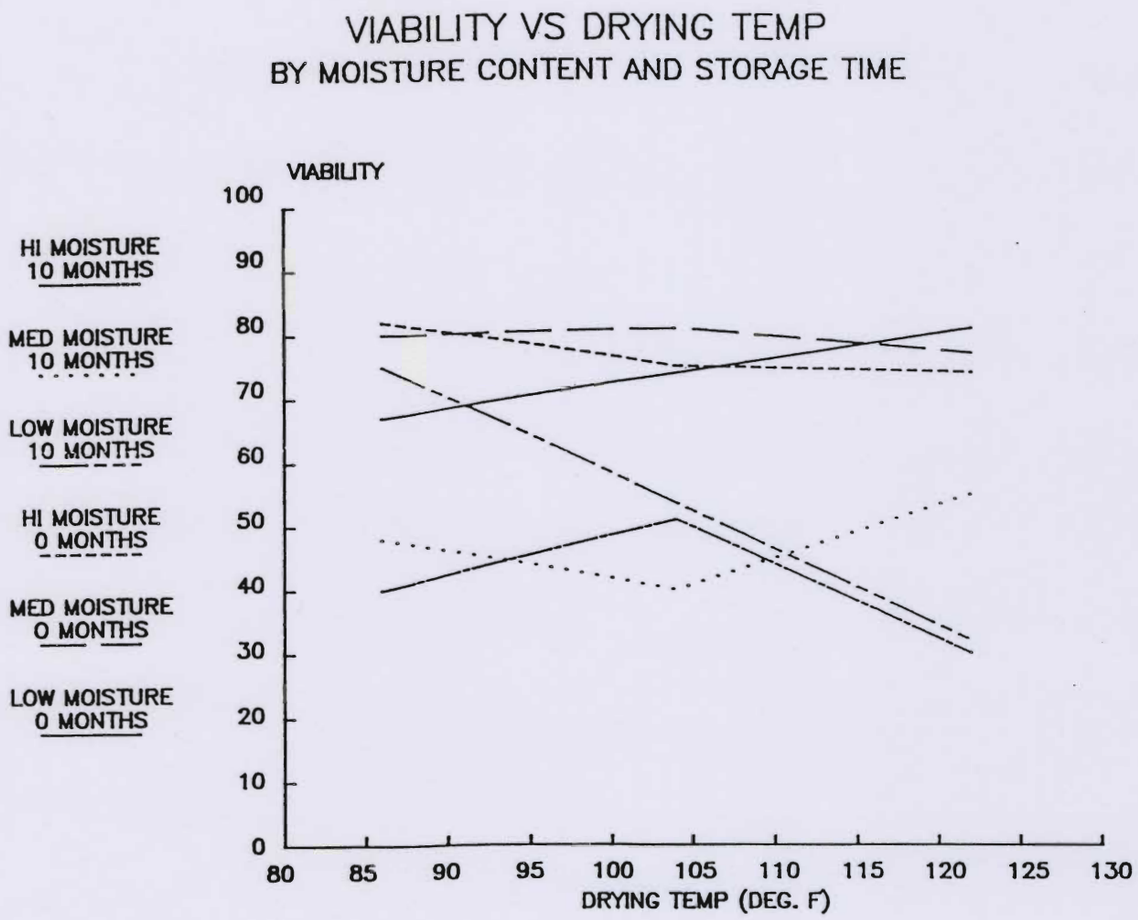


Figure 77. Effect of drying temperature on germinability of beans dried to 13.6% moisture by storage time.

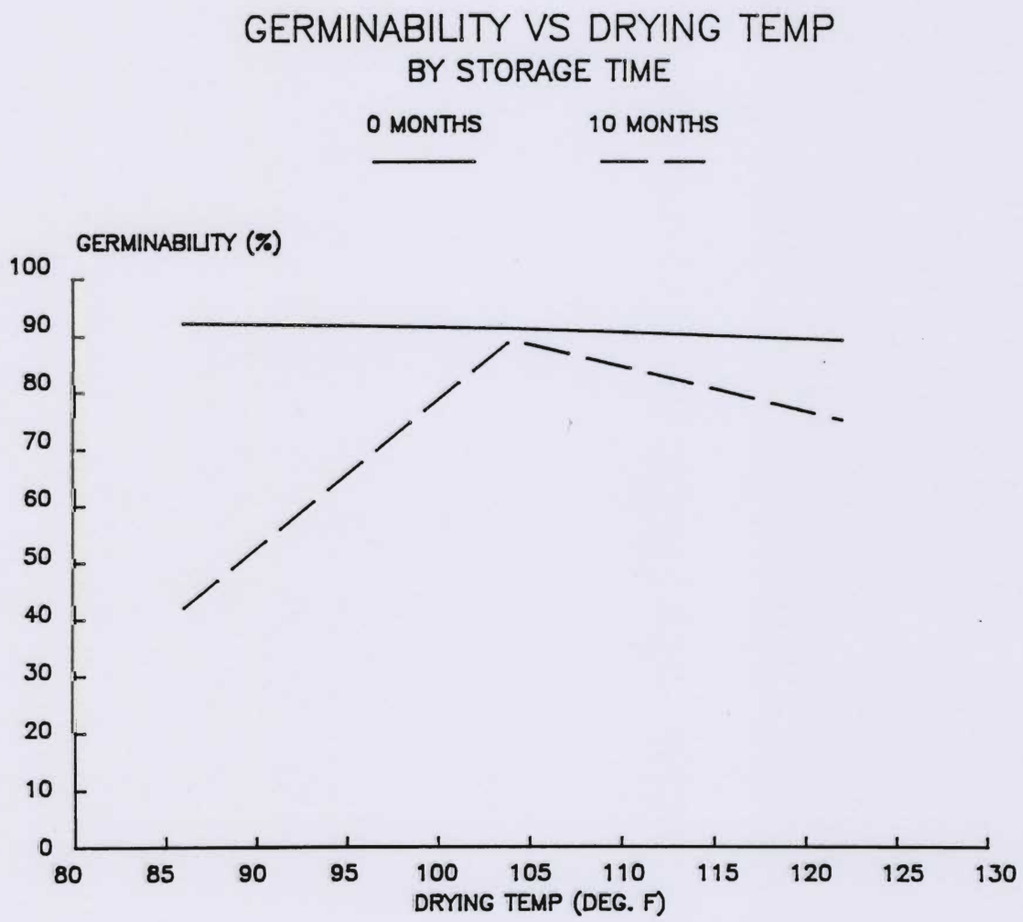


Table 59. Munsell Color Change Data

Drying Temperature: 30°C Moisture Content After Drying: 11.9%

Variety	0 Months	10 Months	Change Noted
yellow/green	7.5Y $\frac{7}{6}$ and 5Y $\frac{6}{6}$, 5Y $\frac{7}{8}$	2.5Y $\frac{6}{6}$, $\frac{5}{8}$	
pink	5R $\frac{6}{4}$ and 7.5R $\frac{6}{4}$ and 10R $\frac{5}{4}$	10R $\frac{5}{6}$, $\frac{6}{6}$	
yellow/brown	10YR $\frac{6}{8}$, $\frac{5}{10}$	7.5YR $\frac{4}{6}$, $\frac{4}{8}$	Change of hue towards yellow slight darkening
zebra striped cream background	7.5YR $\frac{8}{2}$	-	
cream	10YR $\frac{8}{2}$	5YR $\frac{5}{4}$	Change of hue towards yellow darkening, color more saturated
brown	10YR $\frac{4}{4}$, $\frac{3}{6}$, $\frac{3}{4}$	10YR $\frac{3}{4}$	No change

Guide to Abbreviations

Y = yellow
R = red
YR = yellow/red

Example: 7.5YR — hue (yellow/red)
$\frac{8}{2}$ — degree of lightness (value) / degree of saturation (chroma)

As value scores increase, color is lighter.
As chroma scores increase, color is more saturated.

Table 60. Munsell Color Change Data

Drying Temperature: 30°C Moisture Content After Drying: 13.5%

Variety	0 Months	10 Months	Change Noted
yellow/green	7.5Y $\frac{8}{6}$ and 5Y $\frac{7}{6}$	-	at 10 months color too dark to find good match with charts
pink	5R $\frac{7}{4}$	-	at 10 months color too dark to find good match with charts
yellow/brown	7.5YR $\frac{5}{8}$ and 10YR $\frac{5}{10}$, $\frac{6}{8}$	-[a]	data not available
zebra striped cream background	10YR $\frac{8}{2}$ and 7.5YR $\frac{8}{2}$	5YR $\frac{6}{6}$	change of hue towards yellow darkening, color more saturated
cream	7.5YR $\frac{8}{2}$ and 7.5YR $\frac{8}{2}$	-[a]	data not available
brown	10YR $\frac{4}{4}$ and 10YR $\frac{3}{4}$	10YR $\frac{3}{4}$ and $\frac{2}{2}$	No change

[a]unable to find variety in 10 month sample.

Guide to Abbreviations

Y = yellow
R = red
YR = yellow/red

Example: 7.5YR — hue (yellow/red)
$\frac{8}{2}$ — degree of lightness (value) / degree of saturation (chroma)

As value scores increase, color is lighter.
As chroma scores increase, color is more saturated.

Table 61. Munsell Color Change Data

Drying Temperature: 30°C Moisture Content After Drying: 16.6%

Variety	0 Months	10 Months	Change Noted
yellow/green	7.5Y $\frac{7}{6}$, $\frac{8}{6}$	2.5Y $\frac{5}{8}$	darkening
pink	7.5R $\frac{6}{4}$, $\frac{6}{6}$	-	at 10 months color too dark to find good match with charts
yellow/brown	10YR $\frac{5}{10}$, $\frac{5}{8}$	-	darkening
zebra striped cream background	10YR $\frac{8}{2}$ and 7.5YR $\frac{7}{2}$	-	data not available
cream	7.5YR $\frac{8}{2}$ and 10YR $\frac{8}{2}$	-	darkening
brown	10YR $\frac{5}{4}$, and 10YR $\frac{3}{6}$	5YR $\frac{2}{4}$	change of hue towards yellow darkening

[a]unable to find variety in 10 month sample.

Guide to Abbreviations

Y = yellow
R = red
YR = yellow/red

Example: 7.5YR hue (yellow/red)
$\frac{8}{2}$ degree of lightness (value)
degree of saturation (chroma)

As value scores increase, color is lighter.
As chroma scores increase, color is more saturated.

Table 62. Munsell Color Change Data

Drying Temperature: 40°C Moisture Content After Drying: 13.6%

Variety	0 Months	10 Months	Change Noted
yellow/green	7.5Y $\frac{8}{6}$, $\frac{8}{4}$	5Y $\frac{6}{8}$ and 2.5Y $\frac{6}{8}$	darkening, color more saturated
pink	5R $\frac{5}{6}$, $\frac{5}{4}$ and 7.5R $\frac{6}{4}$	7.5R $\frac{4}{6}$	darkening, color more saturated
yellow/brown	10YR $\frac{5}{10}$, $\frac{5}{8}$ and 7.5YR $\frac{6}{10}$	7.5YR $\frac{4}{8}$	darkening
zebra striped cream background	5YR $\frac{8}{1}$ and 7.5YR $\frac{8}{2}$	7.5YR $\frac{5}{6}$	darkening, color more saturated
cream	5YR $\frac{8}{1}$ and 7.5YR $\frac{8}{2}$	7.5YR $\frac{6}{4}$	darkening, color more saturated
brown	10YR $\frac{4}{4}$, $\frac{3}{4}$	10YR $\frac{3}{4}$	no change

Guide to Abbreviations

Y = yellow
R = red
YR = yellow/red

Example: 7.5YR — hue (yellow/red)
$\frac{8}{2}$ — degree of lightness (value) / degree of saturation (chroma)

As value scores increase, color is lighter.
As chroma scores increase, color is more saturated.

Table 63. Munsell Color Change Data

Drying Temperature: 40°C Moisture Content After Drying: 15.1%

Variety	0 Months	10 Months	Change Noted
yellow/green	7.5Y $\frac{8}{6}$ and 5Y $\frac{7}{6}$	-	data not available
pink	5R $\frac{5}{6}$ and 10R $\frac{6}{4}$	-	at 10 months color too dark to find good match with charts
yellow/brown	7.5YR $\frac{5}{8}$, $\frac{5}{10}$	10YR $\frac{4}{8}$	slight darkening change of hue towards red
zebra striped cream background	10YR $\frac{7}{4}$ and 7.5YR $\frac{8}{2}$	7.5YR $\frac{5}{8}$	darkening, color more saturated
cream	7.5YR $\frac{8}{2}$, $\frac{7}{4}$	7.5YR $\frac{5}{6}$	darkening, color more saturated
brown	10YR $\frac{4}{4}$, $\frac{3}{4}$	10YR $\frac{3}{6}$	color slightly more saturated

[a]unable to find variety in 10 month sample.

Guide to Abbreviations

Y = yellow
R = red
YR = yellow/red

Example: 7.5YR — hue (yellow/red)
$\frac{8}{2}$ — degree of lightness (value)
degree of saturation (chroma)

As value scores increase, color is lighter.
As chroma scores increase, color is more saturated.

Table 64. Munsell Color Change Data

Drying Temperature: 50°C Moisture Content After Drying: 13.6%

Variety	0 Months	10 Months	Change Noted
yellow/green	7.5Y $\frac{8}{6}$, and 5Y $\frac{7}{6}$	-	at 10 months color too dark to find good match with charts
pink	5R $\frac{6}{4}$, and 7.5R $\frac{6}{6}$	10R $\frac{4}{4}$	darkening
yellow/brown	10YR $\frac{6}{12}$, $\frac{5}{10}$, $\frac{6}{8}$	-	at 10 months color too dark to find good match with charts
zebra striped cream background	10YR $\frac{9}{1}$ and 7.5YR $\frac{8}{2}$, $\frac{7}{4}$	7.5YR $\frac{6}{4}$	slight darkening
cream	7.5YR $\frac{8}{2}$ and 10YR $\frac{8}{2}$	-[a]	data not available
brown	10YR $\frac{4}{4}$	10YR $\frac{3}{4}$	no change

[a]unable to find variety in 10 month sample.

Guide to Abbreviations

Y = yellow
R = red
YR = yellow/red

Example: 7.5YR — hue (yellow/red)
$\frac{8}{2}$ — degree of lightness (value) / degree of saturation (chroma)

As value scores increase, color is lighter.
As chroma scores increase, color is more saturated.

Table 65. Munsell Color Change Data

Drying Temperature: 50°C Moisture Content After Drying: 16.5%

Variety	0 Months	10 Months	Change Noted
yellow/green	5Y $\frac{8}{6}$	-	at 10 months color too dark to find good match with charts
pink	5R $\frac{6}{6}$, $\frac{6}{4}$	-	at 10 months color too dark to find good match with charts
yellow/brown	10YR $\frac{6}{8}$, $\frac{6}{12}$	-[a]	data not available
zebra striped cream background	10YR $\frac{9}{2}$, and $\frac{8}{4}$	-	at 10 months color too dark to find good match with charts
cream	7.5YR $\frac{8}{2}$, $\frac{7}{2}$	-	at 10 months color too dark to find good match with charts
brown	10YR $\frac{4}{4}$, $\frac{5}{4}$	7.5YR $\frac{3}{4}$	change of hue towards yellow slight darkening

[a]unable to find variety in 10 month sample.

Guide to Abbreviations

Y = yellow
R = red
YR = yellow/red

Example: 7.5YR — hue (yellow/red)
$\frac{8}{2}$ — degree of lightness (value) / degree of saturation (chroma)

As value scores increase, color is lighter.
As chroma scores increase, color is more saturated.

CONCLUSIONS

The drying parameter having the most important influence on bean quality was the final moisture content to which the beans were dried. Beans having the highest moisture contents after drying were harder after cooking and showed increased color changes. Dryer temperature had no effect on instrumental hardness. The expected decreases in viability and germinability due to increasing dryer air temperatures were not observed.

LITERATURE CITED

Association of Official Seed Analysts. 1970. Rules for testing seeds. Proc. Assoc. Off. Seed Anal. 60(2):1-116.

Aykroyd, W.R., and Doughty, J. 1982. "Legumes in Human Nutrition". Food and Agriculture Organization of the United Nations. Rome, Italy.

Burr, H.K., Kon, S., and Morris, H.J. 1968. Cooking rates of dry beans as influenced by moisture content and temperature and time of storage. Food Technol. 22:336-338.

Ellis, R.H., and Roberts, E.H. 1981. The quantification of ageing and survival in orthodox seeds. Seed Sci. and Technol. 9:373-409.

Ellis, R.H., Osu-Bonsu, K., and Roberts, E.H. 1982a. The influence of genotype, temperature and moisture on seed longevity in chickpea, cowpea, and soya bean. Ann. Bot. 50:69-82.

Ellis, R.H., Osu-bonsu, K., and Roberts, E.H. 1982b. Desiccation and germination of seed of cowpea (Vigna unguiculata). Seed Sci. & Technol. 10:509-515.

Harrington, J.F. 1959. Drying, storing and packaging seeds to maintain germination and vigor. In "Proc. Miss. Short Course for Seedsmen", University of California, Davis.

Lamb, E., and Hardman, L.L. 1986. Final Report. Survey of Bean Varieties Grown in Rwanda. US AID-Rwanda Local Crop Storage Cooperative Research, LCS/FSM II (Research Component):University of Minnesota.

Longe, O.G. 1980. Carbohydrate composition of different varieties of cowpea (Vigna unguiculata). Food Chem. 6(2):153-161.

McKay, D.B. 1972. The measurement of viability. In "Viability of Seeds" (ed. E.H. Roberts). pp. 172-201. Chapman and Hall, London.

McKenzie, B.A. 1972. Drying soybeans with heated and unheated air. Publication No. AE-84, Purdue University, Lafayette, IN.

Mensah, J.K., Nelson, G.L., Hamdy, M.Y., and Richard, T.G. 1985. A mathematical model for predicting soybean seedcoat cracking during drying. 28(2):58-587, 591.

Misra, R.N., Young, J.H., and Hamann, D.D. 1978. Finite element procedures for estimating shrinkage stresses during soybean drying. ASAE Paper No. 78-3559. ASAE, St. Joseph, MI 49085.

Nellist, M.E. 1980. Safe drying temperatures for seed grain. In "Seed Production" (ed. P.D. Hebbleth-Waite). pp. 371-388. Butterworths, London.

Otten, L., Brown, R., Reid, W.S. 1984. Drying of white beans - effect of temperature and relative humidity on seedcoat damage. Can. Agric. Eng. 26:101-104.

Pfost, D.L. 1975. Environmental and varietal factors affecting damage to seed soybeans during drying. Ph.D. Dissertation, The Ohio State University Library, Columbus.

Tetrazolium Testing Committee of the Association of Official Seed Analysts. 1970. Tetrazolium Testing Handbook for Agricultural Seeds. (ed. D.F. Grabe).

Tittel, C. 1979. Die Trocknung von Leguminosensamen fur die Langzeitlagerung. Kulturpflanze. 27:175-180.

Toole, E.H., and Toole, V.K. 1946. Relation of temperature and seed moisture to viability of stored soybean seed. U.S. Department of Agriculture 753.

Vis, H.L., Yourassowsky, C., and Van der Borght, H. 1975. "A Nutritional Survey in the Republic of Rwanda". Tervuren, Belgium: Musée Royal de l'Afrique Centrale.

Walker, R.J. 1972. The effects of drying on soybean germination and seedcoat cracking. M.S. Thesis, The Ohio State University Library, Columbus.

SECTION VIII

THIN-LAYER DRYING OF RWANDAN BEANS

(Phaseolus vulgaris)

ABSTRACT

Thin layer drying data were collected for a Rwandan bean mixture (approximately 27% initial moisture) over the temperature range 28-45°C. Data were fit to a drying model (Page, 1949) which was generalized to determine drying constants K and N as a function of drying air temperature. Results indicated that the data fit the model well. The model could be used in the design of appropriate drying systems in Rwanda.

INTRODUCTION

Dry beans (Phaseolus vulgaris) are the most important source of vegetable protein in Rwanda. Vis et al. (1975) found that beans provided from 20 to 89% of the daily protein supply of rural areas of Rwanda; the estimated consumption of dry beans is 40 kg per person per year (Lamb and Hardman, 1986).

Post-harvest practices for drying beans are of concern in Rwanda and elsewhere since significant spoilage and quality loss can occur during storage if moisture contents have not been reduced to safe levels by drying. In Rwanda, beans are normally sun-dried before storage, but drying practices vary from farmer to farmer and moisture contents after sun drying may not always be low enough to permit long-term storage at the warehouse level. In some cases artificial drying using forced heated air may be necessary to prevent storage loss.

Thin-layer drying models have been developed for many grains to simulate

deep-bed drying for use in improved dryer designs and in the operation of drying systems (Hutchinson and Otten, 1983). However, there is little published information on thin-layer drying of beans and no information on thin-layer drying of bean mixtures such as those commonly found in Rwanda. Therefore this research was undertaken with the objective of developing a thin-layer drying model for beans which could be used in the design of appropriate drying systems in Rwanda.

LITERATURE REVIEW

This review will acquaint the reader with the drying theories most pertinent to the analysis and understanding of the research conducted in the present study. It will include discussions of the use of models to describe grain drying, factors influencing drying rate, and apparatus used to generate thin layer drying curve data.

Models Used to Predict Thin-Layer Drying Rates

Morey et al. (1978) have summarized models used in grain drying simulation. Some of these models include a thin-layer equation to predict deep-bed drying rates. Hutchinson and Otten (1983) state that the parameters in these thin-layer equations depend on the material being dried and the drying conditions and that they must be determined experimentally.

A theoretical model which has been widely used in the literature to predict thin-layer rates is the diffusion model, given by Fick's second law:

$$\frac{\delta M}{\delta t} = \Delta \times (D \Delta M) \qquad (1)$$

where

M = moisture content

t = time

D = diffusion

Hutchinson and Otten (1983) outlined the assumptions inherent in the diffusion model: 1) the primary mechanism for moisture transport is diffusion; 2) the principal driving force for mass transport is the internal moisture content gradient; 3) temperature within the kernel is assumed constant; 4) either vapor or liquid diffusion predominates. If both occur simultaneously, the diffusion coefficient must represent the combined effects of liquid and vapor diffusion.

This model has been used to describe the thin-layer drying behavior of peanuts (Whitaker and Young, 1972), corn (Henderson, 1974; Sharaf-Eldeen et al., 1979), rough rice (Wang and Singh, 1978), and white beans (Hutchinson and Otten, 1983), and good agreements with experimental data have been found. However, some researchers maintain that some of the assumptions made in using the diffusion equation are not valid (Sharaf-Eldeen et al., 1979; Singh et al., 1972). Hutchinson and Otten (1983) suggest that the reason for such good agreement between experimental data and this equation may be that its solutions decay exponentially with time in a manner similar to experimental drying curves.

Empirical and semi-empirical models have also been used to predict thin-layer drying rates. One such model is the simple "lumped" model analogous to Newton's law of cooling in heat transfer (Syarief et al., 1984):

$$MR = \frac{M - Me}{Mo - Me} = \exp(-Kt) \qquad (2)$$

Where:

MR = moisture ratio

M = moisture content, % dry basis

Mo = initial moisture content, %

Me = equilibrium moisture content, %

k = drying constant

t = time, minutes

This model has been used to describe thin-layer drying data of corn (Rodrigues-Arras, 1956); to study the drying rates of fully exposed grain kernels (Hukili and Schmidt, 1960) and fully exposed popcorn (White et al., 1981) and in simulation of agricultural dryer performance (O'Callaghan et al., 1971).

A modification of the above equation was developed by Page (1949):

$$MR = \frac{M-Me}{M-Mo} = \exp(-Kt)N \qquad (3)$$

where: K and N are drying constants

This model has been used in studies to describe thin-layer drying data of soybeans (Overhutts et al., 1973; Hutchinson and Otten, 1983), sunflower seed (Syarief et al., 1984) and yellow dent corn (Li and Morey, 1984). Mathematical procedures used to determine the drying constants K and N are described by Li and Morey (1984).

Factors Influencing Drying Rate

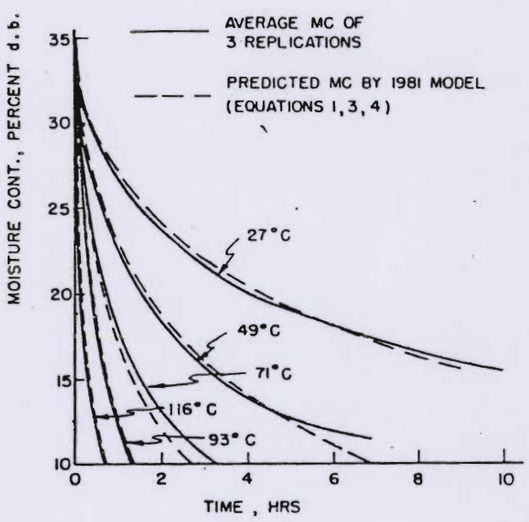
A. Drying Conditions

The drying conditions influencing drying rate are commonly accepted to be temperature, relative humidity, and airflow rate (Hutchinson and Otten, 1983). Drying rates are expected to increase as temperature and airflow rate increases, and to decrease as relative humidity increases.

1. Temperature

There is considerable evidence of the effect of temperature on grain drying rates in the literature. Thin-layer drying constants (K, N) are normally determined as functions of dryer air temperature (and other factors). For example, Li et al. (1984) conducted thin-layer drying experiments on yellow dent corn (1981 crop) at temperatures of 27, 49, 71, 93, and 116°C (80, 120, 160, 200, and 240°F) at airflow rates between 0.1 $m^3/s\text{-}m^2$ and 0.5 $m^3/s\text{-}m^2$, initial moisture contents between 23 and 36.4% dry basis, and relative humidities between 5 and 40%. Temperature had the greatest effect on drying rates of any of the variables studied. Figure 122 shows the effect of temperature on the drying rates of corn (change in percent moisture, dry basis, over time) (35% initial moisture). The largest differences in drying rates were observed between 27 and 71°C; as temperatures increased differences in drying times were noticeably smaller. The thin-layer drying model developed contained generalized expressions of K and N as functions of temperature and initial moisture content (see discussion of initial moisture content below).

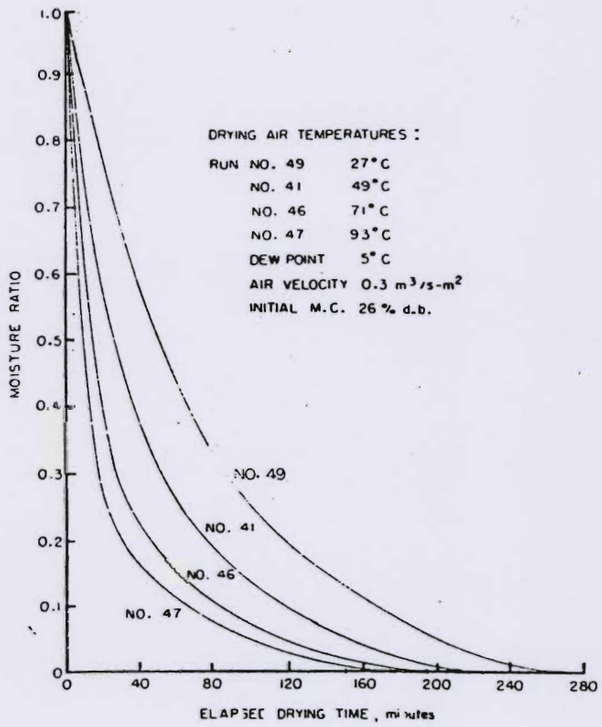
Figure 78. Effect of temperature on observed and predicted moisture content during drying of yellow dent corn (Li and Morey, 1984)



Syarief et al. (1984) found that dryer air temperature influences thin-layer drying rates of sunflower seed. The seed was dried at 27, 49, 71, and 93°C at various initial moisture contents and dryer air velocities at a constant relative humidity (dewpoint temperature 5°C). The results for seed at 26% (d.b.) initial moisture content and air velocity 0.3 $m^3/s-m^2$ are shown in Figure 123. Moisture ratio was plotted against drying time to give the drying curves. Again, the largest differences in drying times were between 27 and 71°C; differences between 71°C and 93°C were much smaller. Four thin-layer drying models including Page's (1949) equation were compared for their ability to describe the experimental data. The drying constants K and N from this equation were generalized as functions of drying air temperature.

Hutchinson and Otten (1983) also found noticeable temperature effects on thin-layer drying rates of soybeans. They dried soybeans (approximately 21% moisture, dry basis) at 32.8, 38.3, and 49.4°C (91, 101, and 121°F), at an air velocity of 0.6 m/s, and at 58% relative humidity. Ten degrees difference in temperature (91-101°F) influenced drying rate much less than 20°F difference (101-121°F). A two-term approximation of the general series solution to the diffusion equation and Page's (1949) equation were compared as possible drying models for soybeans and white beans. Page's (1949) equation was chosen over the diffusion model because it was relatively easier to calculate. For white beans, the drying constant N was expressed as a function of relative humidity and temperature; K was expressed as a function of relative humidity only. For soybeans, N was also expressed as a

Figure 79. Effect of temperature on moisture ratio during drying of sunflower seed (Syarief et al., 1984)



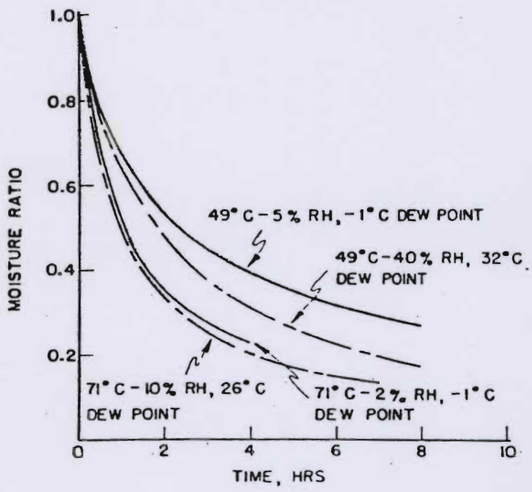
function of relative humidity and temperature, while K was expressed as a function of temperature only.

2. Relative Humidity

The relative humidity of the dryer air affects the equilibrium moisture content reached as a result of drying, and has been found to influence thin-layer drying rates to some extent. Li and Morey (1984) studied the effect of relative humidity on thin-layer drying rates of yellow dent corn. The relative humidities compared were chosen to be extremes that might occur in a deep bed or crossflow dryer at different dryer air temperatures. At 49°C the relative humidities compared were 5% and 40%, and 2% and 10% at 71°C. At 71°C there was little difference in moisture ratios during drying between 2 and 10% RH; at 49°C, the differences between 5 and 40% RH were more noticeable, particularly at moisture ratios less than 0.75 (Figure 124). However, the effect of relative humidity on moisture ratios was much smaller than the effect of temperature. Li and Morey suggested that although RH and a significant effect on moisture ratio at lower moisture ratios, that RH should have little significance in deep-bed drying application since the high relative humidity will occur at the beginning of drying, when moisture ratios are high. Based on these findings, they did not include the relative humidity effect in their moisture ratio model.

Syarief et al. (1984) studied the effect of drying conditions of sunflower seed on 'half response' or the time to remove the first half

Figure 80. Effect of relative humidity on moisture ratio of yellow dent corn dried at two temperatures (Li and Morey, 1984)



of free moisture, ½(Mo-Me). ('Half response' corresponds to the time to reach a moisture ratio of 0.5.) Samples (26% initial moisture, dry basis) were dried at 20 and 80% RH, 27 and 49°C, and 0.1 and 0.3 $m^3/s\text{-}m^2$ air velocity. The effect of relative humidity on half response was significant ($p=0.015$) as was the effect of temperature ($p=0.0006$) and air velocity ($p=0.015$). Since relative humidity was the least significant of the three factors, and is not usually a controlled factor in dryer design, it was not included in the thin-layer drying model developed for sunflower seed.

Hutchinson and Otten (1983) observed a 'small' effect of relative humidity on drying rates of soybeans and white beans. Samples were dried at temperatures varying from 32 to 49°C, relative humidities of 34 and 65% and air velocities of 0.25, 0.36, and 0.58 m/sec. The magnitude of RH effect on drying rates cannot be ascertained since no experimental data from that portion of the study was reported. However, Hutchinson and Otten considered the effect to be large enough to include it as a function in the determination of the drying constants K and N from Page's (1949) equation.

3. Air Velocity

Dryer air velocity is usually considered to be less important than temperature or relative humidity in affecting thin-layer drying rates. Some researchers ignore air velocity completely in analyzing thin-layer drying data according to Henderson and Pabis' (1962) conclusion that resistance to moisture movement at the surface of the grain is

negligible compared to internal resistance.

Syarief et al. (1984) studied the effects of air velocities varying from 0.1 to 0.5 $m^2/s-m^2$ on half response (see discussion above) during drying of sunflower seed (26% initial moisture, dry basis). Air velocity had only a small effect on half response, particularly as it was increased from 0.3 to 0.5 $m^3/s-m^2$. Air velocity was not included as a function in the thin-layer drying model developed for sunflower seed. Li and Morey (1984) also found little effect of the same air velocities on thin layer drying rates of yellow dent corn dried at 49 and 93°C, particularly at moisture ratios of approximately 0.6 and above. The overall effect of air velocity on drying rate was more pronounced at 93°C than at 49°C, but increasing air velocity from 0.3 to 0.5 $m^3/s-m^2$ had less effect than increasing it from 0.1 to 0.3 $m^3/s-m^2$. Air velocity was not considered as part of the function in the thin-layer drying model developed for corn in their study.

Hutchinson and Otten (1983) also found no effect of air velocity on thin-layer drying rates of soybeans and white beans. The air velocities they tested were approximately the same as those used in the two studies discussed above: 0.25, 0.36, and 0.58 m/sec. The effect of air velocity on moisture content during drying of soybeans at 43.9°C and 51% RH is shown in Figure 125.

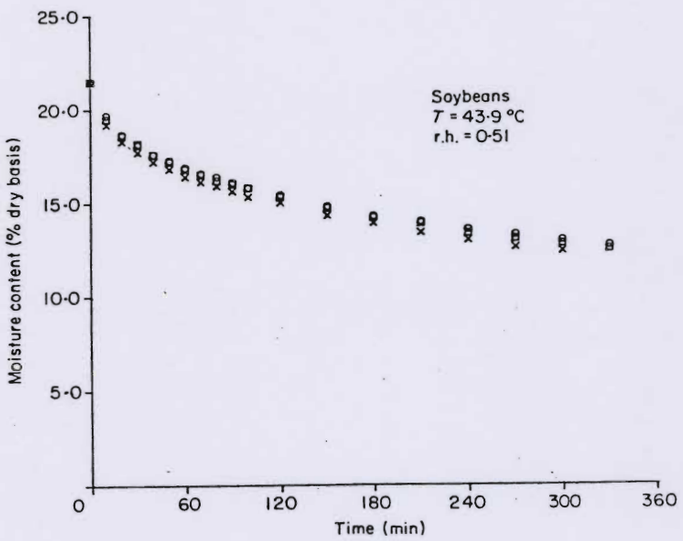
B. Other Factors

There is some evidence in the literature to suggest that the initial moisture content of the grain to be dried may influence its drying rate. Li

Figure 81. Effect of airflow rate on drying rate of soybeans.

X: = 0.58 m/sec; O: = 0.36 m/sec; □ : = 0.25 m/sec.

(From Hutchinson and Otten, 1983)



and Morey (1984) compared drying rates of yellow dent corn at approximately 23, 29, and 36% initial moisture content at dryer air temperatures of 49 and 93°C. The lowest moisture samples decreased in moisture ratio considerably more slowly than the highest initial moisture samples. The effect of initial moisture was more pronounced at 49°C than at 93°C. From these results Li and Morey concluded that initial moisture content had an effect that should be reflected in the generalized drying model. Thus the drying constants K and N from Page's (1949) equation were determined in relation to initial moisture content and dryer air temperatures.

Syarief et al. (1984) observed an effect of initial moisture content of sunflower seed (21% and 26% moisture, dry basis) on half response time. The low moisture samples had somewhat longer half response times than the high moisture samples at the dryer air temperatures and air velocities tested. However, since the drying constants K and N from Page's (1949) equation were only weakly correlated with initial moisture content, it was not included as a function in the final thin-layer drying model.

Growing conditions may also influence drying rates to some extent, but the evidence for this is not conclusive. Li and Morey (1984) studied differences in moisture ratios predicted from drying models for a single variety of yellow dent corn (Jacques JX-52 hybrid) harvested in 1981 and 1982. The model developed for the 1981 corn generally predicted faster drying than that developed for the 1982 corn, and the differences were attributed to differences in growing conditions. Li and Morey also suggested that differences in test weight (673 g/L in 1981; 703 g/L in 1982) might be related to the differences in drying rates.

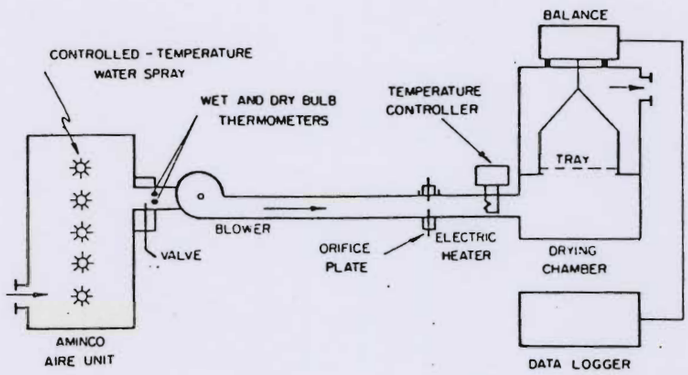
Thin-Layer Drying Apparatus

Dryers used in thin-layer drying experiments normally function by forcing pre-conditioned air through a single layer of product and recording weight change periodically during drying until equilibrium (defined as no further weight change during a specified length of time) is reached. Drying conditions (air temperature, velocity, relative humidity) may be controlled during drying so that drying models may be developed as functions of these conditions.

A schematic drawing of a typical thin-layer drying apparatus is shown in Figure 82. It was used to collect thin-layer drying data on yellow dent corn (see Li and Morey, 1984 for a detailed description of the apparatus). The air conditioning system (Aminco Aire unit) delivered air at the desired dry-bulb temperature and relative humidity to the drying chamber. Relative humidity was measured using the wet and dry-bulb thermometers. Orifice plates of different sizes were used to control and measure airflow. A series of resistance heaters heated the air to the desired dry-bulb temperature just before entering the test chamber. A thermocouple located at the base of the sample tray sensed the drying temperature which was monitored and recorded by a data logger. The sample tray was suspended from a balance placed on top of the test chamber; the edges of the tray extended into a channel filled with oil to form an air seal so that all the dryer air was forced through the bottom of the sample tray (made of wire mesh). Changes in weight were recorded every 10 min with the fan off.

Thin-layer dryers used in other studies are basically modifications of the one described above. Syarief et al. (1984) used basically the same

Figure 82. Thin-layer drying apparatus (Li and Morey, 1984)

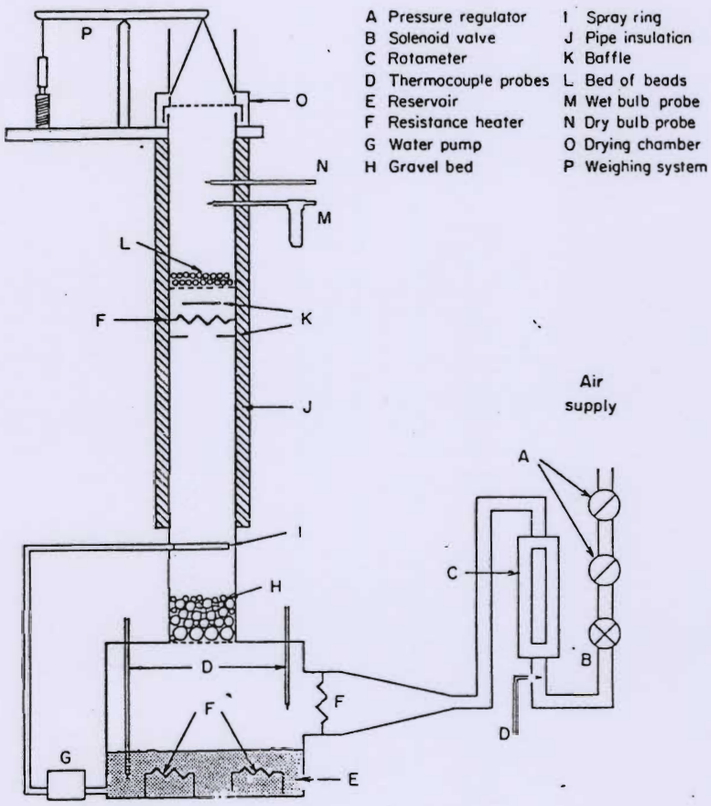


dryer for their thin-layer drying experiments on sunflower seed, the only difference being that a duct was added which recirculated air from the test chamber to the air conditioning system for re-use.

The thin-layer dryer used by Hutchinson and Otten (1983) to determine drying models for soybeans and white beans also operates on essentially the same principles but with several differences in the equipment used (a schematic drawing is shown in Figure 83):

1) A portable air compressor was used as the air supply, and two pressure regulators in series maintained constant airflow rate.
2) Relative humidity was varied by passing heated air through a packed bed of wetted gravel; the amount of moisture added to the air was regulated by setting the temperature of the air entering the packed gravel bed and the temperature of the water sprayed over the bed.
3) A bed of glass beads was located just before the entrance to the test chamber and immediately following the resistance heaters and was used to obtain uniform air velocity and temperature profiles as the air entered the test chamber.
4) The weighing system consisted of an equal arm balance with knife edge and agate bearing pivots. A permanent magnet suspended from one end of the magnetic field generated by passing a current through a copper-wire coil provided the balancing force. Since the strength of the magnetic field depended on the coil current, the sample mass as a function of coil current could be determined. Coil current was measured as voltage drop across a standard one-ohm resistor, connected in series with the coil, with a digital multimeter.

Figure 83. Thin-layer drying apparatus (Hutchinson and Otten, 1983)



In summary, models used to describe thin-layer drying rates, the factors affecting these rates, and apparatus used to collect thin-layer drying data have been discussed. Thin-layer drying data have been collected for various grains including rice, peanuts, corn, sunflower seed, soybeans, and beans. These data show that drying rates increase with increases in dryer air temperature. The effects of relative humidity or air velocity are much smaller and may be negligible. Relatively little research in this area has been conducted on dry beans, and none on bean mixtures.

The objectives of the present study were to: 1) determine moisture loss rates for a mixture of Rwandan beans, 2) identify appropriate functional forms for representing these loss rates, and 3) compare moisture loss rates for Rwandan beans to those for other dry beans and grains such as corn, sunflower seed, and soybeans.

MATERIALS AND METHODS

I. Beans

Approximately 4 kg of high moisture (approximately 27% moisture by AACC 2-stage method 44-15A) mixed beans were purchased from several producers in Butara (Byumba prefecture, northern Rwanda) within 7 days of harvest in late September, 1985. The mixture was characterized by type (Table 66) using the system developed by Lamb and Hardman (1986), except that types were not identified for shininess or size. The beans were screened to remove foreign material and damaged (cracked, shriveled, dented, insect-ridden) beans and

Table 66. Type analysis of a 100 bean sample

Variety #	Seed Shape[a)]	Color Pattern[b)]	Color[c)]	Number of beans
1	lo	hln	cr	38
2	lo	mc	pr	18
3	ro	mc	rs	17
4	ro	mc	br	4
5	lo	tl	bl/pr	16
6	ro	mc	jbr	4
7	lo	tt	pr/bl	3

a). lo = elongate oval
ro = rounded oval

b). hln = hilum ring - black
mc = single color
tl = mottled
tt = speckled

c). cr = cream
pr = purple
rs = pink
br = brown
bl/pr = white mottled with purple
jbr = yellow-brown
pr/bl = purple specked with white

stored in sealed plastic bags in a refrigerator at 6°C to prevent changes in quality before testing. Approximately 12 hr prior to each drying test, 100 g of beans were transferred to another bag which was sealed and allowed to warm up to room temperature.

II. Thin-Layer Drying Apparatus

The thin layer drying apparatus is described in Section VII of this final report. See Figure 126 for a schematic drawing of the apparatus. The apparatus used in the present study had no air unit, valve, wet and dry bulb thermometers, or data logger.

III. Drying Procedure

Before a sample was placed on the sample tray, the entire drying apparatus including the tray was preheated for 30 min at the test temperature. The balance was then tared with the blower and heater off. Beans were spread evenly on the surface of the tray to ensure uniform drying and even weight distribution. The initial sample weight was recorded and the balance was tared again before drying was started.

In order to determine the influence of air velocity on drying rate, a preliminary experiment was conducted in which two 100 g samples were dried in separate runs in the apparatus for 9 hr at 113°F (31°C) at the maximum and the minimum air volumes delivered by the blower, i.e., approximately 27 and 5 cubic feet per minute (cfm), respectively. These yielded apparent velocities of 80 cfm/ft^2 (0.4 $m^3/(s\text{-}m^2)$ and 15 cfm/ft^2 (0.075 $m^3/(s\text{-}m^2)$, respectively. The samples were weighed and weight loss was recorded at 15 min intervals throughout

the drying process. Results of a paired t-test indicated that there was no significant difference in drying rate due to air velocity ($p > 0.05$). Therefore, all subsequent tests were conducted at an air velocity of 27 cfm.

Two replicate drying runs were conducted at drying temperatures of 82, 93 and 113°F (28, 34, and 45°C). Samples were weighed and weight losses were recorded at 15 min intervals for the first 7 to 12 hr of drying and then at larger time intervals up to 8 hr as weight loss slowed. Samples were considered to have reached equilibrium with the drying air when at least two successive weighings at 5 to 8 hr intervals showed no further weight change (to the nearest 0.1 g). Total drying times ranged from 50 to 80 hr. After drying, moisture contents of samples were determined using the AACC standard one stage method #44-15A for whole beans.

Analysis of Results

Thin layer data were fit to the following equation (Page, 1949):

$$MR = \frac{M - M_e}{M_o - M_e} = \exp\ (-Kt)N \qquad (1)$$

where

MR = moisture ratio, decimal

M = moisture content, percent d.b.

M_o = initial moisture content, percent d.b.

M_e = equilibrium moisture content, percent d.b.

t = time, minutes

K,N = drying parameters

The drying parameters K and N were found for each of the six drying tests--two replications at 28, 34 and 45°C. The parameters were found using linear regression on the transformed equation:

$$\ln [-\ln (MR)] = \ln(K) + N \ln(t) \qquad (2)$$

In calculating the moisture ratio, MR, the equilibrium moisture content was assumed to be the moisture content of the beans at the end of the drying test when no further weight loss was occurring. Data points having moisture ratios above 0.04 were used in the regression procedure.

RESULTS AND DISCUSSION

Regression results for each test are displayed in Table 67. The high R^2 values (greater than 0.996) indicate that the model fits the data well.

To generalize the model, K and N were determined as functions of drying temperature, T in °C, using linear regression. The equation which best described K as a function of T was:

$$K = 0.97748 \times 10^{-2} + 0.1205 \times 10^{-4} T^2 \qquad (3)$$

with $R^2 = 0.7361$

The equation which best described N as a function of T was:

$$N = 1.5614 T^{-0.254} \qquad (4)$$

with $R^2 = 0.5143$

Table 67. Regression results

Drying Air Temparature °C	K	N	R^2
28	0.02395	0.6233	0.9971
28	0.01436	0.7238	0.9964
34	0.02747	0.6135	0.9972
34	0.02012	0.6562	0.9964
45	0.03175	0.6029	0.9986
45	0.03655	0.5870	0.9982

The relatively poor R^2 values for equations 3 and 4 are due to the small range in temperature (28-45°) over which the thin layer drying tests were run and relatively large variations in K and N values between replicates as shown in Table 65.

Measured moisture ratios from each replication are compared to the moisture ratio calculated with the general model (equations 1, 3 and 4) in Figures 128, 129 and 130 for drying air temperatures of 28, 34 and 45°C, respectively. The results show that the general model adequately fits the measured drying data. The figures also illustrate the relatively small variation between replications.

Drying rate generally increased with temperature, but the differences in rates were small due to the small range of temperatures studied. Drying rates at 28 and 34°C were quite similar; the largest difference occurred between these two temperatures and 45°C.

Thin layer drying rates for beans dried at 28°C were compared to rates for sunflower seed and yellow dent corn dried at 27°C by comparing times of half response, MR = 0.5, or the time required to remove the first half of free moisture ($\frac{1}{2}(M_o-M_e)$) (Syarief et al., 1984). The time of half response for beans was approximately 4 hr, compared to 50 min for sunflower seed (Syarief et al., 1984) and approximately 6 hr for corn (Li and Morey, 1984). The differences in drying rates are attributed to differences in drying characteristics between seed types.

Figure 84. Moisture ratio vs elapsed drying time.
Observed and predicted values (28°C).

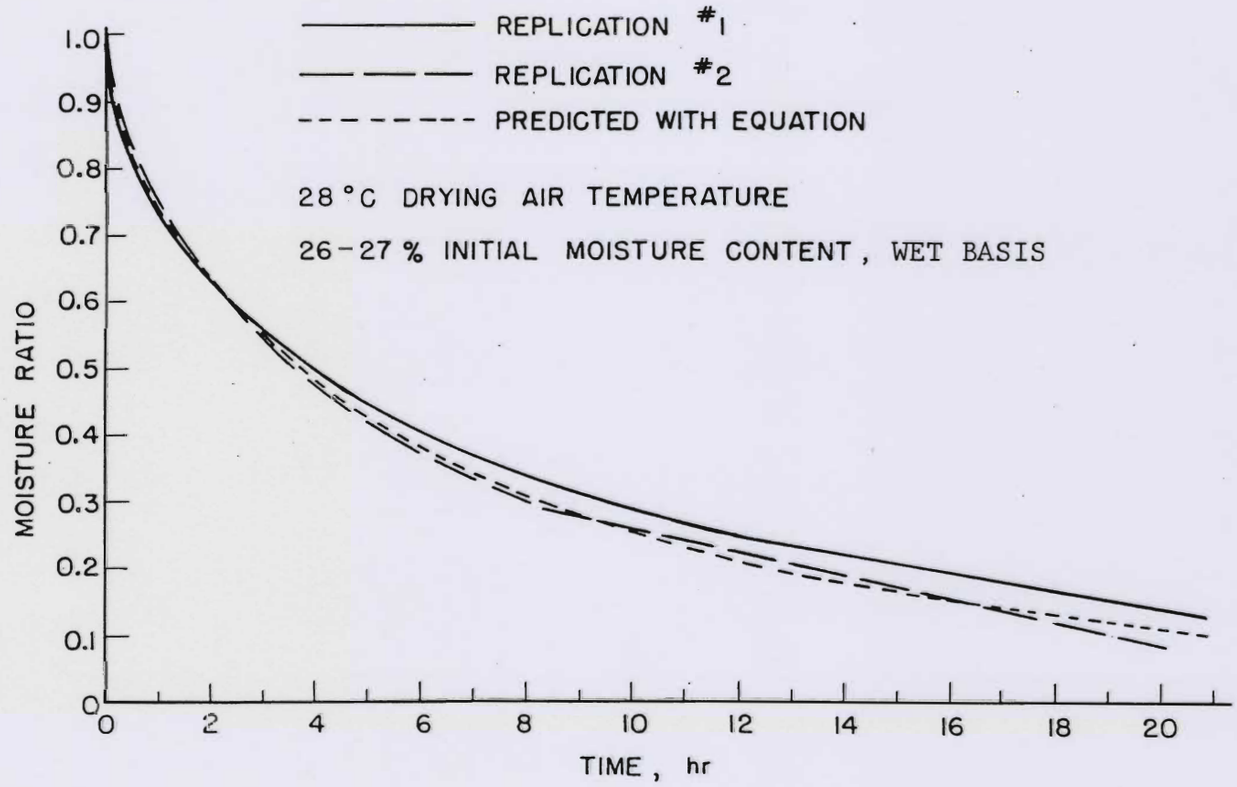


Figure 85. Moisture ratio vs elapsed drying time.
Observed and predicted values (34°C).

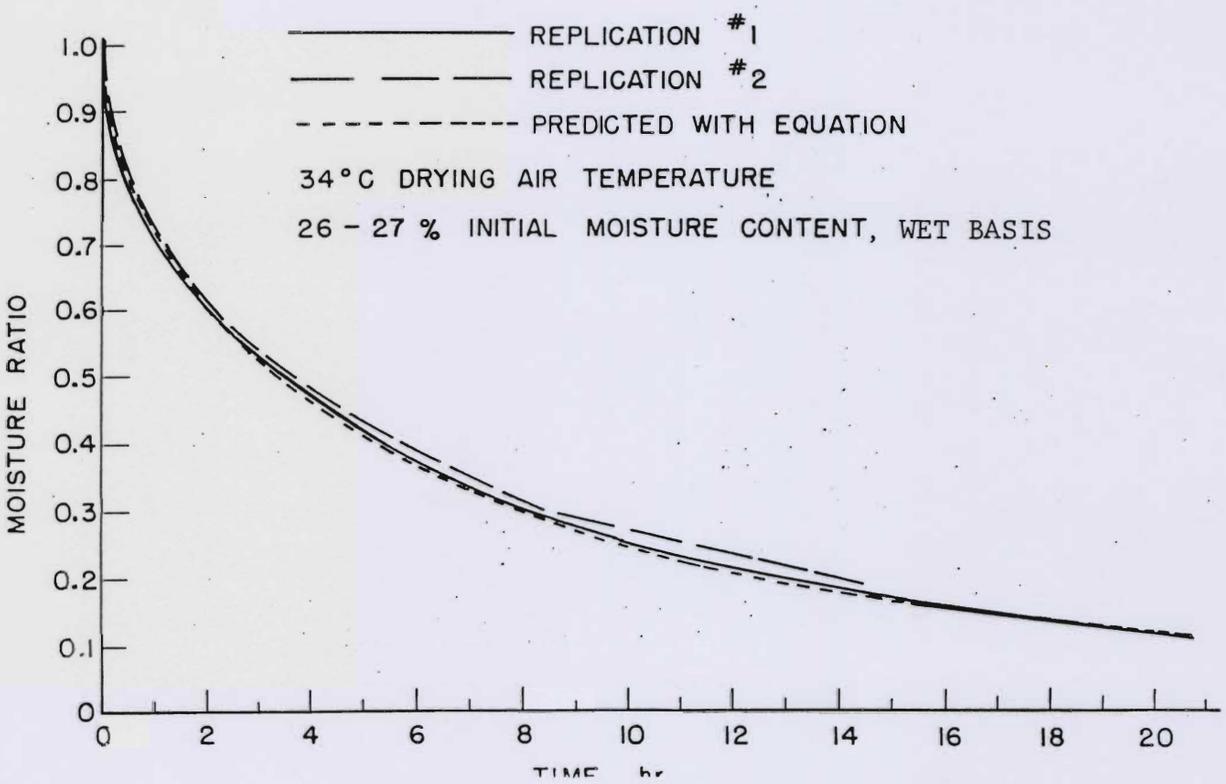
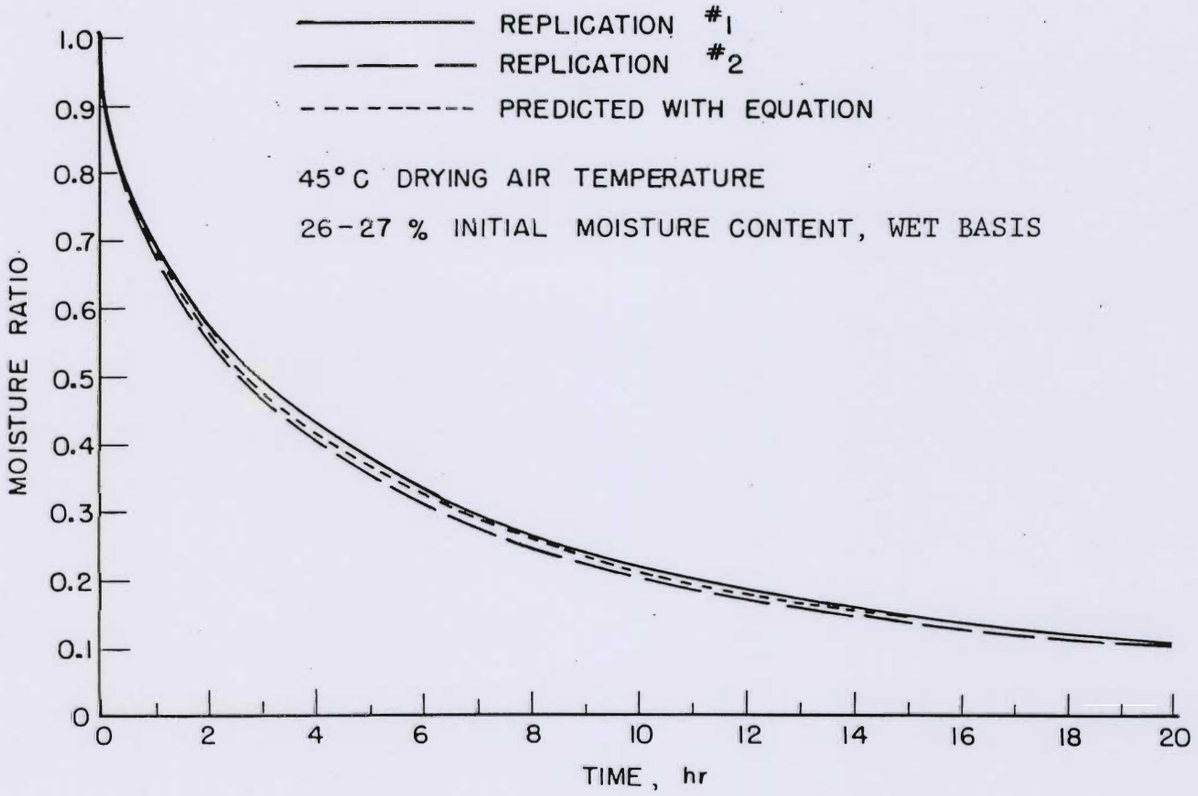


Figure 86. Moisture ratio vs elapsed drying time.
Observed and predicted values (45°C).



CONCLUSIONS

As measured by time of one-half response in moisture ratio, the Rwandan bean mixture dried in two-thirds of the time reported for recent U.S. corn (yellow dent) varieties at 28°C. The drying model of Page (1949) fit the data well over the range of drying temperatures of 28-45°C.

LITERATURE CITED

Henderson, S.M. 1974. Progress in developing the thin-layer drying equation. Trans ASAE. 17:1167, 1168, 1172.

Hutchinson, D, and Otten, L. 1983. Thin-layer air drying of soybeans and white beans. J. Fd. Technol. 18:507-522.

Lamb, E.M., and Hardman, L.L. 1986. "Final Report of Survey of Bean Varieties Grown in Rwanda". USAID-Rwanda Local Crop Storage Cooperative Research Project, LCS/FSMII (Research Component): University of Minnesota.

Li, H., and Morey, R.V. 1984. Thin-layer drying of yellow dent corn. Trans ASAE. 27(2):581-585.

Morey, R.V., Keener, H.M., Thompson, T.L., White, G.M., and Bakker-Arkema, F.W. 1978. The present status of grain drying simulation. Paper No. 78-3009 ASAE, St. Joseph, MI.

Overhults, D.G., White, G.M., Hamilton, H.E., and Ross, I.J. 1983. Drying soybeans with heated air. Trans ASAE. 16:112, 113.

Page, C. 1949. Factors influencing the maximum rates of air drying shelled corn in thin layers. Unpublished M.S. Thesis, Purdue University (library), Lafayette, IN.

Scharaf-Eldeen, Y.I., Hamdy, M.Y., Keener, H.M., and Blaisdell, J.L. 1979. Mathematical description of fully exposed grains. Paper No. 79-3034. ASAE, St. Joseph, MI.

Singh, R., Barre, H.J. and Hamdy, M.Y. 1972. Drying spherical porous bodies. Trans ASAE. 15:338.

Syrarief, A.M., Morey, R.V., and Gustafson, R.J. 1984. Thin-layer drying rates of sunflower seed. Trans ASAE. 27(1):195-200.

Vis, H.L., Yourassowsky, C., and Van der Borght, H. 1975. "A Nutritional Survey in the Republic of Rwanda." Tervuren, Belgium. Musée Royale de l'Afrique Centrale.

Wang, C.Y., and Singh, R.P. 1978. A single-layer drying equation for rough rice. Paper No. 78-3001. ASAE, St. Joseph, MI.

Whitaker, T.B., and Young, J.H. 1972. Simulation of moisture movement in peanut kernels: evaluation of the diffusion equation. Trans. ASAE. 15:163.

SECTION IX

BEAN VARIETY STUDY

EFFECT OF VARIETY ON COOKABILITY AND SENSORY PREFERENCES AT FOUR DIFFERENT LOCATIONS

ABSTRACT

Cookability and sensory preference tests were conducted on six bean varieties during one year of storage at four locations in Rwanda. There were varietal differences in cookability, but none of the varieties became hard-to-cook in the twelve months of storage. Although there was some general agreement on the sensory preferences among people at the different testing locations, regional preferences did exist. Preferences for different bean varieties did not appear to be influenced by cookability. During the twelve months of storage no decrease in either cookability or sensory preference scores was observed.

INTRODUCTION

Legumes are an important source of protein in many parts of the world. In certain areas of Africa, consumption of legumes is particularly high; these areas include Rwanda, Burundi, and adjacent parts of Uganda (FAO, 1982). In a survey conducted in six rural areas of Rwanda, Vis et al. (1975) reported daily intakes of dry beans (Phaseolus vulgaris) ranging from 83 to 371 g, providing from 20 to 89% of the daily protein supply.

The diversity of bean types in eastern and central Africa is documented. Van Rheenen (1979) classified 997 Kenyan seed samples on the basis of color,

size, and shape. He identified ten most common types out of a total of 78. In a survey of bean varieties grown in Rwanda, Lamb and Hardman (1986) identified more than 280 varieties which are commonly grown and consumed in mixtures containing an average of 11 different varieties. Results of Lamb and Hardman's survey also showed that consumers living in different regions of the country prefer to grow bean mixtures containing different predominant types. Preferences for bean types depended on a number of agronomic and culinary criteria, including good taste and fast cooking time. Thus Rwandan consumers are aware of varietal differences in cookability. Furthermore, the cookability and sensory qualities of dry beans change during storage and there are varietal differences in the extent of that deterioration (Morris and Wood, 1956).

Since there is little published information on Rwandan consumer preferences by variety and the influence of cookability and/or storage on these preferences, the present study was undertaken to provide more insight into the differences among varieties in sensory preferences, cookability and their changes during a year's laboratory storage.

LITERATURE REVIEW

VARIETAL DIFFERENCES IN SENSORY QUALITY AND COOKABILITY OF BEANS

There is considerable evidence to suggest that consumers in many parts of the world have well-defined varietal preferences for beans. These preferences depend on a combination of physical, culinary, and agronomic characteristics of the seeds which are frequently interrelated. For example, seed size and color are physical characteristics often associated with desirable or undesirable culinary characteristics. In Central America, consumers prefer medium-sized red

and black beans which are dull in appearance; a shiny appearance is associated with longer cooking times (Linares et al., 1981).

In Puerto Rico, Rodriguez-Sosa et al. (1984) found differences in sensory evaluations of three seed types. Red kidney, white, and striped bean samples were prepared "Puerto Rican style" for sensory evaluation. The beans were soaked in three times their weight of tap water until their weight had doubled (from 7 to 18 hours), boiled until soft, and then cooked in a stew containing spices, other vegetables, and meats. Judges evaluated samples for appearance, flavor, texture and overal acceptability using a structured category scale numbered from 1 (dislike) to 6 (like very much). The striped seed types were rated higher in all categories than the red or white seed types, but differences were often small. This may be due in part to the way in which the samples were prepared. In particular, flavor differences among seed types would be less noticeable in a highly spiced dish than if they were served plain. In addition, since all samples were cooked until soft, seed type differences in texture (i.e. hardness) were also probably minimized. Even so, texture was the culinary characteristic most highly correlated with overall acceptability ($r = 0.92$), followed by flavor ($r = 0.83$), and appearance ($r = 0.70$).

In Kenya, Van Rheenen (1979) reported that many different colors and sizes of seed types are acceptable, but that in one district (Embu) medium-sized red beans are especially preferred because of the attractive color they lend to the food cooked with them.

In an extensive nationwide survey of bean varieties grown in Rwanda, Lamb and Hardman (1986) reported that farmers had definite preferences for both large and small seed types; they related desirable culinary or agronomic characteristics to beans in each size group. In general, large-seeded types

were characterized as having good taste, fast cooking times, and high market value. These types were more commonly grown in the northern and eastern regions of the country. Small-sized seed types were usually characterized as high yielding, resistant to diseases in the field, and tolerant to infertile soil. Even though small seed varieties may not be especially preferred for their culinary qualities, they are very commonly grown in the regions of the country where they are well-adapted to the existing growing conditions, particularly in the southwestern regions. Familiarity, in turn, is one factor that tends to increase the preferences for a food (Beauchamp and Muller, 1977).

Further evidence of size/color preferences for bean types in Rwanda has been reported by Dessert (1984a and 1985a). She conducted a survey of farmers in five communes of Ruhengeri (Nkuli, Kigombe, Mukingo, Kinigi, and Nyakinama), and three communes of Butare (Kigembe, Huye, and Nyabisindu). The farmers, the majority of whom were women, were questioned concerning bean preparation methods and acceptability criteria for dry beans.

Dessert reported that in Ruhengeri, 75% of the farmers mentioned one variety, Mutiki 2 (large red mottled with white) as having a desirable color pattern. Another variety, Urushimandengo (large orange), was also mentioned as having a preferred color. However, these varieties comprised only 14% and 9% respectively, of the varieties cited for preferred color. Preferences for seed color were not investigated in Butare, but the results in Ruhengeri indicated that color preferences existed but were diverse. Generally varieties having a preferred seedcoat color also tended to be considered "good to eat". Ninety-two percent of the farmers questioned in Ruhengeri preferred to plant large-sized seeds. In Butare only 36% preferred to plant large-sized seeds, the remaining 64% preferred to plant small- or medium-sized seeds.

Cookability - the ability of beans to imbibe water during soaking and/or cooking, and to soften during cooking - has also been found to influence consumer preferences for different bean varieties. Dessert (1985a and b) identified significant differences in cooking times between ten bean varieties grown in Rwanda, and found good compatibility between laboratory and consumer evaluations of cooking time. Dessert also observed that consumers in Ruhengeri and Butare were able to associate certain bean varieties with such qualities as capacity for water adsorption, flavor, broth quality (no definition given), and eating quality (a general term including flavor, odor, color, and texture).

In Ruhengeri, consumers frequently thought varieties having "poor broth quality" were "not good to eat", while varieties thought to have longer cooking times, or poor capacity for water absorption were still frequently thought to be "good to eat". Thus while Rwandan consumers were aware of cookability differences between varieties and these differences likely influenced preferences to some extent, cookability alone did not appear to dictate preferences.

Dessert (1986) found further evidence of consumers' awareness of varietal differences in cookability in a study comparing Rwandan farmers' evaluations of cooking time to instrumental measures of cooking time. A group of 20 farmers who had participated in on-farm varietal trials were asked to prepare and consume the varieties and mixtures they had grown using traditional preparation methods. The varieties tested were Kirundo, Kilyumukwe (large red), Umutikili, Rubona 5 (large red mottled with white), Ikinimba (small black), and A197. An improved ISAR (Institut des Sciences Agronomiques du Rwanda) mixture and a local mixture were also included.

The farmers rated the samples for cooking time using a 5-point scale (1 = excellent, 5 = unacceptable). Cooking time was estimated in the laboratory

using a bar-drop cooker, which is an adaptation of the cooker developed by Mattson (1946). Twenty-five beans of each sample were soaked overnight in distilled water, drained, and placed in depressions in the bottom plate of the bar-drop apparatus with a 90 g metal bar resting on top of each bean. The apparatus was placed in a large glass beaker and the beans were covered with distilled water and boiled. Cooking time was estimated as the time necessary for 13 of the metal bars to drop through the beans.

Consumers were able to discriminate differences in cooking times between varieties and mixture, and their evaluations correlated well with the instrumental measures. Samples perceived by farmers to have more acceptable cooking times generally had shorter cooking times by the bar-drop method.

Varieties Kirundo and Kilyumukwe had two of the shortest and most acceptable cooking times (46 min bar drop index; approximately 1.5 on the cooking time scale). Varieties Rubona 5 and Ikinimba had the longest cooking times (51 min and 61 min bar drop index, respectively) and were also perceived by consumers to have less acceptable cooking times (2.2 and 2.5 on the cooking time scale, respectively).

If the midpoint of the cooking time scale, 2.5, is used as the cutoff point between acceptable and non-acceptable cooking time, all of the samples fell within the acceptable range; varieties and mixtures differing noticeably in laboratory evaluations of cooking time may still be acceptable according to consumer perceptions of cooking time. Although the results of Dessert's work suggest that cooking time may be less important in determining Rwandan consumers' preferences than some of the other criteria mentioned above, it would appear that cooking time differences can be quite reliable.

Consumer preferences for different varieties likely also depend to some

extent on post harvest storage conditions, including bean moisture content, ambient relative humidity and temperature, and length of storage.

Morris and Wood (1956) compared consumer evaluations of flavor and texture of Great Northern, Michelite, Pinto, Red Kidney, Red Mexican, and California Small White beans. Each variety was adjusted to 5 or 6 different moisture contents ranging from 3.5% to 17.5% (wet basis) and stored for up to 24 months at 77°F (25°C) in tightly sealed cans. Samples were evaluated at six month intervals for off-flavor and firmness of cotyledons by a trained panel of 9-13 judges, using a seven point structured category scale. There was evidence of varietal influence on flavor and texture deterioration (increased firmness) during storage of 12-13% moisture beans.

Rwandan consumers are also aware of storage-induced changes in cooked bean quality. Dessert (1984a) questioned farmers in Ruhengeri concerning their mode of bean storage and changes noted in bean quality after storage. Small percentages (18-37%) of respondents pointed out local varieties whose cooking time, eating quality, or color were unacceptable after storage. One variety in particular, Nyamukecuru (small, khaki-colored), was frequently mentioned for its undesirable culinary qualities after storage.

Dessert (1985a) investigated the influence of growing conditions on the cooking time of ten local and improved bean varieties in Rwanda. The varieties tested were Rubona 5, Kibobo, Kilyumukwe, Ikinimba, GLP-X-1124 (small brown mottled with red), Nsizebashonje (small cream mottled with brown), Mutiki 2, Nyiranizungu, Var. 11, and Kalima (these latter three are med-large red mottled with cream). The ten varieties were grown during three different seasons (1984A, 1984B, and 1985A; "A" and "B" refer to the two major growing seasons) at the ISAR experimental stations in three different agroclimatic

regions of the country - Karama (east), Rubona (south), and Rwerere (north). The cooking times of freshly harvested samples were evaluated using the bar drop method described above.

An analysis of variance indicated significant differences due to variety and agroclimatic region. There was a significant interaction between agroclimatic region and growing season, indicating that regional effects on cooking time differed with season. Cooking times of beans grown in Rwerere were significantly shorter than of beans grown in Rubona or Karama. Cooking times averaged over growing season and location ranged from approximately 35 min for variety Kalima to 46 min for Rubona 5. Varieties Ikinimba and Kilyumukwe had significantly shorter cooking times than Rubona 5. From these results, Dessert concluded that such varietal comparisons are valid only among beans grown in the same agroclimatic region and perhaps in the same field, since growing conditions (soil fertility, for example) probably vary somewhat from field to field.

Linares et al. (1981) noted differences in physical, sensory, and culinary qualities of 20 Central American varieties of black, red, beige, and white beans. Differences in culinary qualities (cooking time, soaked bean hardness) were related to such seed physical properties as color, lustre, size, and percent seedcoat. The varieties used in their study were all grown under the same conditions, thus preventing differences in growing conditions from influencing culinary and physical characteristics.

In order to determine cooking time, they soaked 100 beans in room temperature tap water for 16 hours and then boiled them. Cooking time was defined as the time necessary to boil the sample until 50% of the seeds exhibited split seedcoats. Broth thickness after cooking was measured using a Saybolt viscometer. They measured seed size by weight of 100 beans and by volume

(of sand displacement by 100 beans). No information was given concerning how percent seedcoat was determined, but it likely was the percent of the weight of the beans that was due to the seedcoat.

Cooking time decreased with seed size and increased with percent seedcoat: small beans having a higher percentage of seedcoat tended to have longer cooking times than large beans having a smaller percentage of seedcoat. These results also indicate a relationship between seed size and percentage seedcoat. Cooking time also appeared to be related to seed lustre. Dull varieties tended to cook faster than shiny varieties. Thus seedcoat properties (percent seedcoat, lustre) appear to govern cookability to some extent; the results of this study also tend to confirm consumer preferences for dull bean types in Central America.

Leaching of solids during soaking of Phaseolus vulgaris bean types has been linked to water absorption rate and seed coat thickness/permeability (Deshpande et al., 1984). Beans having faster water absorption rates lost more solids during soaking and were thought to have thinner, more permeable seedcoats than those with slower absorption rates. Seed coat thickness/permeability could also influence solids loss during cooking, although this did not appear to be the case in the Linares et al. (1981) study: beans with either thick or thin seed coats were equally likely to yield thick broth.

Quast and da Silva (1977) found that cooking rates differed between black beans and brown beans (Carioca variety) and varied with cooking temperature. Samples of each variety were hydrated for 12-16 hours at 22°C, and cooked for three different lengths of time at 98, 116, and 127°C. After cooking, bean softness was evaluated in a Kramer Shear Press by shearing about 100 g drained beans in the standard shear-compression cell. The maximum force was divided by

the exact sample weight and the results were expressed in lbs force/g (f/g). Samples measuring 2.5 lb f/g were considered to be "eating soft".

For each variety and cooking time, log maximum shear force was plotted against cooking time in order to determine the cooking times required to reach certain degrees of softness. At 98°C, black beans required approximately 260 min to reach "eating softness", whereas brown beans required approximately 150 min. As cooking temperatures increased, cooking rate differences between the two varieties decreased.

Varietal differences in cooking time have also been shown by Morris and Wood (1956) who studied the influence of moisture content on the keeping quality (flavor, cotyledon firmness) of dry beans. They used cooking times ranging from 50 to 90 min (after 17 hours soaking at 40°F in a 0.5% salt solution) to prepare control samples of Great Northern, Michelite, Pinto, Red Kidney, Red Mexican, and California Small White beans (approximately 10% moisture, stored at approximately 23°C) for sensory evaluations of flavor and texture. They cooked small beans (Michelite, Red Mexican, and California Small White) for 80 or 90 minutes and large beans (Red Kidney and Great Northern) 50 to 60 minutes. Since the beans were grown in different regions of the United States (Idaho, Michigan, California), cooking time differences could also have been related to differences in growing and climate conditions.

Thus the available literature, sketchy as it is, clearly suggests that varietal differences in sensory qualities, cookability and storage stability do exist. Studies that have specifically examined preferences for Rwandan beans have provided evidence for a number of factors, both agronomic and culinary, influencing people's preferences. However, these Rwandan studies are based on preferences determined from questionnaire data, not from people actually tasting

the beans, and as such they probably have not measured sensory preferences. The analyses by Dessert on cookability support the observations that bean varieties differ in cookability. Together these studies suggest some very interesting questions: Are the sensory qualities of some Rwandan bean varieties preferred to others? Do such sensory preferences depend on the hardness or cookability of the beans? Are the preferences for colors and sizes observed in the questionnaire data still observed when these beans are taste tested? Do some Rwandan bean varieties store better than others? Do people in different regions of Rwanda have different sensory preferences for beans?

In the following study we have attempted to at least partially answer some of the above questions for a limited number of bean varieties. Our specific objectives were: 1) to determine how well consumers from three different regions liked each of six commonly grown Rwandan bean varieties and to determine whether this degree of liking changes during one year of storage, 2) to compare the cookability of these varieties at 0, 6, and 12 months of storage, and 3) to determine whether differences in the sensory desirability of the beans can be related to differences in cookability.

MATERIALS AND METHODS

Beans

Six Rwandan bean varieties, selected to include four large-seeded types generally recognized for their desirable culinary attributes (Rubona 5, Muhondo, Kilyumukwe, and Tostado) and two small-seeded types generally recognized for their desirable agronomic characteristics (Karolina and Ikinimba), are listed in Table 68 and described by the system developed by Lamb

and Hardman (1986) (Varieties were not identified by shininess or size). Abbreviations in the key are based on French terminology (n = noir:black, rg = rouge:red, etc.). These beans were used for both the cookability tests and the sensory tests.

Beans (approximately 10 kg/variety) were purchased from OPROVIA, ISAR at Rubona, and from several markets in Kigali. All but the Muhondo and Kilyumukwe varieties were purchased separately; the latter had to be sorted from local mixtures. After removal of damaged and broken beans and foreign material, the beans were treated with the insecticidal dust Actellic (1% pirimphos methyl manufactured by Twiga Chemical Industries, Ltd., P.O. Box 30172, Nairobi, Kenya) at the rate of 1 kg Actellic/1000 kg beans.

Moisture Determination

Initial moisture contents were determined by the AACC (1975) two stage method (44-15A) wherein the second stage is a grinding step and the ground sample is dried for one hour at 130°C. Final moisture contents (after 12 months storage) were determined by the AACC (1975) one stage method (44-15A) wherein whole beans are dried for 72 hrs at 103°C. A mechanical convection oven (Blue M Stabil-Therm Model OV-500C-2Y, Blue M Co., Blue Island, IL) was used for both methods. Mechanical problems with the micromill (Belart Technilab 500, Belart Products, 6T Industrial road, Requannock, NJ 07440) required the use of the one stage method for final moisture content determinations.

Table 68. Description of varieties used according to method developed by Lamb and Hardman (1986)

Variety (common name)	Seed shape[a]	Seed coat[b] Color pattern	Color[c]
Karolina	rp	mc	rg
Ikinimba	ro	mc	n
Rubona 5	ro	tt	rg/cr
Muhondo	ro	hln	j
Kilyumukwe	lo	mc	pr
Tostado	lo	tl	jbr/rg

a) rp = rounded, flat
ro = rounded, oval
lo = elongated, oval

c) rg = red
j = yellow
pr = purple
jbr/rg = yellow brown (mottled with red
n = black
rg/cr = red (speckled with cream)

b) mc = single color
hln = black hilum ring
tl = mottled
tt = speckled

Storage

The beans (11.7-15.1% moisture, wet basis) were stored for 12 months in tightly covered 5-gal. (approximately 18 liter) plastic buckets at room temperature (approximately 23°C). The buckets were opened at two-week intervals for several minutes to allow exchange of gases between the storage vessels and the room atmosphere, then reclosed.

Bean cooking for instrumental hardness testing

One-third cup of intact, undamaged beans (approximately 150 beans) and one-half teaspoon of iodized salt were combined in excess tap water in a 2 qt (1.8 litre) stainless steel saucepan. The saucepan was then covered. The hotplate was regulated to maintain a moderate boil (about 96°C) for three hours (see final report, Section I, "Development of Standard Laboratory Sensory and Cookability Tests" for a discussion of the development of the standard three hour cooking time). Boiling water was added as necessary during cooking to maintain the water level and boiling rate.

The cooked beans were drained and transferred to small enamel dishes for cooling to room temperature before instrumental testing. An inverted plate was placed over the beans to minimize drying.

Instrumental hardness testing

Bean hardness was tested with a Chatillon dial push/pull gauge (Model DPP-500G) and test stand (Model LTS, John Chatillon and Sons, Inc., 83-30 Kew Gardens Road, Kew Gardens, NY 11415) similar to the one described by DeMan and Kamel (1982). The puncture test cell was as described by Bourne (1972), consisting of a 1/8" (0.3 cm) diameter stainless steel probe attached to the guage and centered over a 1/4" (0.6 cm) diameter hole in a stainless steel plate

mounted on the test stand. Cooked beans were placed individually over the hole and punctured through both cotyledons by manually raising a lever which raised the bottom portion of the test cell. The gauge (0-500 g, 5 g graduations) was read to the nearest 5 g. Mean grams force (MGF) was based on a 100 bean sample. Percent hard-to-cook was the number of beans in a 100 bean sample requiring $\geq$ 450 g force to puncture. The cut-off point of 450 g was determined by squeezing individual cooked beans between the thumb and index finger and comparing tactile sensations with the g force registered by those beans using the tester. At about 450 g bean cotyledons ceased to disintegrate or mush completely; instead, they separated into a few larger pieces.

Bean cooking for sensory acceptance testing

The cooking and preparation procedures were the same as for the instrumental hardness tests except that beans were cooked on site at four different geographic locations designated below. Four cups of intact dry beans were combined with two teaspoons of iodized salt and excess water in covered metal vessels and boiled for three hours over charcoal-fueled cooking stoves (braseros). Logistics required that equipment, water and beans be delivered to the sites and set up on the day preceding a test so that testing could be initiated by midmorning. Tap water from the OPROVIA laboratory was used to standardize the procedure and because water was not always available at the sites.

Test sites

Sensory tests were conducted at a high altitude, low mean annual temperature site, Ruhengeri (1900 m, 17.7°C); an intermediate altitude/intermediate temperature site, Butare (1750 m, 19.9°C) and a low altitude/ high temperature

site, Kibungo (1680 m, 21°C) (Sirven et al., 1974). These were the Ruhengeri, Sovu and Bare nutritional centers, respectively. Sensory testing was also conducted at the Kacyiru military camp near Kigali.

Subjects

Forty to fifty individuals evaluated cooked beans at each site. The subjects at the nutritional centers, mostly parents (male and female) who brought their children there, were volunteers. Those at the military camp also included both males and females. Subjects ranged in age from 20 to 50 at test sites. Females usually outnumbered males at the nutritional centers; the opposite was true at the military camp, even though attempts were made to equalize sex ratio.

Sensory evaluations

A set of four questions was developed (see final report Section I, "Development of Standard Laboratory Sensory and Cookability Tests") to give information on how well subjects liked a sample of beans. The subjects were questioned individually and orally in the native Rwandan language, Kinyarwanda, by research personnel and, at the nutritional centers, by trained nutrition staff.

Before the tests began, the entire group of subjects met together with one of the research staff who briefly explained the test format and answered questions. The tests were usually administered in a classroom or cafeteria. Each subject was called in individually and questioned one-on-one by the questioner. The tests usually began about 10:00 a.m. and lasted about 2½ hours, depending on the number of questioners. It worked well to have five questioners (three research technicians and two staff nutritionists) plus one person to

serve samples and collect empty dishes. At the military camp, the tests took somewhat longer as there were no personnel on site to help administer the tests.

All six samples were presented to subjects at the same time, each in a separate coded enamel bowl. Subjects were instructed to taste the samples one at a time and then to answer the four questions. Responses were recorded by the questioners. The order in which samples were tested was randomized for each subject.

First, subjects were asked to respond YES or NO to the question, "Would you eat these beans on a normal basis?". (During the first test at each location this question was asked incorrectly. Therefore no data from this question at 0 months will be presented.) Then they were shown a hedonic scale numbered from 0 to 20 and anchored at the left end with a frowning face and at the right with a smiling face. Underneath the smiling face was a sentence in Kinyarwanda, "I like these beans very much", and underneath the frowning face, "I don't like these beans at all". The subjects were asked to point to a place on the line corresponding most closely to their preference for that sample. The third and fourth questions were designed to provide information on the value of 1 kg of each of the six bean varieties relative to that of 1 kg of mixed beans on the local marketplace. Subjects were asked the current market price of 1 kg of beans (Question 3) and then how much they would pay for a kg of beans they had just tasted (Question 4).

Analysis

Responses to questions were tabulated and averaged by region and variety. The number of subjects willing to eat the beans on a normal basis was expressed as a percentage. The mean hedonic score for each sample was multiplied by 5 and

thus expressed as a percentage of the scale. The mean market value was expressed as the percentage of the current market price the subjects would pay for the beans they had just tasted.

Hedonic scores and the market values were analysed by SPSSX MANOVA (Norusis, 1985) with the hedonic scores and market values as dependant variables and sex, location, storage time, and bean variety as factors. The entire data array contained 3,438 observations, 234 of these contained missing data. Therefore many of the means in the tables may show slight disagreement. The willing-to-eat indices were not analyzed statistically as only two storage times were represented.

RESULTS AND DISCUSSION

Instrumental Tests

Table 67 presents moisture contents initially and after twelve months storage. Moisture content changed very little during storage; a general trend toward decreased moisture content with storage time could have been due to an inadequate seal between the plastic buckets and the lids. Table 67 also gives instrumental hardness values in terms of mean grams force and percent hard-to-cook after zero, six and twelve months storage. Instrumental hardness data is plotted graphically in Figures 131 (MGF) and 132 (% hard-to-cook).

Hardness measured as mean grams force showed some variation among varieties and over storage time; however, none of the varieties had become hard-to-cook in twelve months under the storage and test conditions in this study. The trend toward increased cookability after storage for six months can not be explained. The initial uncookability of the Muhondo variety (454 g force) is equally

Table 69. Influence of storage time on cookability (mean force and percent hard-to-cook) of six selected bean varieties

Variety (common name)	Percent moisture		Instrumental Hardness					
			Mean g Force			Percent hard-to-cook		
	0 mo.[a]	12 mo.[b]	0 mo.	6 mo.	12 mo.	0 mo.	6 mo.	12 mo.
Karolina	13.7	12.3	274	256	340	8	6	36
Ikinimba	11.9	12.1	349	296	347	27	11	44
Rubona 5	12.5	12.2	407	405	354	25	33	53
Muhondo	13.4	12.4	454	268	357	68	9	37
Kilyumukwe	15.1	13.2	347	263	313	20	8	18
Tostado	11.7	11.6	312	204	310	8	0	7

[a]AACC (1975) two stage method for ground beans (see text, moisture determination section).

[b]AACC (1975) one stage method for whole beans (see text, moisture determination section).

Figure 87. Effect of storage time on instrumental hardness (mean grams force) by variety. Measurements were made at 0, 6 and 12 months storage time on 100 beans from each variety.

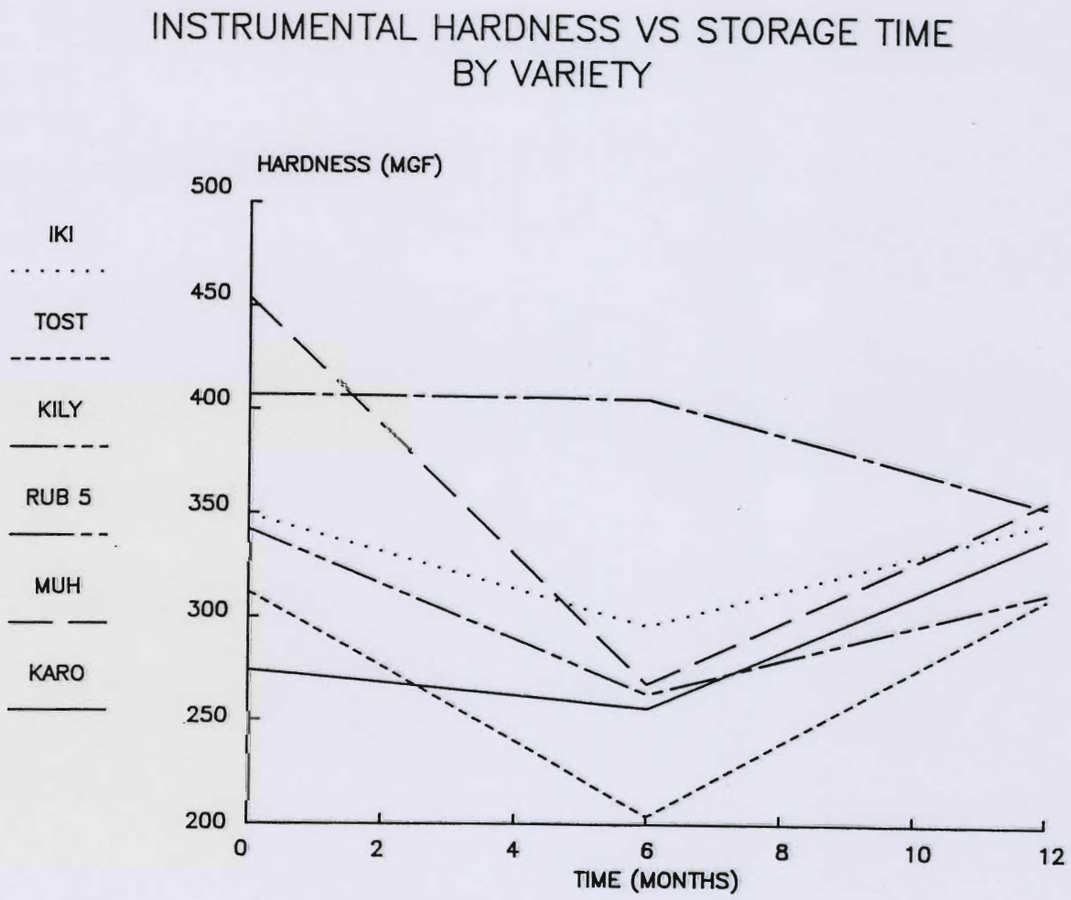
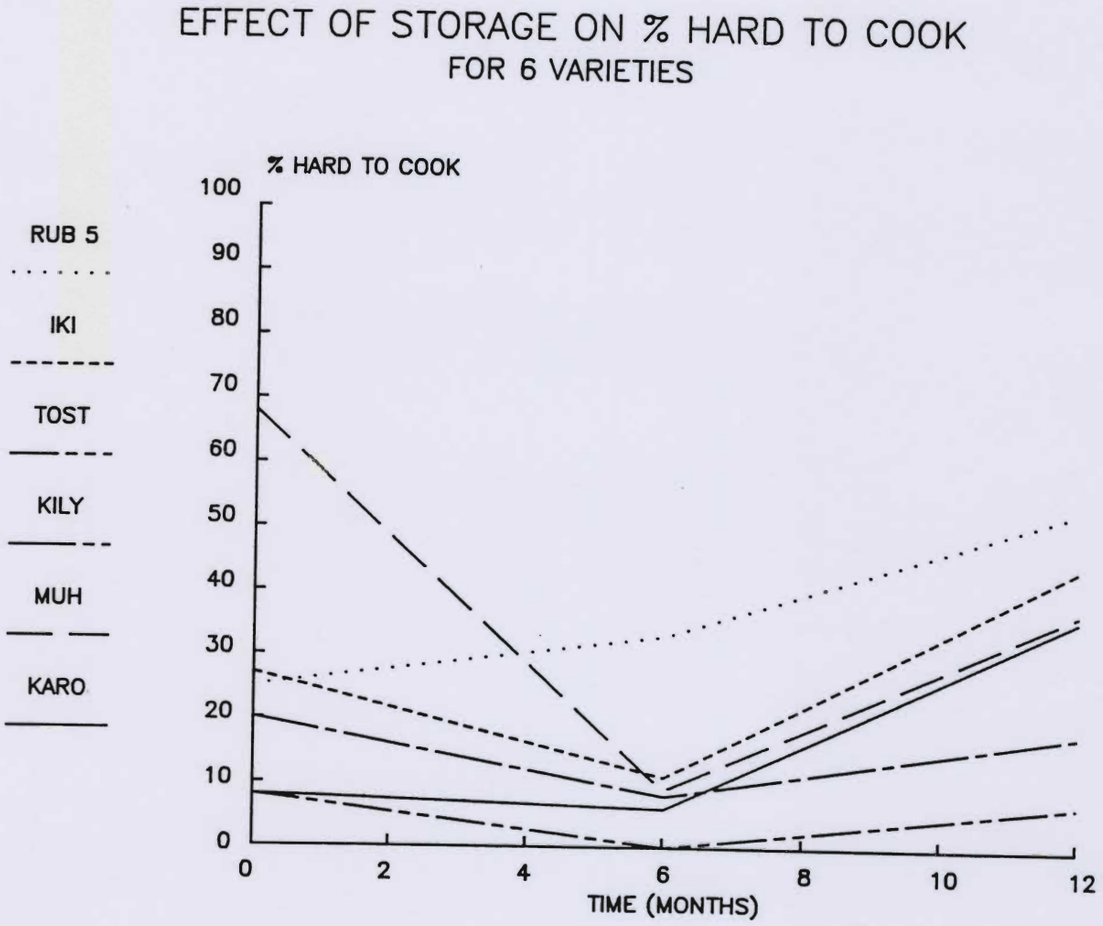


Figure 88. Effect of storage time on instrumental hardness (percent hard-to-cook) by variety. Measurements were made at 0, 6 and 12 months storage time on 100 beans from each variety.



unexplainable. The three hour cooking time is longer than is generally employed in cookability studies and may have been too long to detect the onset of the hard-to-cook defects by measuring mean gram force.

The percent hard-to-cook data also show a trend toward increased cookability after six months storage, with two thirds of the individual Muhondo beans being hard-to-cook at the beginning of the storage period. The percent hard-to-cook data show a clearer trend toward decreased cookability in the six months to twelve months storage period than do the mean gram force data. Both sets of data suggest that Tostado had better storage quality (in terms of cookability) than the others, followed closely by Kilyumukwe; Rubona 5 had the poorest storage quality. These last results support those by Morris and Wood (1956) who also found varietal differences in cookability (cotyledon firmness) after similar storage periods and at similar moisture contents and temperature.

Moisture content was apparently unrelated to instrumental hardness. Varieties at approximately the same moisture content before storage (for example, Karolina and Muhondo) sometimes differed greatly in hardness, while varieties differing greatly in moisture content (for example, Kilyumukwe and Tostado) sometimes had about the same instrumental hardness. After 12 months storage the highest moisture content variety (Kilyumukwe) was just as cookable as the lowest moisture content variety (Tostado). Varieties having similar moisture contents were just as likely to be similar in instrumental hardness (for example, Karolina and Ikinimba) as they were to be different (Karolina, Rubona 5). The latter results also suggest a relationship between variety and instrumental hardness.

In the case of Kilyumukwe, it is possible that insect damage influenced cookability during storage. Just preceding the six month instrumental and

sensory tests, we noted that this variety had been seriously attacked by bruchids. Insects may have been able to penetrate these higher moisture beans (15.1%) more easily than those at lower moisture contents. As soon as the infestation was noticed, obviously damaged seeds were removed and the remaining beans were frozen for 48 hours to destroy any remaining insects. Bruchid damage could have influenced instrumental hardness.

Sensory tests

1. Hedonic scores

The Karolina, Kilyumukwe and Tostado varieties received the highest hedonic scores overall. The Ikinimba variety was the least liked (Table 68). Considerable variation in scores existed between bean varieties and the three factors: location, storage time and sex of panelists. Results of the sensory tests at the four locations and the three storage times are displayed in Table 69.

Test location

There were obvious differences in hedonic scores for the different varieties. Mean hedonic scores for the six varieties at each location are shown in Figures 133 - 136 and in Table 68. Karolina was the most liked variety in Butare. Kilyumukwe and Tostado were consistently the best liked varieties in Ruhengeri, Karolina, Kilyumukwe and Tostado were generally the best liked varieties in Kibungo and at the Kacyiru military camp. Ikinimba was the least liked variety at all locations except Butare. Generally the subjects in Butare and Kibungo gave higher hedonic scores; subjects at Kacyiru gave the lowest. Correlations between the hedonic scores at the

Table 70. Mean of all hedonic scores broken down by test location and bean variety. Each cell is averaged over all subjects and all storage times.

Test Location	Bean Variety						
	Karolina	Ikinimba	Rubona 5	Muhondo	Kilyumukwe	Tostado	All Varieties
Butare	87	67	67	70	59	61	69
Kibungo	84	55	66	63	73	76	70
Ruhengeri	58	43	61	60	82	78	64
Kacyiru	57	37	50	52	61	63	53
All Locations	71	51	61	62	69	69	

Table 71. Influence of Storage Time on Consumer Acceptability of Six Selected Bean Varieties at Four Locations

Location / Variety	Question 1[a]		Question 2[b]			Market Value[c]		
	6 mo	12 mo	0 mo	6 mo	12 mo	0 mo	6 mo	12 mo
Butare								
Karolina	94	77	89	86	84	97	90	90
Ikinimba	58	50	72	64	66	85	72	74
Rubona 5	50	58	67	61	73	79	69	82
Muhondo	52	60	75	63	73	80	73	83
Kilyumukwe	36	48	52	57	70	64	64	79
Tostado	44	48	65	59	72	68	70	80
Ruhengeri								
Karolina	70	35	54	64	56	68	76	68
Ikinimba	24	9	43	42	46	60	53	58
Rubona 5	62	35	61	61	63	76	73	76
Muhondo	39	52	61	54	67	75	70	76
Kilyumukwe	82	78	88	76	83	100	86	91
Tostado	80	89	77	75	84	90	88	90
Kibungo								
Karolina	96	87	89	89	74	92	103	100
Ikinimba	28	57	55	55	57	64	64	80
Rubona 5	42	65	71	67	61	80	74	87
Muhondo	58	35	70	68	54	77	81	76
Kilyumukwe	58	76	83	65	70	87	81	99
Tostado	82	89	77	77	73	81	82	111
Kacyiru Military Camp								
Karolina	77	64	48	65	55	76	82	69
Ikinimba	4	41	23	33	49	63	55	62
Rubona 5	50	55	46	51	56	75	73	67
Muhondo	65	50	50	52	55	77	76	66
Kilyumukwe	54	61	46	51	60	85	82	72
Tostado	77	70	66	59	65	85	88	76

a) Would you eat these beans on a normal basis? Percentage responding yes.
b) Mean sensory preference level expressed as percentage of scale length.
c) Percentage of mean current market price of a locally purchased bean mixture consumers would be willing to pay for the varieties evaluated.

Figure 89. Hedonic scores (mean preference scores expressed as percentage of scale length) for Butare by variety and by storage time.

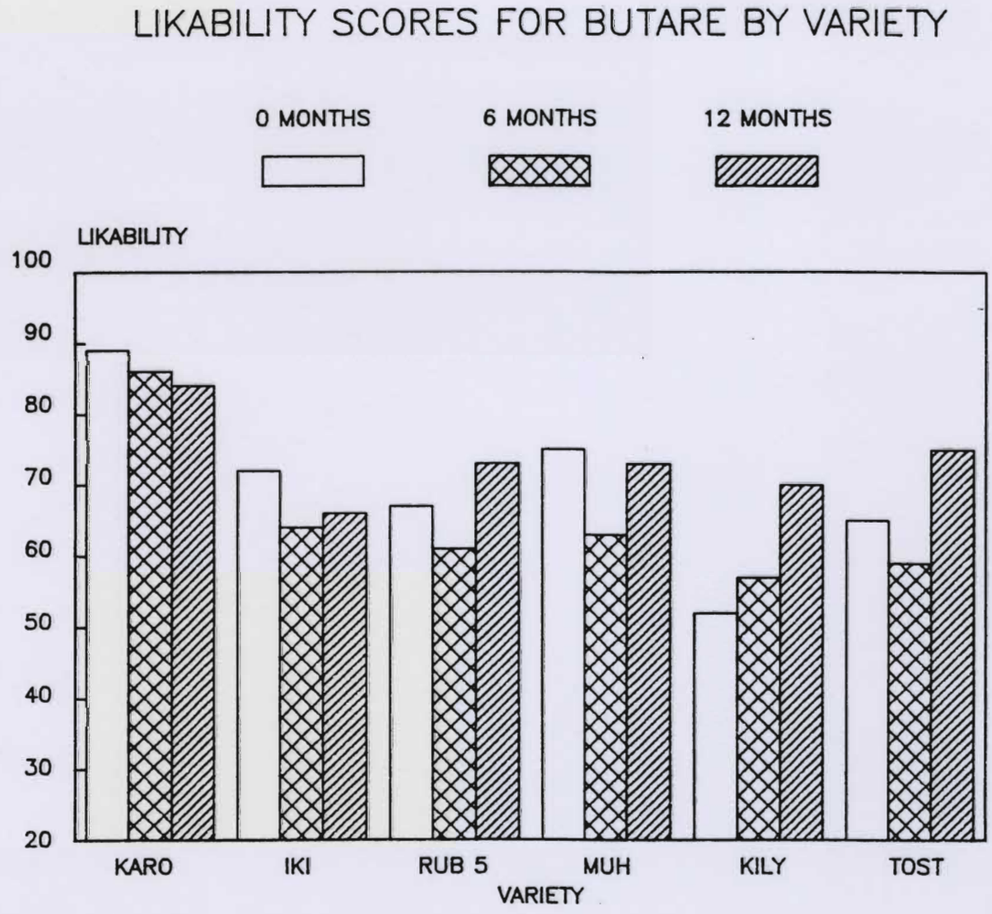


Figure 90. Hedonic scores (mean preference scores expressed as percentage of scale length) for Ruhengeri by variety and by storage time.

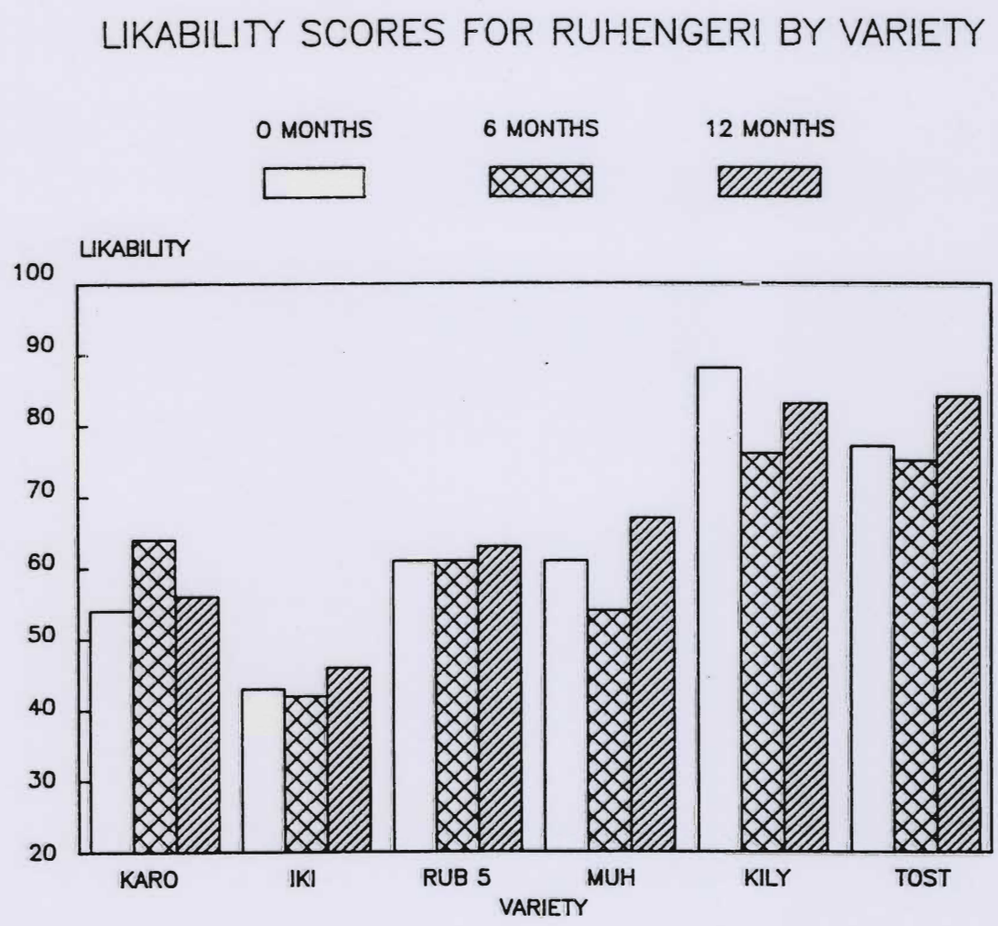


Figure 91. Hedonic scores (mean preference scores expressed as percentage of scale length) for Kibungo by variety and by storage time.

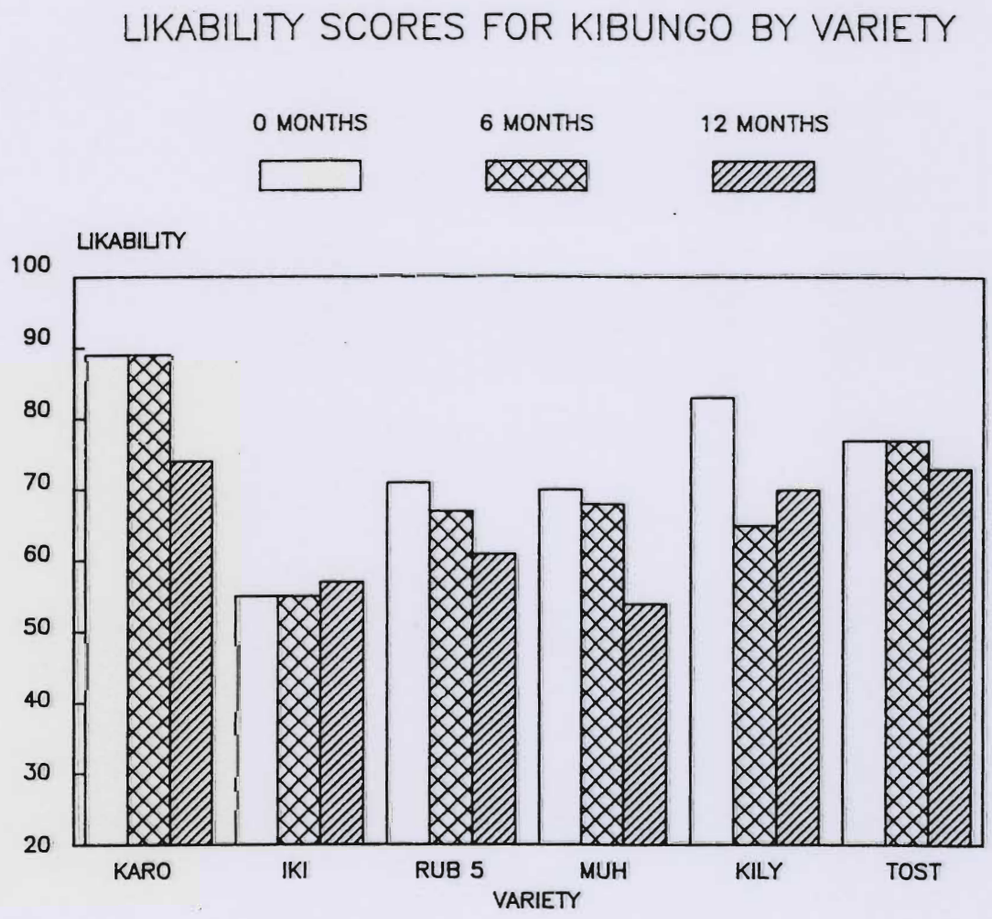
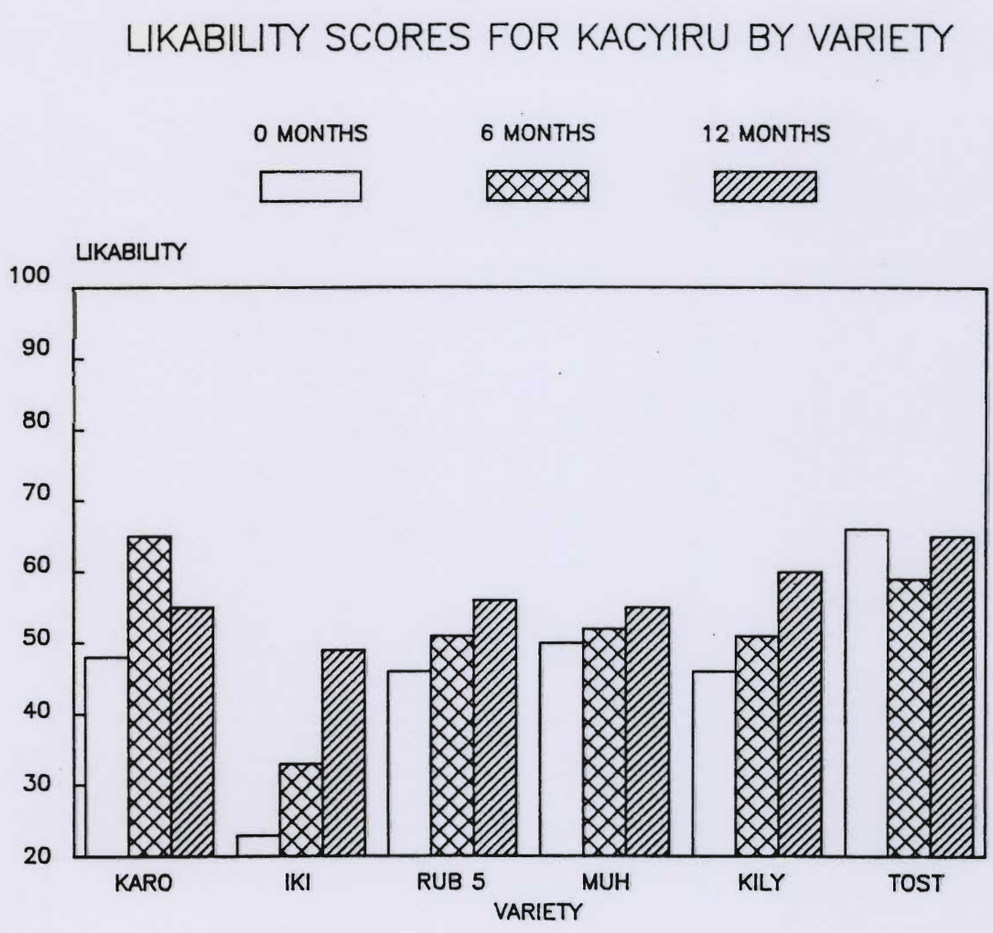


Figure 92. Hedonic scores (mean preference scores expressed as percentage of scale length) for Kacyiru by variety and by storage time.



different locations and the mean scores for all locations at all times showed that the scores from Kacyiru had the largest correlation ($r = 0.85$) with the mean scores from all locations. This might be expected since the subjects at Kacyiru represented many regions of the country while subjects at the other locations were restricted to the local population.

Effect of storage time

There was no overall decrease in hedonic scores from harvest to 12 months storage (Table 70). Although the effect of storage time was significant ($p = 0.46$, $F = 3.12$, 3060 df) no useful trends were observed.

Effects due to sex

Females tended to give higher scores than males (Table 71) ($p < 0.001$, $F = 51.41$, 3060 df).

2. Market value

The market value data support the hedonic score data in showing that the Karolina, Kilyumukwe and Tostado varieties were most preferred and the Ikinimba beans were least preferred.

Effect of test location

Market values differed by location in a similar manner to the hedonic score data (Table 72). Market values at Kibungo were higher than at other locations and considerably higher during the 12 month test (Table 73). This is in agreement with their relatively high hedonic scores. Subjects in Kacyiru gave the lowest market values which might be expected since they also gave the lowest hedonic scores.

Table 72. Mean of all hedonic scores broken down by storage time and bean variety. Each cell is averaged over all subjects and all test locations.

Storage Time (months)	Bean Variety						
	Karolina	Ikinimba	Rubona 5	Muhondo	Kilyumukwe	Tostado	All Varieties
0	69	50	61	63	71	66	63
6	77	49	60	59	64	70	63
12	68	54	63	62	71	73	65

Table 73. Mean of all hedonic scores broken down by sex and bean variety. Each cell is averaged over all three times and all four test locations.

Sex	Bean Variety					
	Karolina	Ikinimba	Rubona 5	Muhondo	Kilyumukwe	Tostado
Male	67	47	58	60	68	68
Female	77	55	66	64	69	72

Table 74. Market values (price subjects were willing to pay for a sample of beans divided by current market price) expressed as percent and broken down by test location and bean variety. Each cell is averaged over all subjects and all test times.

Test Location	Bean Variety						
	Karolina	Ikinimba	Rubona 5	Muhondo	Kilyumukwe	Tostado	All Varieties
Sovu	93	76	76	78	68	73	77
Bare	100	71	82	80	91	98	87
Ruhengeri	71	58	75	74	92	90	77
Kacyiru	75	50	72	73	80	83	74
All	86	66	76	76	83	86	

Table 75. Market values (price subjects were willing to pay for a sample of beans divided by current market price) expressed as percent and broken down by storage time and location. Each cell is averaged over all bean varieties and all subjects.

Storage Time (months)	Location			
	Butare	Kibungo	Ruhengeri	Kacyiru
0	79	81	78	77
6	73	82	75	76
12	81	99	77	69

Effect of storage time

Like the hedonic score data, the market values showed no overall decrease during the 12 months of storage (Table 74). Although the effect of storage was significant ($p < 0.001$, $F = 16.52$, 3060 df) the pattern and extent of changes were similar to those observed for the hedonic score data (Table 70). The apparent slight increase in market value at 12 months storage is likely due to the high values from Kibungo (Table 73).

Effect of sex

Females and males did not differ in the market values they produced for the different beans (Table 75). This contrasts with the observation that females gave significantly higher hedonic scores than males. The analysis of variance indicated a significant interaction between sex and location ($p < 0.001$, $F = 14.73$, 3060 df). From Table 76 one can see that this is likely due to the very high market values from the males at Kibungo.

Both hedonic scores and market values can be considered to measure how well a sample of beans is liked. The correlation coefficient between all the values for each measure was 0.57, indicating a generally good agreement between the two measures. Although the willingness-to-eat index was not tabulated or analyzed so extensively, a study of Table 69 should convince one that this data shows trends similar to those shown by the hedonic score and market value data.

Relationship between measures of cookability and measures of sensory preference

There was no relationship between hedonic score and either measure of instrumental hardness. (Figures 137 and 138 show the relationship between hedonic score and hardness measured as mean grams force and as percent

Table 76. Market values (price subjects were willing to pay for a sample of beans divided by current market price) expressed as percent and broken down by storage time and bean variety. Each cell is averaged over all subjects and all test locations.

Storage Time (months)	Bean Variety						
	Karolina	Ikinimba	Rubona 5	Muhondo	Kilyumukwe	Tostado	All Varieties
0	84	68	77	77	84	81	79
6	88	62	72	75	78	85	77
12	85	69	80	77	87	92	81

Table 77. Market values (price subjects were willing to pay for a sample of beans divided by current market price) expressed as percent and broken down by sex and bean variety. Each cell is averaged over all storage times and test locations.

Sex	Bean Variety						
	Karolina	Ikinimba	Rubona 5	Muhondo	Kilyumukwe	Tostado	All Varieties
Male	83	67	76	76	85	86	79
Female	89	67	77	77	81	87	80
All	86	67	77	77	83	86	79

Table 78. Market values (price subjects were willing to pay for a sample of beans divided by current market price) expressed as percent and broken down by sex and location. Each cell is averaged over all bean varieties and all storage times.

Sex	Location			
	Butare	Kibungo	Ruhengeri	Kacyiru
Male	76	102	77	74
Female	79	85	76	71

Figure 93. Plot of hedonic scores (% of scale length) vs Instrumental Measurements of Hardness. Each point represents the means for a single variety of beans at a specific storage time (6 varieties x 3 storage times = 18 points). Sensory means are averaged over all four test locations.

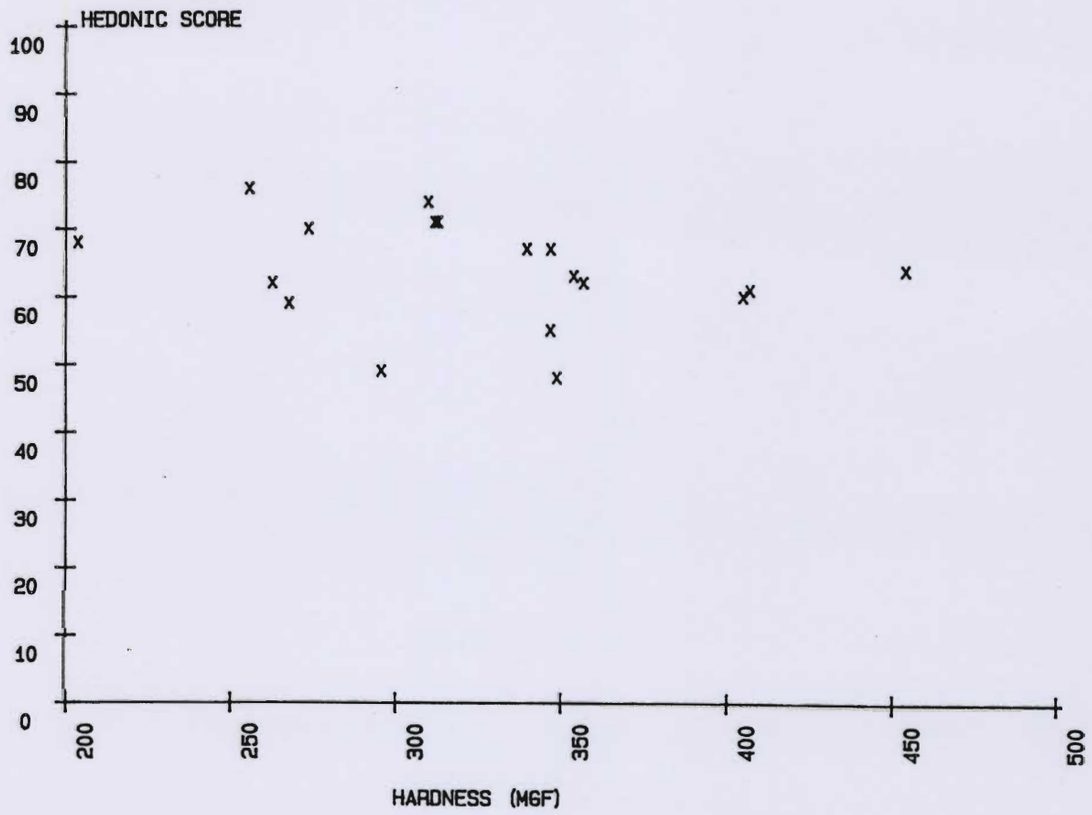
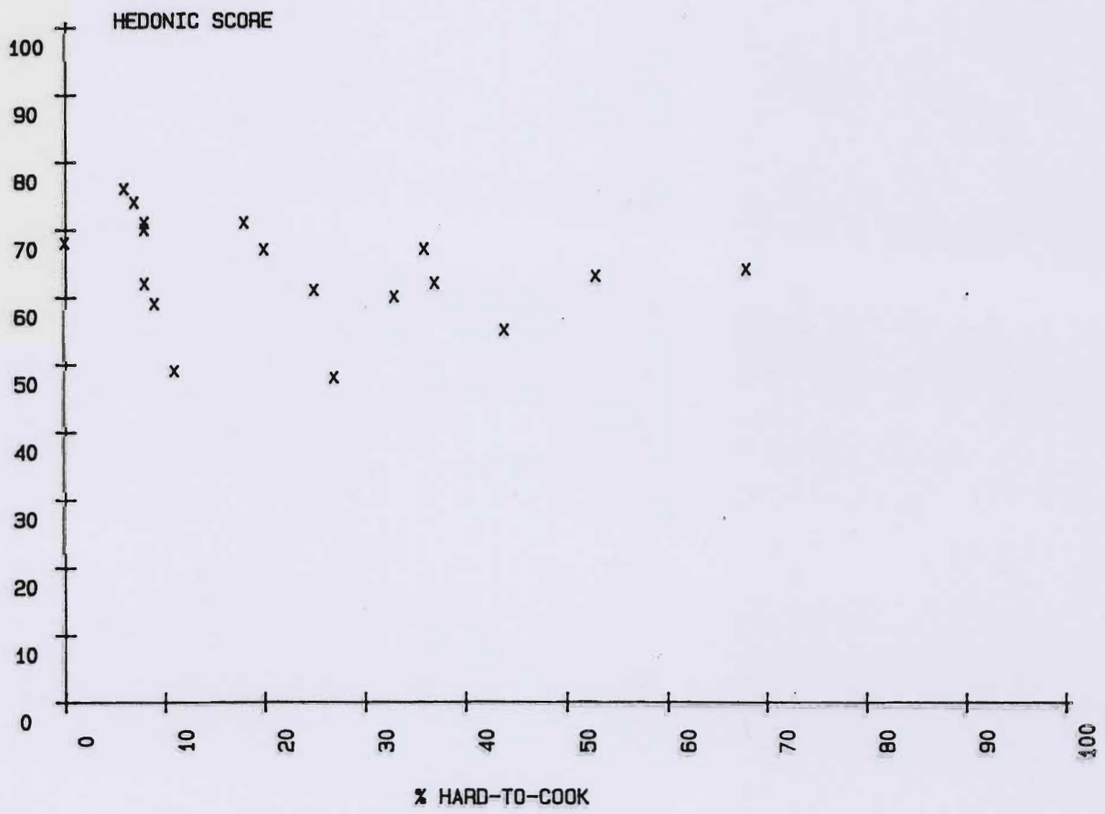


Figure 94. Plot of hedonic score is the percentage hard-to-cook beans (% of beans requiring $\geq$ 450 g force to puncture). Each x represents a single variety of beans at a specific storage time (6 varieties x 3 storage times = 18 points). Sensory means are averaged over all four test locations.



hard-to-cook.) This suggests that the differences in hardness among these six varieties does not explain the observed differences in sensory preferences. This observation is in agreement with those of Dessert (1984a and 1985a).

We can only speculate on what different features of these beans were responsible for the differences in sensory scores since the two factors we designed our study to test (hardness and storage time) were unrelated to the sensory scores.

The Ikinimba variety (small black beans) was the least liked variety in this study. This may have been at least partly due to their color which is known to leach out onto other foods and cookware surfaces. On the other hand Karolina and Kilyumukwe, both red colored, were the most preferred beans overall, perhaps indicating a preference for that color.

Subjects in Ruhengeri preferred the large-seeded varieties (Rubona 5, Muhondo, Kilyumukwe and Tostado) to the small-seeded varieties (Karolina and Ikinimba). This parallels the observation of Lamb and Hardman (1986) that large-seeded varieties are more commonly grown in this region. Subjects in Butare tended to prefer the small-seeded varieties which parallels Lamb and Hardman's observation that small-seed varieties were most commonly grown in this region.

Other sensory attributes such as specific flavor qualities or textural qualities other than hardness were not examined in this study. Further studies of varietal preferences could profitably focus on these attributes as well as size and color. Varietal differences in tolerance to storage time may also be important. The 12 months storage time in this study was not long enough to produce detrimental effects on either the cookability or the sensory pleasantness of the beans.

CONCLUSIONS

Karolina, Kilyumukwe and Tostado varieties were best liked overall while Ikinimba was generally least liked. The sensory preferences for the different varieties varied somewhat by region. These preferences may be related to subjects' familiarity with the beans since people living in regions where large seeded varieties are commonly grown appeared to prefer the large seeded varieties, while people living in regions where small seeded varieties are commonly grown appeared to prefer the small seeded varieties. The small black variety, Ikinimba may have been least liked because of its undesirable color. Preferences did not depend on cookability and did not decrease during the 12 months of storage.

The Tostado variety was the most cookable followed by Kilyumukwe; Rubona 5 was the least cookable. An unexplained increase in cookability occurred at 6 months of storage, but generally the cookability of the beans did not decrease over the 12 months of storage. Some varieties appeared to be less susceptible to changes in cookability during storage than others, but storage in excess of 12 months will be necessary to determine which varieties maintain their cooking quality longest.

LITERATURE CITED

Association of Official Analytical Chemists. 1975. Official Methods of Analysis (12th ed.). Method 44-15A. pp. 1-2.

Aykroyd, W.R., and Doughty, J. 1982. "Legumes in Human Nutrition". Rome: Food and Agriculture Organization of the United States.

Beauchamp, G.K. and Muller, O. 1977. The development of flavor preferences in humans: A review in .... Kare, M.R. and Muller, O., eds. The Chemical Senses and Nutrition. Academic Press.

Bourne, M.C. 1972. Texture measurement of individual cooked dry beans by a puncture test. J. Food Sci. 37:751.

Burr, H.K., Kon, S., and Morris, H.J. 1968. Cooking rates of dry beans as influenced by moisture content and temperature and time of storage. Food Technol. 22:336.

DeMan, J.M., and Kamel, B.S. 1982. A simple texture test system. J. Text. Studies. 13:241.

Desphande, S.S., Sathe, S.K., and Salunkhe, D.K. 1984. Interrelationships between certain physical and chemical properties of dry bean (Phaseolus vulgaris L.) Qual. Plant Foods Hum. Nutr. 34:53.

Dessert, K. 1984a. ISAR Annual Report (Programme Legumineuses).

Dessert, K. 1984b. CIAT-Institut National des Sciences Agronomiques du Rwanda Rubona. Annual Report. Centro Internacional de Agricultura Tropical.

Dessert, K. 1985a. ISAR Annual Report. Institut des Sciences Agronomiques du Rwanda. Rubona.

Dessert, K. 1985b. In "Journées des Etudes - Programme Legumineuses". Institut des Sciences Agronomiques du Rwanda, Rubona.

Dessert, K. 1986. Compatability of on-farm farmer evaluation of bean cooking time in Rwanda with bar drop cooking time index. In Bean/Cowpea CRSP Reports, Michigan State University.

Dos Santos Garruti, R., and Bourne, M.C. 1985. Effect of storage conditions of dry bean seeds (Phaseolus vulgaris L.) on texture profile parameters after cooking. J. Food Sci. 50:1067.

Lamb, E.M., and Hardman, L.L. 1986. "Final Report of Survey of Bean Varieties Grown in Rwanda." US AID-Rwanda Local Crop Storage Cooperative Research Project, LCS/FSMII (Research Component): University of Minnesota.

Linares, B.S., de Bosque, C.M., Elias, L.G., and Bressani, R. 1981. Caracteristicas technológicas y nutricionales de 20 cultivares de frijol commun (Phaseolus vulgaris). I. Caracteristicas fisicas del grano. Turrialba. 31(1):1.

Mattson, S. 1946. The cookability of yellow peas. Acta. Agr. Suecana II. 2:185.

Mora, M.A. 1982. Influencia de diferentes temperaturas y contenidos de humedad sobre el tiempo de coccion de frijol (Phaseolus vulgaris L.) almacenado durante 18 meses. Agronom. Costarr. 6(1/2):87.

Morris, H.J., and Wood, E.R. 1956. Influence of moisture content on the keeping quality of dry beans. Food Technol. 10:225.

Norusis, M.J. SPSS-X. Advanced Statistics Guide. 1985. McGraw-Hill.

Quast, D.G., and da Silva, S.D. 1977. Temperature dependance of the cooking rate of dry legumes. J. Food Sci. 42(2):370.

Rodríguez-Sosa, E.J., de Caloni, I.B., Cruz Cay, J.R., and Feliciano, J.B. 1984. Hydration and cooking properties of dry beans. J. Agriculture Univ. Puerto Rico. 68(3):259.

Sefah-Dedeh, S., Stanley, D.W., and Voisey, P.W. 1979. Effect of storage time and conditions on the hard-to-cook defect in cowpeas (Vigna unguiculata). J. Food Sci. 44:790.

Sirven, P., Goetanegre, J.F., and Prioul, C. 1974. In "Géographie du Rwanda". Editors A. de Boeck: Bruxelles.

Van Rheenen, H.A. 1979. Diversity of food beans in Kenya. Econ. Bot. 33(4):448.

Varriano-Marston, E., and Jackson, G.M. 1981. Hard-to-cook phenomenan in beans: structural changes during storage and imbibition. J. Food Sci. 46:1379.

Vis, H.L., Yourassowsky, C., and Van der Borght, H. 1975. A nutritional survey in the Republic of Rwanda. Tervuren, Belgium: Musée Royale de l'Afrique Centrale.

RECOMMENDATIONS

1. The Food Science section of the laboratory needs a highly trained scientist. Funding should be sought to provide advanced training of that person. At the same time, efforts should be made to obtain short-term training for the laboratory technicians.

2. In order to respond to the multiple obligations of this laboratory (various services, extension, training, and research), the laboratory must obtain additional equipment to increase its capabilities and complement the present equipment.

3. A microbiology section should be created within the current laboratory of the Project. This section should include the current mycology laboratory and that proposed for mycotoxin analysis. These laboratories would be provided with the necessary supplies, instruments, and the space for carrying out qualitative and quantitative analysis of raw and processed foods as well as for preparation of fermentation cultures. Studies should also be made of fungi which thrive in environments having low oxygen levels and high levels of carbon dioxide. These facilities should consist of separate as well as shared compartments which would probably require some modifications to the existing structures.

   The laboratories involved with bean cookability and grain quality conduct many tests analyzing physical quality. The scope of these tests could be enlarged by analyzing raw and processed fruits and vegetables as well as dairy products, fish, and meats. A microbiology section could conduct tests on all food products.

4. Investigations should be made of the relationship between color and cookability, germination, sensory preferences of consumers, and various environmental factors (e.g., gas composition). Color should be studied by using appropriate instrumentation such as the Hunter or Gardner meters for measuring colors and color differences.

5. A laboratory study should be conducted to determine the proportions and concentrations of carbon dioxide and oxygen which assure the optimal retention of bean quality including bean color, cookability, sensory preferences, germination, and control of insects and fungi.

6. A supplementary study should be conducted on soaking of beans before cooking in order to understand the effect of soaking on nutritive value, such as the change in thiamine, ascorbic acid, pH, and other factors during soaking in water containing rock salt and during cooking. The nutritional centers should participate actively in the extension to rural areas of the advantages offered by soaking.

7. Studies should be conducted on the variability of bean mixtures and the effect of this variability on instrumental measures of hardness and moisture content in beans. The variability of instrumental hardness and moisture content values has been quite large during these studies and a part of this large variability might be related to the variability in the composition of the bean mixtures.

8. Studies of bean cookability and sensory preferences for different varieties of beans should be continued. These studies should be pursued until a large data base is obtained on the cookability and sensory preferences for all bean varieties constituting more than 5% of a given mixture. Studies should be continued for 18 months to 2 years since no significant change in cookability or sensory preference was observed after 12 months during the previous studies.

9. Data from the large-scale bag storage study should be analyzed in depth. This important data base will be useful for finding answers to a variety of questions concerning the relationships which exist between sensory quality, hardness, and storage conditions of beans.

10. The food quality analysis laboratory should develop and maintain good relations with local food processing industries. The activities could include: assistance in the development of new products, support of quality control programs, calibration of equipment, conduct of sensory tests, and the resolution of various problems encountered by these industries. In order for the laboratory to become eventually self-sufficient, an appropriate fee should be charged for these services.